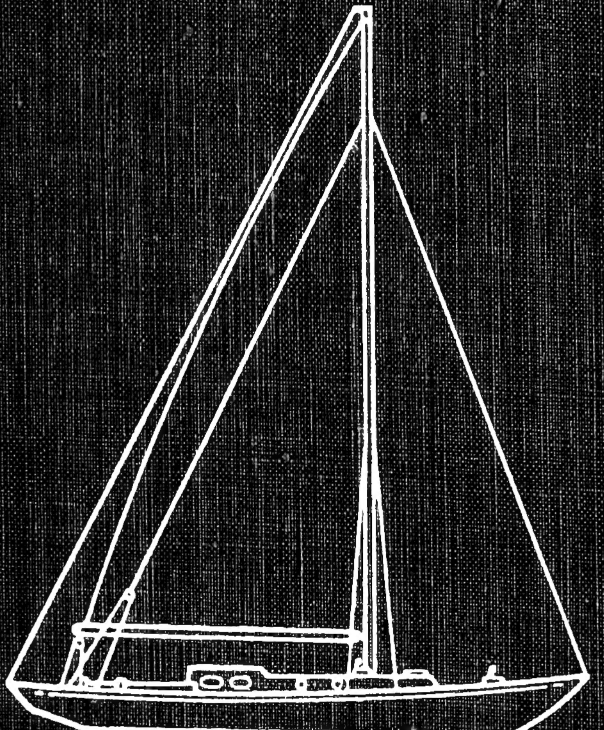
MARINE DESIGN MANUAL

FOR FIBERGLASS
REINFORCED
PLASTICS



GIBBS & COX, INC.

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FOR
Fiberglass Reinforced Plastics

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FOR

Fiberglass Reinforced Plastics

Gibbs & Cox, Inc.
Naval Architects and
Marine Engineers

Sponsored by
Owens-Corning Fiberglas Corporation

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McGRAW-HILL BOOK COMPANY, INC.
NEW YORK TORONTO LONDON
1960

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ISBN 07-023175-3

1213141516 HDBP 75432

The data and information contained in this Design Manual have been prepared from the best available sources. However, the value of the test data depends upon the control of so many variables, and the application of the data depends so much upon skill and experience that neither Owens-Corning Fiberglas Corporation nor Gibbs & Cox, Inc. assume any responsibility, expressed or implied, for results obtained in the application by others of the data and information contained in this manual. These quantitative data and examples were prepared with extreme care for general guidance and are accurate for the specific conditions and processing which pertained to the collection and compiling of the data.

Foreword

This Design Manual has been prepared by Gibbs & Cox, Inc. under the sponsorship of the Owens-Corning Fiberglas Corporation, manufacturers of fiberglass products for the reinforced-plastics industry, as a part of a program for the advancement of the industry through the dissemination of technical information on the materials and processes presently in use. As a firm of Naval Architects, Gibbs & Cox, Inc. has always been interested in new materials which appear to have application in the Marine Field. Therefore, it was natural that these two organizations combined their efforts to investigate thoroughly this new structural material.

In the compilation of this manual, it was necessary to acquire additional knowledge about the physical properties of the basic laminates and to determine the types and details of construction considered the most satisfactory. This effort required the contributions of many organizations and are acknowledged in the Preface. The results of this testing and study are presented as a Marine Design Manual for guidance in the development of reinforced-plastic structures for marine and other applications.

This Manual was prepared by the following members of the Hull Division of Gibbs & Cox, Inc.:

Matthew G. Forrest - Vice President - Naval Architecture

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John P. Montgomery - Contributor

This Manual was also reviewed in detail by Owens-Corning Fiberglas Corporation.

Preface

The rapid expansion of the application of fiberglass reinforced-plastic laminates as a structural material in many fields has surpassed the accumulation of the necessary technical data and design information such as is available for the application of other established structural materials.

Within the relatively short period since the introduction of fiberglass reinforced-plastic laminates, a considerable amount of research effort has been expended by government and industry to determine the potential value and limitations of this new material. However, most of the effort has been spent in developing data for specific applications. As a result, little well controlled data has been made available to organizations, designers and fabricators. The necessity for a large scale program for evaluating the basic engineering properties of fiberglass material has long been recognized. The influence of geometry, laminate construction, molding methods and fabrication techniques on these basic properties is extremely important.

To develop this required engineering data, Owens-Corning Fiberglas Corporation sponsored a cooperative program which included the following participating organizations:

Participating Organization	Function
Owens-Corning Fiberglas Corporation	Sponsor
Gibbs & Cox, Inc.	Engineering Development
Bellingham Shipyards Co.	Fabricator
Glasspar Co.	Fabricator
Lunn Laminates, Inc.	Fabricator
Zenith Plastics Company, Division of Minnesota Mining and Manufacturing Company	Fabricator
Cornell Aeronautical Laboratory	Qualification Tests
Massachusetts Institute of Technology	Testing
National Bureau of Standards	Testing

PREFACE

Participating Organization	Function
New York Naval Shipyard, Material Laboratory	Testing
Picatinny Arsenal, U.S. Army Ordnance	Testing
The Budd Company	Impact Testing
University of Dayton Research Center	Data Processing
Forest Products Laboratory	Advisory

Sufficient development of the necessary technical information and data has been completed to justify the compilation of this Design Manual. This development consisted of the evaluating of the data from an extensive test program to establish necessary physical properties for fiberglass mat, woven roving and cloth reinforced laminates molded by the contact molding method. The use of this data and suggested methods of analyses are demonstrated in the design examples, as a guide for designers and fabricators.

Throughout this entire program, complete cooperation was maintained by all participating organizations as well as other interested organizations providing information and assistance.

Gibbs & Cox, Inc. fully realizing that only partial completion of this tremendous task has been accomplished, sincerely wishes to thank the Owens-Corning Fiberglas Corporation, the sponsor, and all the other contributing organizations as well as all the individuals, who worked on and/or assisted in this program for their excellent cooperation.

In addition to the test program referred to above, considerable information was obtained from an extensive list of available references. Gibbs & Cox, Inc. wishes to acknowledge these fine references which were of considerable importance in the development of this manual.

GIBBS & COX, INC.

Contents

CONTENTS

APPENDIXES

Abstracts

CHAPTER 1. INTRODUCTION

The use and advantages of fiberglass reinforced plastics as structural materials and their acceptance by major industries, particularly the marine industry, are discussed and illustrated. Technical status of basic materials, production and engineering experience and data is presented. The purpose of the manual as a guide for designers and fabricators is emphasized.

CHAPTER 2. BOAT HULL DESIGN

Types of construction; single skin unstiffened and stiffened, sandwich, and composite are discussed. Framing is defined and discussed. Reasons for choice of laminate are explained. Design considerations are discussed and loads to be assumed for design purposes are given. Detailed examples of the structural design are given for a rowboat, a day sailer, a runabout, a cruising sailboat, and a displacement type power cruiser.

CHAPTER 3. DESIGN DETAILS

Importance of good design details is explained. Right and wrong loading directions for laminates are given. Acceptable joint and connection details are discussed and illustrated for deck edge to shell, gunwales, shell halves, keel ballast to hull, repair, bulkhead or frame to shell, cabin trunk to deck, fittings with pulling and pushing loads, appendages and outfitting. Mechanical fasteners are discussed and values given for spacing and strength. Trouble causing details including hard spots, stress concentrations, and knife edge crossings are discussed and illustrated.

CHAPTER 4. MATERIALS AND MOLDING METHODS

The basic types of chopped strand, mat, woven roving and cloth fiberglass reinforcements and their application to boat hull construction are discussed and tabulated. The applications of polyester and epoxy resins, inhibitors, catalysts and accelerators in fiberglass laminates are discussed. The use of foam plastics for buoyancy, and wood, foams and honeycombs for stiffener and sandwich core materials are described.

Fundamental methods of molding used in fiberglass boat construction including contact, bag, autoclave, matched die and the new sprayed reinforcement technique are described and illustrated.

ABSTRACTS

CHAPTER 5. ENGINEERING PROPERTIES OF LAMINATES

Direction properties of cloth and woven roving reinforcements are briefly discussed. Relationships between reinforcements, molding methods, physical and mechanical properties are discussed and tabulated. The basic engineering properties of fiberglass laminates determined from an extensive and supplementary test programs are presented in tabular form. Graphs indicating impact, fatigue and creep properties are given. Factors effecting the engineering properties of laminates are discussed and graphs of the effects of water immersion and long term loading are given. A summary table for the physical and mechanical properties of low density core materials is presented.

CHAPTER 6. DESIGN OF LAMINATES

The behavior of laminates under load are discussed. Suggested factors of safety for laminates are given. Methods, formulas and approaches to the design of both isotropic and orthotropic laminates in tension, compression and flexure are presented. Laminates as flat rectangular plates under various load conditions are analyzed. Tables of approximate critical buckling loads, and lateral loads are presented. A brief discussion on methods of analysis for sandwich construction is given. Detail design examples applying the methods of analysis and design approaches discussed are included as guidance for the designer.

MARINE DESIGN MANUAL

FOR

Fiberglass Reinforced Plastics

1

Introduction

THE MATERIAL

Fiberglass reinforced plastics are at this time competitive high performance structural materials. The basic fibers are among the strongest structural elements known. Although it would be inadvisable to consider reinforced plastics as the universally superior structural material, they are clearly superior in many cases and competitive in others. It may also be expected that additional research and improved processes will further upgrade the basic materials and the finished products. New confidence in design, coupled with experience in dependable commercial production, will permit widespread diversification of economically sound applications.

Although the strength to weight performance has indicated an advantage over some of the more familiar materials, there are many other characteristics which have influenced the increasing use of this material. Desirable compound curvatures can readily be achieved with this moldable material which can be formed as easily in one shape as another without the use of expensive forming tools. The ability to construct a one piece structure, eliminating complex load carrying joints, improves the performance and dependability of the complete structure. Particularly in comparison with wooden structures, fiberglass reinforced plastics used in an integral structural design eliminates a wide assortment of fastenings and hardware.

In considering the design of a structure to carry different types of loads, variation in strength can be easily accomplished in any portion of the structure, with the same basic materials, by simply changing the cross-section and orienting the high strength fibers in the direction of stress. Large tension loads can be efficiently supported by using cloth or unidirectional fibers oriented so as to be aligned with the direction of load. An impact resistant area can be created by increasing laminate thickness locally with reinforcements selected for high impact strength and oriented so as to be equally good in all directions. To support bending loads, stiffeners can be added to a panel in a conventional manner, or sandwich construction may be used. In any economic analysis, this factor must receive considerable attention. The same raw materials of fiberglass and resin in the stock room will produce an unlimited variety of thicknesses and forms. The equivalent of I beams, angle stiffeners and extruded sections are all available. No longer are the forms and sections limited to the availability of certain standard stock items. The rib and plate configuration of most structures need not be tailored specifically to the dimensions of familiar components. Modification and correction can be accomplished directly without delay and without major adjustment of expensive tooling. With proper design many internal components heretofore requiring individual installation can be easily combined with the primary strength structure in a single molding operation.

Like most other materials, fiberglass reinforced plastics are subject to some deterioration with exposure and weathering. But because of their relative inertness to attack by a large number of deteriorating causes and their ability to minimize water absorption, they can successfully withstand most of the elements which accelerate the aging processes in metals and woods, and will therefore need less maintenance.

PRESENT APPLICATIONS

From the time, about 1940, when the first experimental structures were developed using fiberglass reinforced plastics, the possibilities of widespread application of this new material were exciting. In almost every case, even for complex high performance items, the strength to weight performance is excellent. This desirable characteristic has continued to hold true with well designed and fabricated structures, Figs. 1-1 to 1-4.

Of all the applications of fiberglass reinforced plastics, the marine applications, where high structural performance and maximum durability are at a premium, seem to illustrate more of the positive reasons for selecting this material in preference to others. The primary and well known marine application is in the hull construction of military, pleasure and commercial craft. Figs. 1-5 to 1-10 illustrate some boat hull applications. The trend toward the application of this material, in larger boat hulls, Figs. 1-11 to 1-15 is continuing. Shipboard applications such as fairwaters, tanks, antenna trunks, telephone booths, partitions, torpedo tubes and crew shelters has further proven the material's suitability to the marine industry. Other successful marine applications are submarine fairwaters, Fig. 1-16, buoys and floats, Fig. 1-17.

TECHNICAL STATUS

In common with all new materials it has taken time and experience to amass dependable data on the qualities and performance of the material in different configurations. The very characteristics which provides the greatest potential benefit in the use of fiberglass reinforced plastics also creates the greatest difficulty. This is due to the fact that the composite laminate is created in place by combining diverse basic materials under a wide variety of environmental conditions. Obtaining consistent quality in these materials may not be more difficult than is the case with older and more familiar materials but it involves a vastly different approach compared with manufacturing practices developed over the years for older and more familiar materials.

Designers who have become experienced in using particular forms of fiberglass reinforced plastics have engineered applications which fulfill all the promise of the early experimental structures. Fabricating shops using processes with which they have become familiar have successfully met the most exacting standards. Quantity production of small boats and automobile bodies has demonstrated the ability to compete successfully on engineering and economic grounds. Airplane and missile applications, Figs. 1-18 and 1-19, leave no doubt that dependable quality can be achieved in limited production. Many applications illustrate an ability to utilize the unique qualities which can be fashioned into a reinforced plastic structure. But there has been a legitimate hesitancy to apply fiberglass reinforced plastics, even in situations where the apparent qualities would indicate them as ideal. This reluctance has been based upon a lack of reliable engineering data.

The flexibility in choice of the types of reinforcement and resin poses a problem of utilizing experience with one combination in dealing with a different combination. Not only has the bulk of engineering experience been limited, but lack of standardized data has made it difficult to utilize experience in dealing with different forms and processes.

Fig. 1-1. Largest Aircraft Radome, 29' Long, 20' Wide and 7' Deep *(Courtesy Zenith Plastics Company, Division of Minnesota Mining and Manufacturing Company)*

Fig. 1-3. Large House *(Courtesy Monsanto Chemical Company)*

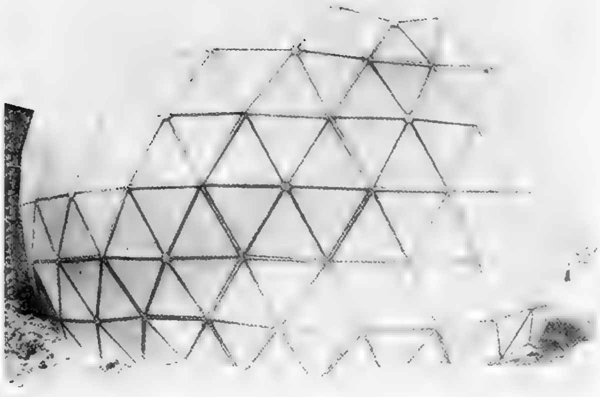


Fig. 1-2. 45' High Radome for NATO Early Warning Defense System *(Courtesy Universal Moulded Products Corporation)*

Fig. 1-4. Truck Cab *(Courtesy White Truck Company)*

Fig. 1-5. 26' Navy Motor Whale Boat
(Courtesy Lunn Laminates Incorporated)

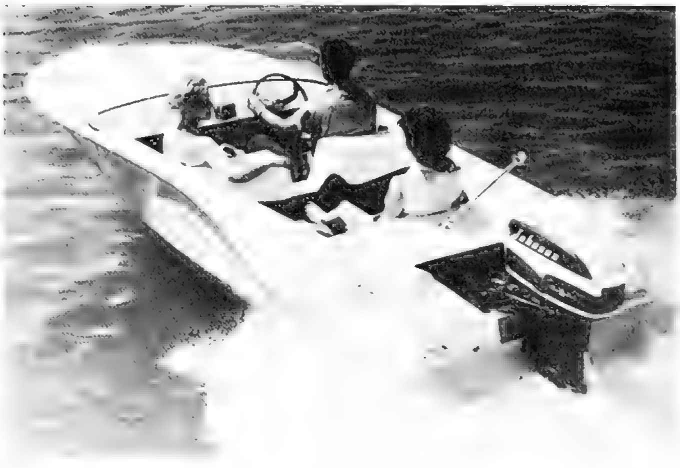


Fig. 1-8. 15' High Speed Runabout
(Courtesy Lake and Sea Boat Company)

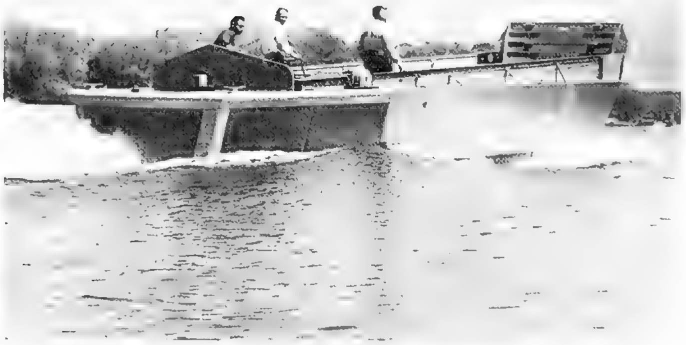


Fig. 1-6. 36' Navy Landing Craft
(Courtesy Lunn Laminates Incorporated)

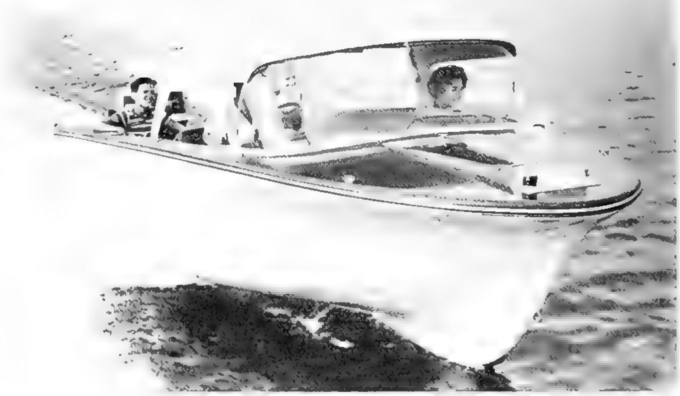


Fig. 1-9. 18' Day Cruiser *(Courtesy Southwest Manufacturing Company)*

Fig. 1-7. 24' Lifeboat - Dropped Tested from a Height of 10' Without Damage to Hull
(Courtesy Lane Lifeboat Company)

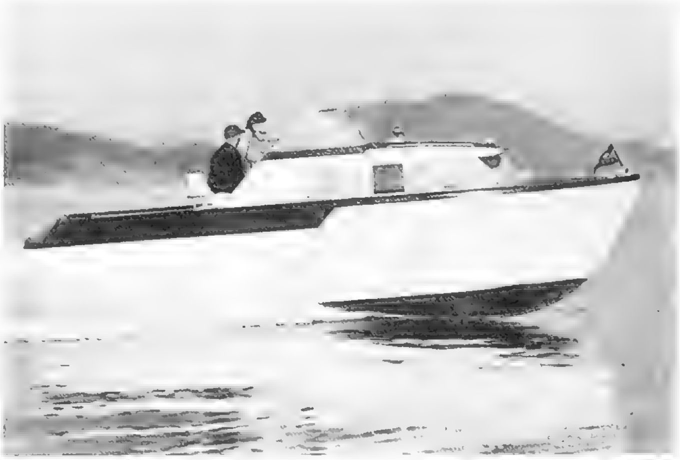


Fig. 1-10. 24' Express Carrier
(Courtesy Skagit Plastics Incorporated)

Fig. 1-11. 40' Yawl
(Courtesy American Boat Building Co.)

Fig. 1-12. 40' Sloop - BOUNTY II
(Courtesy Coleman Boat and Plastics Company)

Fig. 1-13. 40' Coast Guard Patrol Boat
(Courtesy W.R. Chance Associates)

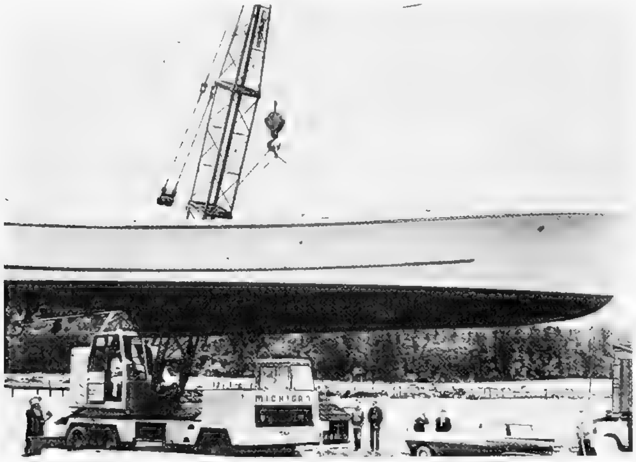


Fig. 1-14. 50' Utility Boat *(Courtesy Skagit Plastics Incorporated)*

Fig. 1-15. 65' Offshore Crew Boat
(Courtesy Plastics Research, Inc.)

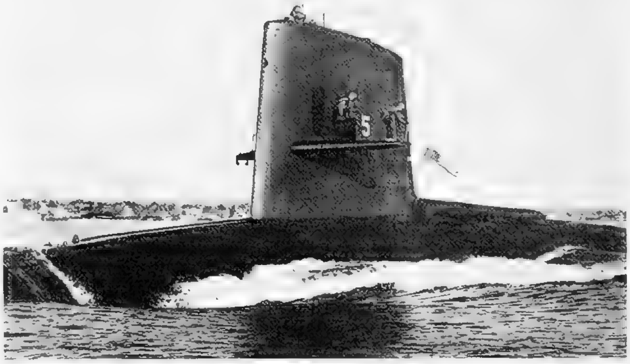


Fig. 1-16. Submarine Fairwater
(Courtesy Lunn Laminates Incorporated)

Fig. 1-17. Pontoon Camel Float
(Courtesy Skagit Plastics Incorporated)

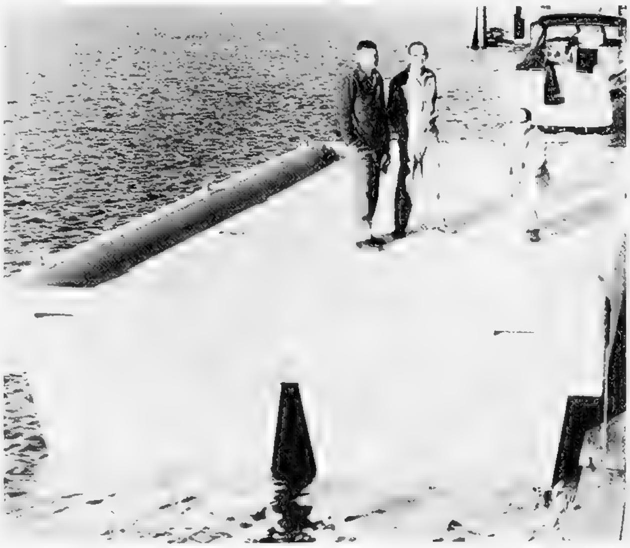


Fig. 1-18. Passenger Aircraft with many Fiberglass Parts; Wing Tips, Tail Cone, Seats, Coat Racks, Window Frames, Bulkheads, etc. *(Courtesy Lockheed Aircraft Corporation)*

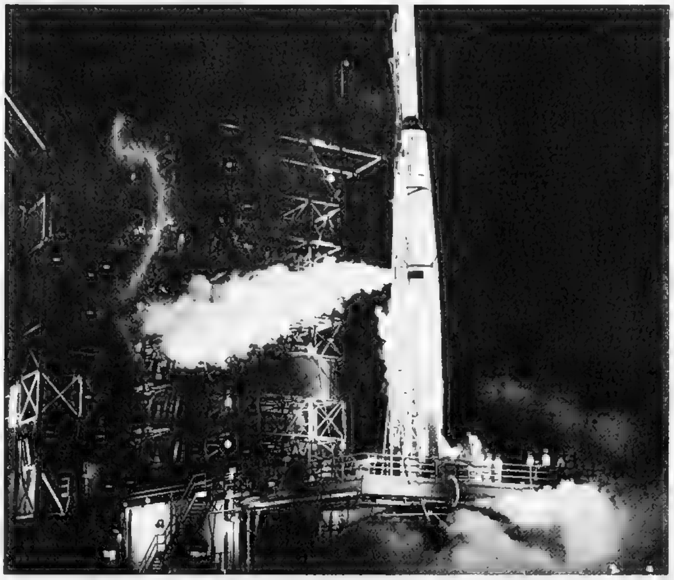


Fig. 1-19. Thor-Able Rocket - with many Fiberglass Parts; Nozzles, Pressure Vessels, Satellite Container, etc. *(Courtesy U.S. Air Force)*

DATA PRESENTED

Over a period of several years in a test program sponsored by the Owens-Corning Fiberglas Corporation and directed by Gibbs & Cox, Inc. and with the cooperation of many agencies, a correlated body of data has been accumulated and analyzed to provide the basis for the data presented in this manual.

It would be a task beyond the scope of the manual to present all of the available data pertaining to the state of the art at the time it is compiled. In this manual the data are applied by example to marine design. Furthermore, since the data were obtained on a standardized basis it is possible for any fabricator to make samples following the same construction and process techniques as those used in the test program. If these fabricator samples are then tested in accordance with the standard procedure, a calibration factor can be established relating the fabricator's sample data to the whole body of data. If the fabricator continues to follow the same pattern of calibration testing when working with new formulations of resin and reinforcement, his new data will then be comparable with the older data and any other new data accumulated by the same standard process regardless of where it originates. In practice the engineer or fabricator should use the data presented for initial selection of a material combination and molding process. He can then calibrate each material combination and molding process to obtain refined design data.

The test program was an extensive one which is described in Chapter 5. Aside from the obvious physical characteristics which are tabulated, there are other significant factors which are indicated in appropriate parts of this manual. The designer or manufacturer will be able to draw other conclusions from having the broad body of comparable data to analyze. One of the most obvious but most important aspects of the data is the indication of the spread in performance values which occurs with material made by different manufacturers all attempting to reproduce identical specimens. This spread may be the result of many factors besides the experience of the man making the laminate. Any designer or manufacturer contemplating a new product must realize that he may inadvertently produce items of varying quality while following what appears to be good practice.

In order to assist in the use of the data presented, it has been found desirable to divide some of the data into high and low ranges. If the manufacturer can satisfy himself by sample testing that he can reproduce materials of the higher quality, then it will be safe to use the higher values for that material combination and process. It will be noted that in the test program, manufacturers were not consistently high or low quality producers. Each fabricator produced both high and low quality laminates depending on the reinforcements used. There was no material which appeared to be easy to produce and no material or process which seemed to be uniformly difficult. The producers making the test laminates were all selected as highly qualified and dependable fabricators. Therefore a manufacturer may expect to find that he is a low quality producer for some material or combination.

It will be apparent that a marine design manual deals with structural loads and forms similar to those that apply to many other construction fields. While there has been no attempt to consider artistic effects and surface problems, these considerations can be superimposed upon the basic structural factors discussed and illustrated in this manual. One restriction of this document is that the reinforcements and processes for which detailed data are available are those of most interest to the marine industry. Some of the higher performance material combinations and forming processes are not included simply because the magnitude of the job of accumulating and analyzing the data precluded more than this first basic approach for a major field of interest. It should be noted that the procedure for making samples, testing and analyzing data will be suitable for any selected material. The data included here will serve as a comparison to indicate trends and the illustrations would be applicable if new data were fed in as acquired and as appropriate.

It may be expected that one of the most interesting and significant advances will be in the direction of larger structures for boat applications. For this reason the illustrations in this manual have included an array of sizes to suggest the factors which influence different design selections. With judgment these factors may be extrapolated to larger sizes than those included herein.

As more dependable data is obtained and as quality control develops either through more precise forming processes or inspection techniques it will be possible to design much more closely to the potential performance of these materials. Safety factors are discussed in this manual for specific applications. Some areas of structural loading are imperfectly understood at the present time. If fatigue, for instance, is a critical condition of loading, the calibration process discussed as essential for any new product will have to include enough typical testing to insure that the design factors for this feature are adequate. However, in most refined articles where design is very precise there is an appreciation of the need for proof testing and even sample destructive testing, regardless of the amount of data available and the experience with the material.

PURPOSE OF MANUAL

The primary purpose of this manual is to provide the designer with technical data and design approaches as guidance for analyzing fiberglass reinforced plastics structures for boat hulls and other marine applications.

This manual should also serve to persuade serious designers and builders that fiberglass reinforced materials follow predictable behavior patterns. The data and illustrations should assist those who are actually working with these materials to utilize them more efficiently. The presentation of this information in a positive and logical pattern should give economically minded manufacturers sufficient confidence to use a new material where the economics indicate a potential gain.

2

Boat Hull Design

This Chapter is devoted to the structural design of the boat hull. No attempt is made to consider the many and serious problems involved in determining the proper shape of the hull, laying out satisfactory arrangements, ensuring adequate stability, providing sufficient buoyancy in small boats, or estimating power required to obtain a predetermined speed.

Solutions to the above problems, and others are important and complex. When a substantial investment is involved, either in the building of a large boat or the building of a number of similar small boats, the use of a competent naval architect is highly recommended.

Structural design is one of the most important parts of the complex problem of boat design. Its purpose is to insure that the structural integrity of the boat is maintained for almost every conceivable loading to which it will be subjected in service. This Chapter should enable anyone familiar with the basic principles of strength of materials, to solve most of the small boat structural design problems. Conservative design is stressed again and again in this manual for a very simple reason: structural failure in service usually involves grave risk to human life. This fact places great responsibility on those involved in determining the scantlings of any boat, large or small.

In the case of special design problems, as illustrated in Fig. 2-1, the services of a competent structural consultant are required.

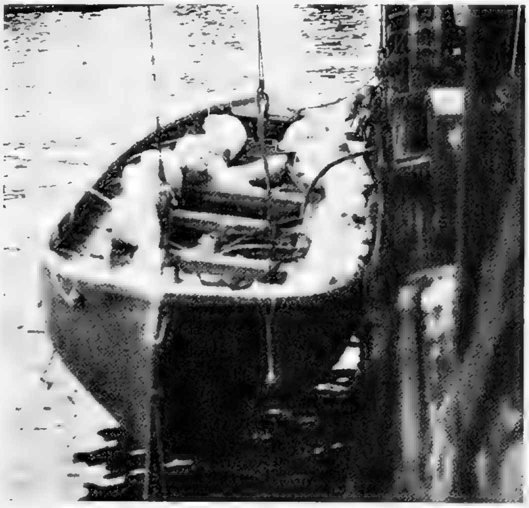


Fig. 2-1. Fiberglass reinforced plastic lifeboat, loaded with sandbags, being swung against a pier to test for impact resistance

(Courtesy Lane Lifeboat Co.)

A boat hull is essentially an envelope or shell of predetermined shape. The thickness of this shell and the size and location of whatever supports are provided must be selected to prevent the boat from breaking up or losing its shape under the action of the various loads placed on it in service.

Traditionally, especially in wooden frame and plank construction, the sizes or scantlings of the various components of the boat have been chosen on the basis of years of experience with successful and unsuccessful designs. This experience has been reduced to tables of standard scantlings for boats of a given size and type, such as the rules for the construction of wooden yachts published by Lloyds (3), Herreschoff (4) and Nevins (5). These tables and similar steel scantling tables are not however, applicable to fiberglass reinforced plastic boats because of the difference between the basic materials and types of construction. A frame and plank wooden boat must be made rigid to prevent the many joints from working and starting leaks. This requirement usually results in scantlings larger than necessary to resist the applied loads on a strength basis. Fig. 2-2 indicates the differences between frame and plank and fiberglass construction. In steel boats corrosion allowances are necessary which make up a high percentage of the thickness of the thin hull plates.

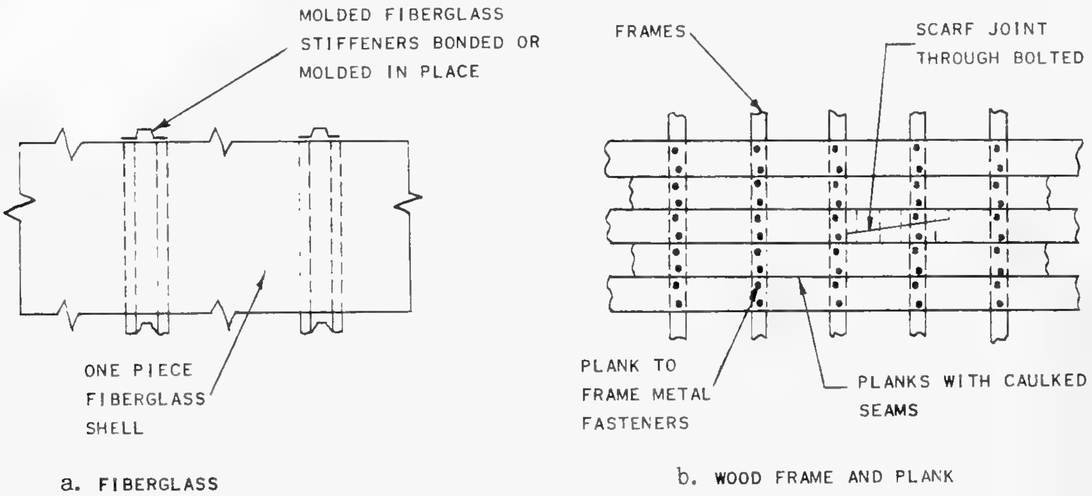


Fig. 2-2. Fiberglass and wood frame and plank hull construction

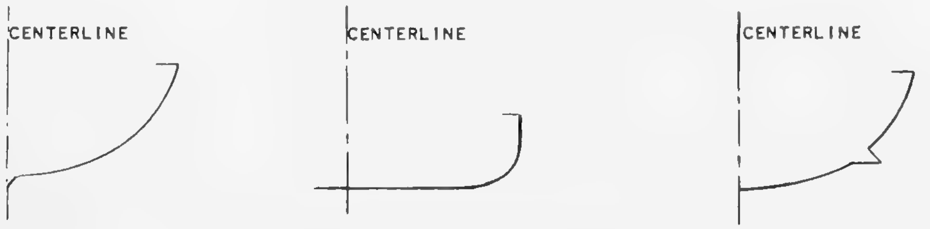
Since the fiberglass reinforced plastic hull eliminates the many seams and butts characteristic of wooden construction and the corrosion allowance required in steel boats, determination of the hull scantlings should be based on the strength and other characteristics of fiberglass laminates and not on simple equivalence to a comparable wood or steel hull.

TYPES OF CONSTRUCTION

Fiberglass boat hulls may be constructed of unstiffened single skin laminates, single skin laminates stiffened with ribs or frames, sandwich construction of thin face laminates with a low density core, or some combination of these types. Selection of the type of construction is dependent upon the hull size, appearance, intended service, reinforcement, fabricator experience, quantity, production facilities, and economic considerations. Some doubt may exist as to the most suitable type of construction for any specific boat hull. Usually more than one type of construction is suitable, but only one specific type will result in the most economical design. In general, a fabricator developing a new small boat for quantity production will produce a prototype to test the soundness of the hull structure, performance of the hull form and suitability to mass production. Modifications to improve the original prototype and reduce production costs, are usually necessary prior to and during quantity production. This is usually impractical for larger boat hulls unless quantity production is contemplated. In such a case, careful study, from both structural and economic viewpoints, will usually indicate the best choice.

Unstiffened Single Skin

The simplest form of a fiberglass boat hull is the single skin without stiffening. This construction consists of a laminate molded to the desired form, the laminate being several plies of resin impregnated reinforcement. This type of construction is used primarily for small, open, low speed boats up to about eighteen feet in length. The term "unstiffened" as used here means that no framing is added and the hull has an interior surface unbroken by projecting ribs Fig. 2-3a. Many times interior fittings such as thwarts and buoyancy tanks are used to provide some support for the shell in addition to performing their primary function.



a. UNSTIFFENED

b. FLAT AREAS ARE NOT RECOMMENDED FOR UNSTIFFENED SKINS

c. MOLDED-IN SPRAY STRIP

Fig. 2-3. Unstiffened single skin hull construction

The unstiffened single skin may be used with any of the molding methods discussed in Chapter 4. In selecting this type of construction it must always be remembered that the single skin derives considerable strength from the curved shape common to most small boats. Large flat areas, Fig. 2-3b, should be avoided. In vee-bottomed boats a molded in spray strip, Fig. 2-3c, may sometimes be used in lieu of stiffeners to provide the necessary rigidity. For an example of a boat with an unstiffened single skin hull see Fig. 2-4.

Single Skin with Framing

As the size of the boat and the severity of service increases, or when large flat surfaces are required, the unstiffened single skin becomes too flexible or limber. Solving the problem by means of large increases in thickness, while theoretically possible, causes molding difficulties and is also very uneconomical. Therefore, for minimum weight and cost, framing should be added to the hull. Framing in this case may be a member which serves only as a stiffener without any other purpose or it may be a built-in bunk locker, or other component already serving an additional function.

The framing is usually oriented in two basic directions; longitudinal, that is parallel with the long axis of the boat, or transverse, which is perpendicular to the long axis of the boat, Fig. 2-5. In the case of longitudinal framing, occasional large transverse frames may be necessary to support the longitudinal frames. The designation of the framing system is determined by the direction of the greater number of smaller frames which

Fig. 2-4. Unstiffened single skin hull *(Courtesy Marscott Plastic Company)*

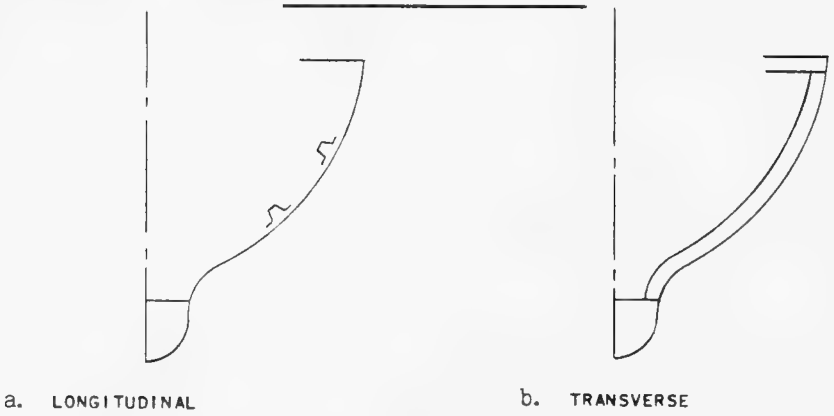


Fig. 2-5. Hull framing

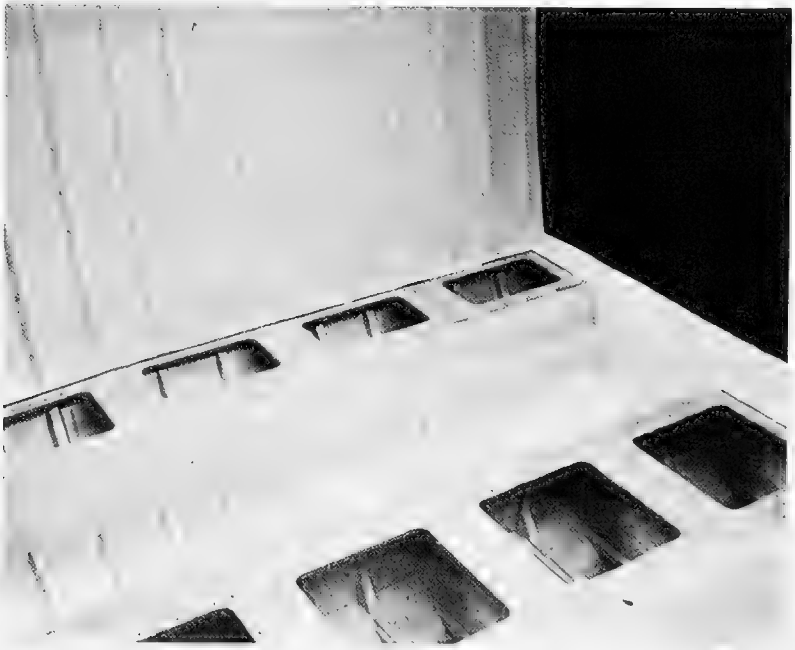


Fig. 2-6. 56' Deborine hull. - Transversely stiffened single skin *(Courtesy P.D. De Laszlo)*

support the shell rather than the larger frames. In addition to this primary framing system, local stiffening must sometimes be added in way of local loads. This stiffening, where possible is oriented to resist the applied load most effectively. For an example of a stiffened single skin hull see Fig. 2-6.

The choice of framing orientation depends largely on a compromise between the interior arrangement and economical construction of the boat. In wood frame and plank construction, transverse framing is necessary because the planks run longitudinally and the frames must be perpendicular to them to provide proper support and fastening, Fig. 2-2b. In fiberglass construction this is not necessary, and the designer has greater freedom of choice. In the normal small boat, transverse members are in the form of bulkheads, tanks, and seats which provide support for the longitudinal framing. In larger boats with cruising accommodations, built-in bunk tops and sides, shelves and so forth can be used as the longitudinal frames to reduce the number of stiffening members. For these reasons, longitudinal framing is frequently preferred in fiberglass hulls.

The essential requirements for a frame are that it withstand all the applied loads and provide sufficient stiffness to maintain the form of the entire structure with a minimum expenditure of material. The construction of the fiberglass frame may vary with the size requirement.

For small boats, where the required frame sizes are small, frames are sometimes made of unidirectional roving built up to form a solid rectangular cross-section; Fig. 2-7.

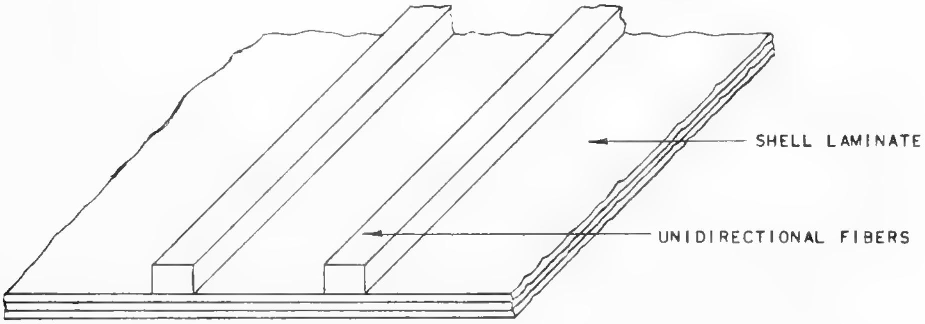


Fig. 2-7. Stiffener for small boats - solid laminate

This type of stiffener has the advantage of simplicity and good bending characteristics.

For larger boats and higher loadings, where greater strength and rigidity is required, the use of the solid stiffener becomes uneconomical because of the amount of material required. In most hulls a closed shaped stiffener is used which consists of a solid or hollow core or form covered with a fiberglass laminate. This, in effect, makes a closed box or semicircle section when combined with the shell. Typical configurations are shown in Figs. 2-8 and 2-9. Usually the cores or forms, over which the stiffeners are molded, are used to give the desired shape and are not considered to contribute to the strength. The effect of the core material on the rigidity of the stiffeners may be considered if warranted. The material for the form is chosen for lightweight, workability, and ability to withstand the handling required in the molding process. Typical form choices are cardboard mailing tubes for the half-round stiffeners, Fig. 2-8 and balsa wood or unicellular foams for the hat stiffeners, Fig. 2-9. A detailed discussion of low-density core materials is given in Chapter 4.

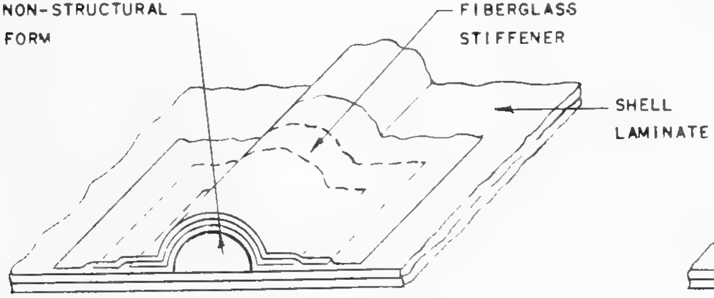


Fig. 2-8. Half-round stiffener, with hollow core

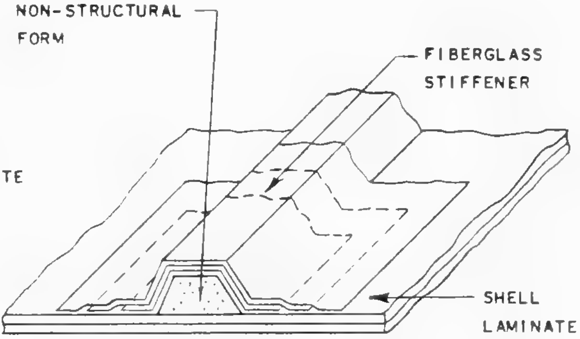


Fig. 2-9. Hat stiffener with full lightweight core

Method of analysis and graphs of section modulus and moment of inertia for half-round and hat stiffeners are given in Chapter 6.

These stiffener configurations give the designer the opportunity to vary the stiffness and strength of the section simply by changing the cross-sectional dimensions instead of changing the thickness of the fiberglass laminate. For maximum strength and rigidity the reinforcement preferred for the stiffener laminate is woven roving, with the thickness approximately equal to that of the shell laminate. In areas where the interior of the shell is covered with cloth for appearance, this covering can be carried over the stiffeners.

There are two basic ways to connect the frames to the skin. The preferable method is to add the stiffeners during the molding of the shell before the shell laminate cures. This may be done with any of the molding systems. Where matched metal molds are used, the construction of the male portion of the molds is complicated, since it must be recessed to allow for the stiffeners. The other method consists of bonding the stiffeners to the cured shell. This eases the molding problem but makes it more difficult to obtain a good bond. If this method, called secondary bonding is used, care must be taken to ensure that sufficient faying, or contact, area is provided so that the horizontal shear stress in the bonded joint is within allowable limits. A reasonable value for ultimate shear stress at the bond line, using polyester resins, is 800 to 1000 PSI (6). Greater bond shear stress, 1200 to 1500 PSI, can be obtained with epoxy resins (6). These values are all for the wet condition.

Sandwich Construction

The most complex type of construction, and the most difficult to fabricate, is the sandwich. This consists of two fiberglass laminates separated by a core of lightweight material. The purpose of this construction is to increase the rigidity of the flat panel by increasing its thickness without the use of a solid laminate. A solid laminate of equivalent thickness would be very heavy, extremely uneconomical, and would also present some molding difficulties. In sandwich construction it is usually assumed that the fiberglass skins resist all the bending stresses and deflections, while the core resists the shear stresses and deflections, withstands local crushing loads and prevents buckling of the laminate skins in compression. This assumption is discussed in Chapter 6.

Since the strength and rigidity of a sandwich depend on both skins working as a unit at the required separation, the core material must bond firmly to each skin and be sufficiently strong to withstand the loads previously mentioned. The core of a sandwich must therefore be carefully chosen since failure of the core will lead to failure of the entire unit.

As an example of the advantage to be gained from using sandwich construction to increase the strength and rigidity of a given amount of fiberglass laminate, consider a strip of single laminate 1 inch wide and 1/4 inch thick. This strip has a moment of inertia, I, of .0013 in^4 and a section modulus, Z, of .0104 in^3. The same amount of fiberglass divided into two 1/8 inch thick laminates, one on each side of a 1/2 inch thick core, has a moment of inertia, I, of .026 in^4, and a section modulus, Z, of .069 in^3. Therefore with the same amount of fiberglass the strip is now 20 times as stiff and 6 times as strong. The total weight of the structure is increased by the weight of the core, which is much less than the additional weight of fiberglass laminate required to provide equal strength and stiffness. In designing a sandwich, the skins must be made thick enough to withstand local impact, abrasions, and handling.

It will be noticed that the effect of the core has not been considered in the preceding example. The effect of the core on the over-all strength and rigidity of the sandwich varies widely with different physical properties of the core. Some cores, notably wood, have sufficiently high flexural moduli to cause an appreciable effect on the flexural rigidity of the sandwich. Others have such low shear moduli that the effect of shear deflection must be taken into account. In designing a sandwich the effect of the core material used must be investigated to determine whether the core should be considered effective.

Because of the great increase in stiffness and load carrying capacity, sandwich construction is frequently used for relatively large flat panels, particularly where the presence of stiffeners would be objectionable for arrangements. When the shape is complex, the preformed cores are generally difficult and expensive to shape. This difficulty may be overcome by using foamed in place resins with appropriate molds or troweled in place filled resins. Common applications of sandwich construction are for bulkheads, decks and cabin tops on larger boats.

Many different materials have been tried as cores but the most common being used are balsa wood, foamed resins, and honeycombs. A detailed discussion of these core materials is presented in Chapter 4 and physical properties are given in Chapter 5.

Core material for use in shell and weather deck sandwiches must have the ability to prevent water migration within itself and between the core and the fiberglass facings.

Another highly desirable quality is lightweight. In any boat the application of lightweight materials is an advantage since they will permit a reduction in the portion of the displacement which must be allotted for the hull structure. This will allow a correspondingly larger portion of the displacement for useful load in the form of stores, fuel, etc., or increase speed with the same load. For small boats made of sandwich construction to be competitive with single skin and frame construction the lightweight core should provide a lower over-all weight and should also provide positive buoyancy. If the sandwich cannot be made buoyant its lower unit weight compared to an equivalent thickness of solid fiberglass laminate will at least reduce the requirement for positive buoyancy.

Balsa wood cores and unicellular foamed plastic cores can provide positive buoyancy. Honeycombs made of heavy cotton duck and resin impregnated paper are satisfactory but must be handled with extreme care to insure complete resin impregnation for watertightness and to obtain a good bond between the core and faces. Improperly constructed honeycomb laminates in boat hulls have, in the past, caused water migration trouble and their use is not recommended for primary hull construction unless the fabricator has had considerable successful experience with them. Their use should be limited to decks, cabins, flats and bulkheads where they will be used to maximum advantage.

Composite Construction

The term "composite", as used in the marine industry, refers to a boat or ship whose framing is made of one material while the shell and decks are of another. The use of this term began during the transition period when ships were built with iron framing and wood plank shells and decks. For fiberglass boats, it refers to hulls with shell and decks of fiberglass laminate and framing of wood or metal. The wood framing is by far the most commonly used.

Composite construction has been used successfully on a number of boats. There are basic technical objections to composite construction, which will be discussed, but properly applied it can produce a successful boat.

The basic objection to wood framing on a fiberglass shell is that the materials have different physical properties. Wood swells when wet, rots and requires frequent painting while fiberglass does not. These differences can cause maintenance difficulties which simply would not occur if both the framing and shell were entirely of fiberglass laminate construction.

From a structural designer's viewpoint, the major objection to composite construction is the form of the wood stiffeners used. These are normally of the "plank on edge" type and the stiffener itself is very rigid locally. This means that the connection of the stiffener to the shell must be carefully made to prevent the formation of a hard spot. See Chapter 3 for a discussion of this problem. Fig. 3-24 indicates the recommended treatment for the attachment of wooden framing to a shell laminate.

It is a temptation to the builder to cover wood framing with a thin layer of fiberglass to avoid painting and improve the appearance of the boat. This practice is very definitely not recommended. It does not solve the problem of wood swelling or rotting in the presence of moisture. It simply hides the problem so that the boat owner's first indication that trouble exists will be cracking or delamination of the covering laminate, or actual failure of the framing.

The use of metal, usually aluminum, for framing is not common, but it has been used in some designs. The major problems with this type of construction are obtaining a satisfactory bond between the metal and the fiberglass, and eliminating hard spots. In addition, difficulties may occur due to the difference in the moduli and in the rates of expansion and contraction with changing temperature. These differences introduce additional shear stresses in the connecting bond or fasteners.

SELECTION OF LAMINATES

The choice of type and arrangement of reinforcement for a single skin laminate is based on a number of factors. These factors include strength, rigidity, impact resistance, resistance to passage of water, cost of material and labor, ease of handling and appearance. Each of the basic types of reinforcement has its own qualities and these must be utilized in combination to provide the most effective laminate. These are discussed in detail in Chapter 4.

It is obviously impossible to consider all the possible combinations of reinforcement which might be used. As an indication of the choices which are made, and the reasons for them, three laminates will be discussed.

The first laminate, Type A: Consists of 1 ply of 10 ounce cloth on the outboard side, 1 ply of 2 ounce mat and a varying number of plies of 25-27 ounce woven roving.

Considering this laminate in detail: The outside ply of cloth is intended primarily for appearance and as gel coat reinforcement. It is used because of its relatively smooth surface, which reduces the thickness of the gel coat. This ply also provides good tensile qualities for the exterior of the laminate. Some builders replace this ply of cloth with a ply of 3/4 ounce mat as gel coat reinforcement.

The ply of 2 ounce mat serves three purposes. First, it is highly resistant to the passage of water and minimizes the absorption of water by the laminate. Water absorption reduces the strength of the laminate. Second, mat provides greater thickness per layer than either woven roving or cloth, and thus increases thickness with a minimum of cost. Third, the mat prevents the pronounced weave pattern of the woven roving from showing through the cloth and the gel coat. Note that 2 ounce mat is used here, but that 1-1/2 ounce mat can be used to perform the same functions. The 1-1/2 ounce mat is easier to drape and to wet out with resin, but is less effective in increasing thickness and masking the weave of the woven roving.

The plies of woven roving provide the bulk of the laminate thickness, strength, and impact resistance. The number of plies used depends on the strength required for the particular laminate. Woven roving is used here because it is cheaper and requires fewer plies than cloth, and has better impact resistance than mat.

An interior layer of cloth may be added for appearance only, if desired.

The second laminate, Type B, consists of: 1 ply of 10 ounce cloth on the outboard side, a varying number of plies of mat and 1 ply of woven roving on the inboard side.

Considering the laminate in detail: The outboard ply of cloth performs the same function as in Type A laminate.

The plies of mat provide the thickness and strength of the laminate. The number of plies used depends on the strength required.

The interior ply of woven roving is used to provide resistance to impact from objects such as logs.

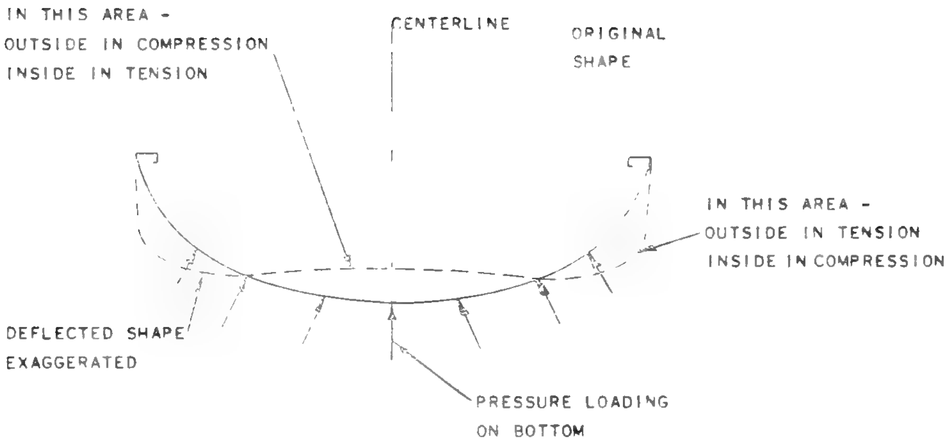
An interior ply of 10 ounce cloth may be added if desired.

The third laminate, Type C, is identical to Type B except that two layers of woven roving are used instead of one. Each component performs the same function as before. The reason for the additional ply of woven roving will be discussed later.

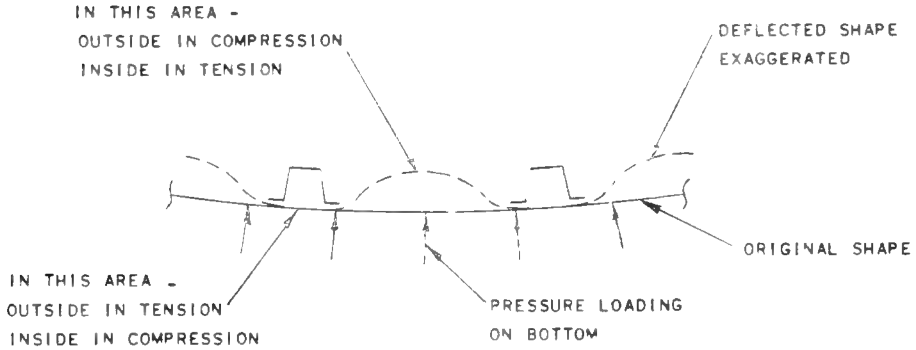
It is sometimes stated that the material with good tensile properties should be placed on the inboard face of the hull laminate because this is the "tension side". In this manual it is recommended that woven roving be placed on the inboard side, for resistance to impact from objects, as distinguished from water impact. Fig. 2-10, indicating the deflected shapes of an unstiffened and stiffened hull laminate under water pressure loading on the outboard sides of the hulls, shows that the outboard face of a hull laminate can also be in tension. Therefore, the arrangement of laminate reinforcing components should be made to provide for tension on the outboard face as well as on the inboard face. The layer of 10 ounce cloth on the outboard side of the laminates previously discussed performs this function. If required, this portion of the laminate may be increased for higher strength.

Loading due to impact from an object places a concentrated rather than a distributed load on the laminate. For the unstiffened hull this change does not change the character of the deflection curve. For the stiffened hull there is a considerable change since the load acts on only one panel. This means that the loaded panel approaches the condition of simply supported edges rather than clamped edges as in the case with the distributed or pressure type of load. In this case, the inboard side of the hull is in tension, and the woven roving is placed there to resist this tension stress.

As an aid in choosing a laminate, Figs. 2-11 and 2-12 have been prepared. Fig. 2-11 is a plot of material cost versus section modulus at the inboard face of the three laminates, Type A, B and C. The figure shows that Type A laminate is relatively expensive but it is widely used on larger hulls

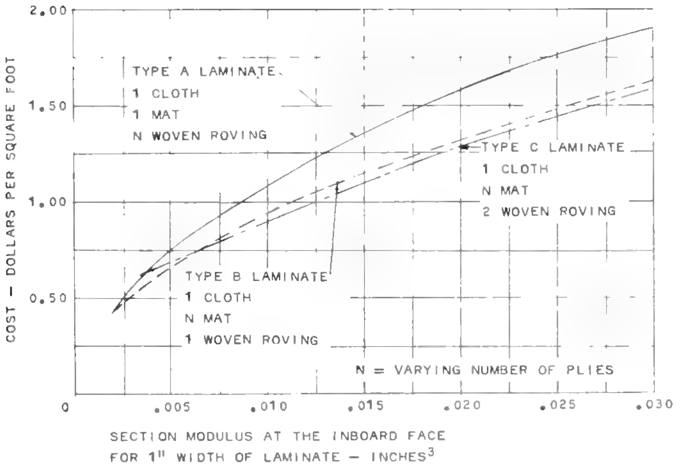


a. UNSTIFFENED



b. STIFFENED

Fig. 2-10. Tensile and compressive stresses in a boat shell



NOTE: COST BASED ON PRICES AS OF JUNE 1959. CURRENT FIGURES SHOULD BE USED FOR ACCURATE ESTIMATES.

Fig. 2-11. Cost versus strength of contact molded fiberglass - polyester laminates

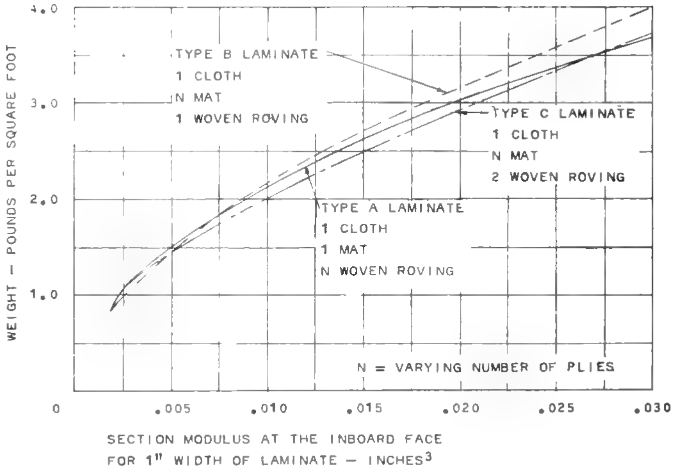


Fig. 2-12. Weight versus strength of contact molded fiberglass - polyester laminates

where laminate cost is relatively a smaller portion of the total cost than it is for the small boats. Fig. 2-11 also indicates the reason for the difference between Types B and C. For section moduli below 0.007in^3, Type B laminate with one ply of woven roving is less expensive than Type C with two. For section moduli above this value, Type C becomes less expensive.

Fig. 2-11 considers material cost based on unit prices for the date indicated and glass percentages and thicknesses usually obtained by contact molding. The effect of changes in unit prices or molding method should, of course, be considered. In addition, labor costs for the different types of material, which vary somewhat with different fabricators, should be considered.

Fig. 2-12 indicates the relationship of weight per square foot of the three laminates described above and the section moduli at the inboard face of the laminates. These data are based on contact molding. The data given in Fig. 2-12 will enable the designer to consider the effect of weight when selecting a laminate.

BASIC DESIGN CONSIDERATIONS

The most difficult technical problem in small boat hull design is the selection of the loads to apply in determining the scantlings of the hull structure. The actual load on any given part of a vessel in service is extremely complex; consisting not only of loads applied by external forces such as water pressure which act directly on the part, but also of loads transmitted from the parts of the boat adjacent to the section or member under consideration. For example, a bulkhead may be loaded directly by equipment mounted on it, and indirectly by water pressure loads which are transmitted from the shell to the frames supporting the shell, and from the frames to the bulkhead which supports them. Although any piece of a boat hull is directly or indirectly connected with all the other pieces, it is not generally practicable to determine the distribution of the loads transmitted from one part to another

The small boat designer must, therefore, resort to more or less assumed design loads. These loads, combined with a choice of the factor of safety which represents, in part, the designer's best judgment regarding the accuracy of his assumed loading, are applied to determine the required scantlings.

The assumed design loads depend on the function of the part of the boat under consideration, and on the size, type, and intended use of the boat. Large ships must be designed to withstand the longitudinal bending stresses imposed on them in waves as shown in Fig. 2-13 in addition to the lateral loads due to water pressure and local loads due to equipment and cargo.

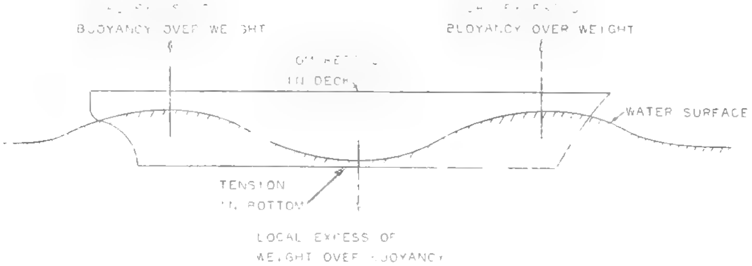


Fig. 2-13. Forces on ship's hull causing longitudinal bending stress

For small boats this same loading condition exists but the length to beam and depth relationships are such that this is usually not a critical loading condition.

In the following pages, the design loads for several general types of boats are discussed, with the intention of covering the broad field of current fiberglass boat hulls. It is recognized that in some instances, statements made regarding the loads which should be used may be controversial. In all cases, the intention is that the loads described shall produce a safe, trouble free boat for operation in the service as described. The loads have been chosen so that the resulting scantlings are generally in accord with good modern practice. However, it must be recognized that fiberglass laminates are a relatively new material for boat hulls and that as more and more service experience is accumulated, it may become apparent that some of the recommended loads are too severe and others perhaps not severe enough. Certainly the standards recommended are not intended as hard and fast rules, nor are they presented as the last word. In the final analysis the individual designer must use his own best judgment in producing a balanced design suitable for the intended service.

DESIGN LOADING

In the design of the various components of a boat's structure, there are two basic criteria which must be considered; vibration and strength.

Vibration Criterion

Critical vibration is familiar to everyone in one form or another. Any physical object has a natural frequency of vibration; that is it tends to vibrate at a particular rate. This rate depends on the geometry of the object, the loads imposed on it, and the material used. If a varying load is imposed on a structure and the frequency of variation is nearly the same as the natural frequency of that structure, the phenomenon of critical vibration or resonance occurs. The amplitude of the critical vibration is high, and the resulting shaking or drumming is unpleasant and may cause structural failure. This structural failure may be due to fatigue at relatively low stress levels or, in the rare case of extreme vibration, to high stresses induced by large deflections.

To date, the vibration of fiberglass laminate panels has not received sufficient attention. The theoretical analysis of orthotropic plate vibration has been investigated (7) but the analysis is quite complex. A further complication is introduced because the modulus of elasticity values generally measured are static values. For certain materials significantly different moduli values are obtained under dynamic conditions such as vibration. Published data (8) on Douglas fir indicates a 10 per cent increase in the dynamic modulus of elasticity compared to the static modulus of elasticity. The only available published article on the vibration of fiberglass laminate (9), which is very limited in scope and cannot be used without substantiating tests, indicates a 50 per cent increase in the dynamic modulus compared to the static modulus of elasticity.

A characteristic of fiberglass laminates which may help alleviate vibration difficulties is internal damping. This term refers to the ability of a material to absorb vibration energy by converting it to heat produced by internal friction. Internal damping has two effects on the vibratory characteristics of a material. First, it reduces, usually to a small degree, the natural frequency. Second, and more important, it reduces the amplitude of vibration drastically at frequencies at or near resonance. The amount of internal damping actually present in fiberglass laminates has not been measured experimentally, but it may be expected to be substantial compared to metals.

In view of the complexity of the theoretical analysis required and the lack of needed experimental data, vibration analysis of fiberglass panels is not, at this time, a practical boat design tool.

At the present time the only practical cure for vibration problems is a trial and error approach. This essentially consists of building the boat, testing it, and if objectionable vibration occurs making suitable corrections.

Examples of corrective action which might be taken include: additional plies of laminate; additional stiffening to reduce panel size; and change the number of blades on the propeller if the measured frequency of vibration equals the RPM times the number of propeller blades. Of these three, the addition of extra stiffeners is recommended as the most practicable and economical.

Strength Criterion

For certain hull components, notably the shell, several different criteria are proposed depending on the type of boat being considered. Following the general discussion, design examples are presented to illustrate suggested methods for the structural design of several types of boats.

Shell and Framing: The basic component of all boats is the shell. Structurally this is a watertight envelope which must be maintained in its designed shape while resisting the exterior water pressure. The framing, in addition to supporting the shell against this pressure must also spread the local interior loads from the engine, mast etc., over a large area of the shell.

In small open boats the shell is usually the only structural member. Small, low speed boats powered by an outboard motor of 10 horsepower or less, and day sailers are examples of this type.

The shell of a low speed open boat is generally subjected to low stresses from water pressure on the bottom, torsion from the sails, and various other over-all loads. The critical loads on these boats are generally local loads due to handling, grounding, minor collision with docks, and so forth. Since these loads are similar for most of these low speed boats, the size of the boat has surprisingly little effect on the laminate used. An exception is the effect of torsion on open, as opposed to decked, sailboats. In order to prevent excessive twisting of the hull, the laminate for the larger sizes of open boats is generally increased. The loads described above are not susceptible to detailed analysis, and the best criteria available are the many successful boats in this category.

Based on current practice, the following laminates are recommended:

For round bottom boats under 12 feet in length - normal low speed pleasure service

1 ply 10 ounce cloth on the outboard side
1 ply 1-1/2 ounce mat
1 ply 14-17 ounce woven roving

For round bottom boats 12 to 18 feet in length - normal low speed pleasure service

1 ply 10 ounce cloth on the outboard side
1 ply 2 ounce mat
1 ply 24-27 ounce woven roving

Boats intended for rougher service than would be considered normal, such as frequent beachings in rocky areas should be strengthened with an additional ply of woven roving. For large open sailboats of the "Thistle" type, 2 plies of 1-1/2 ounce mat may be substituted for the 2 ounce mat, due to the large torsional loading from the sails and the lack of a deck.

The above scantlings are recommended for "round bottom" boats whose shells have curvature in the transverse direction and have some form of centerline stiffening in the bottom. This centerline stiffener or keel is very important as it provides support for the shell when in the water and also when in storage. This member will usually be in the form of an external keel and skeg. Another common method of adding stiffness to the boat in the vicinity of the keel is to lap the middle and/or inner plies of the laminate to form a double thickness in this area. In the case of a flat bottomed boat, such as a conventional skiff, it is recommended that a stiffener of parallel strands of roving be added approximately midway between the centerline and the side. These stiffeners should be 1/2 inch thick and of varying width from a minimum of 1 inch for a 12 foot boat to 3 inches for an 18 foot boat. If desired, the single stiffener may be replaced by a number of smaller longitudinal stiffeners, spaced at equal intervals across the hull, whose total width is equal to that of the single stiffener.

Sometimes it is desired to produce a fiberglass version of an existing class of wood racing sailboats. In this case the determining factor in choosing the scantlings may prove to be the weight limitations of the class rules, and the laminates recommended here may prove to be too light. The designer is referred to the tables of physical properties in Chapter 5 for unit weights of laminates with various types of reinforcement.

The most difficult shell loading to evaluate is that experienced by a relatively high speed planing power boat travelling in waves. Anyone who has experienced a ride on this type of boat knows that severe impact loads occur on the bottom due to high accelerations.

Although some investigations have been made, (10, 11, 12), there is no simple theory available which predicts the maximum impact pressure on the bottom of a boat at high speed. This is particularly true in the case of small light boats. Also, very little experimental data are available on this subject. After consideration of several possible approaches to the problem of predicting bottom pressures for use in design, an empirical relationship has been developed which is considered practical and conservative, particularly for small boats.

The development of this equation consists basically of considering the impact pressure developed when the boat strikes the water. This pressure is given by the formula:

$$p = 1/2 \ \rho \ v^2 \tag{2.1}$$

where p = pressure in pounds per square foot

v = speed in feet per second

ρ = mass density of water in slugs per cubic foot, 1.9924 for salt water at 50 degrees F

By considering v, the effective relative velocity of the water perpendicular to the struck surface of the boat, composed of the vertical and horizontal components of boat velocity and orbital velocity of the water particle in the wave, and relating these values to the forward speed and size of the boat the following equation may be derived:

$$p_I = \frac{AV^2 + B\,V\sqrt{L} + C\,L}{D} \qquad (2.2)$$

p_I = maximum local impact pressure in pounds per square inch to be expected when the boat is driven in waves at the maximum possible speed

V = the forward speed of the boat in miles per hour

L = waterline length of the boat in the at-rest position

$$D = \frac{1}{\dfrac{\rho \times 1\ \text{ft}^2}{2 \times 144\ \text{in}^2}} = 144.55,$$ a constant including water density and dimension conversion factors

A, B and C are constants expressing the relationships between wave height, wave length, boat size and conversion from feet per second to miles per hour. These have been evaluated from the experimental data obtained during tests made on a PT boat (13).

A = 2.151 B = 1.267 C = 16.884

The nomograph presented as Fig. 2-14 provides a ready means for evaluating this equation. To use this nomograph proceed as follows:

Place a straight edge on the graph so that it passes through the appropriate speed on scale A, and the appropriate length on scale C.

Mark the point at which the straight edge crosses the line located between scales A and B.

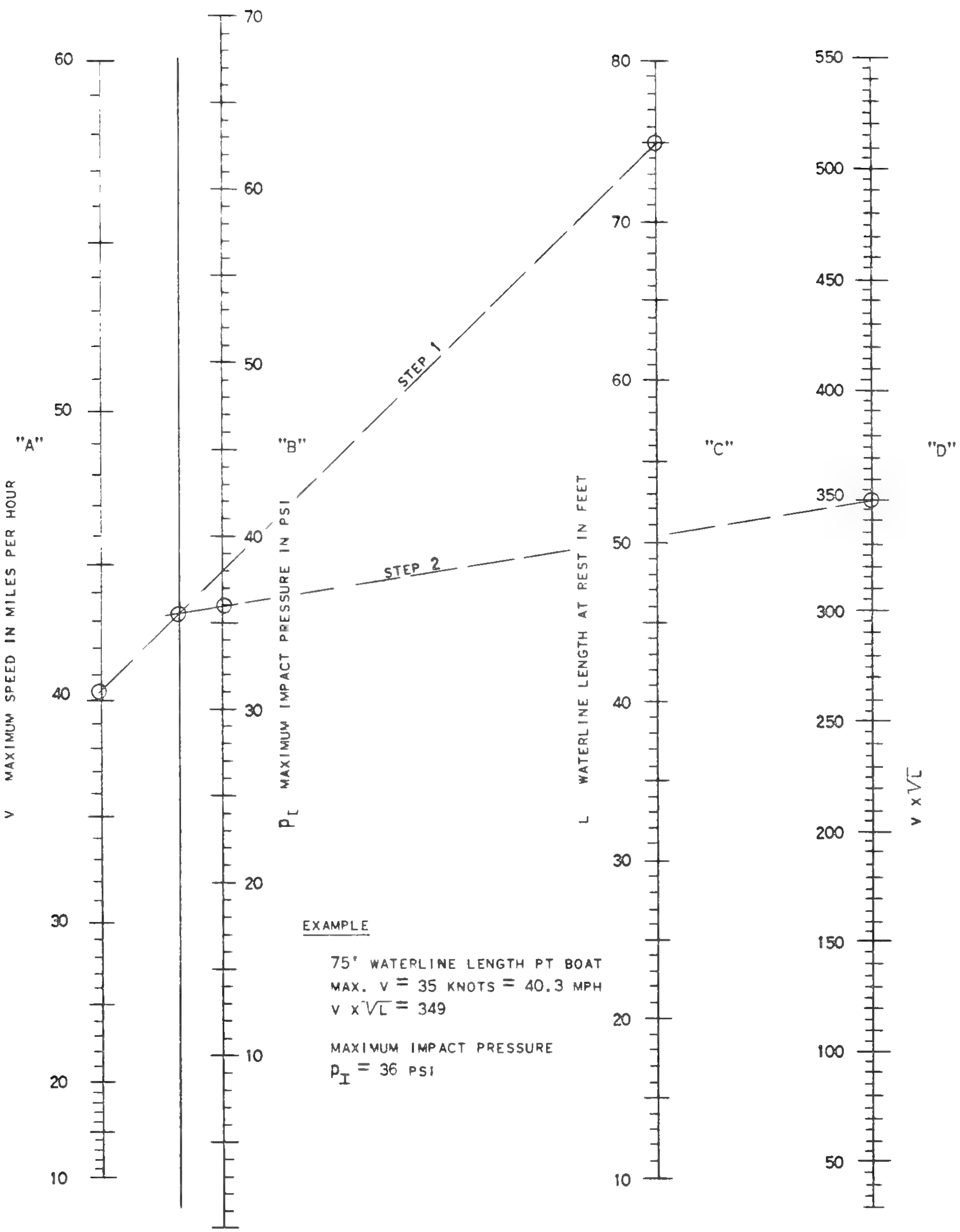
Compute $V \times \sqrt{L}$.

Rotate the straight edge so that it passes through the previously marked point on the line between scales A and B and the computed value of $V \times \sqrt{L}$ on scale D.

Read the pressure at the point at which the straight edge crosses scale B.

A detailed example is indicated on Fig. 2-14.

The pressure obtained from the procedure given above represents the maximum bottom impact pressure which will be present over a small area of the bottom, for short periods of

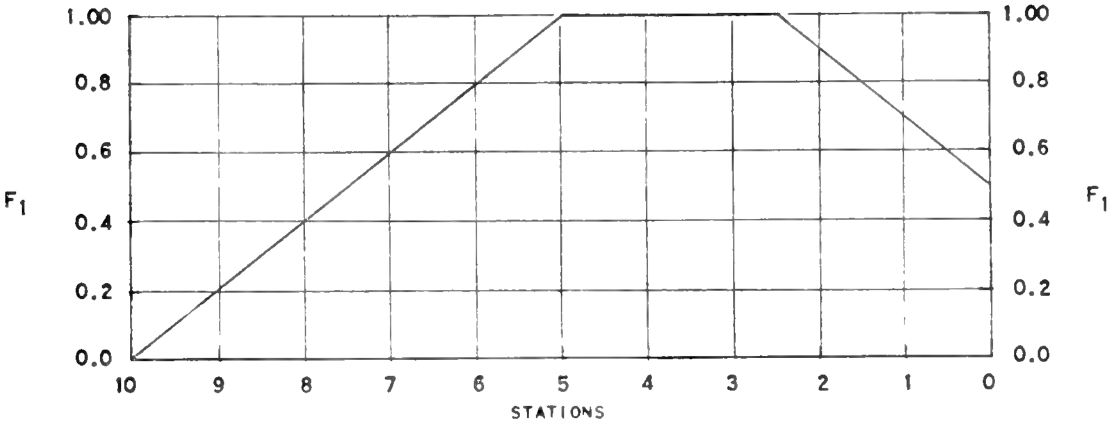


EXAMPLE

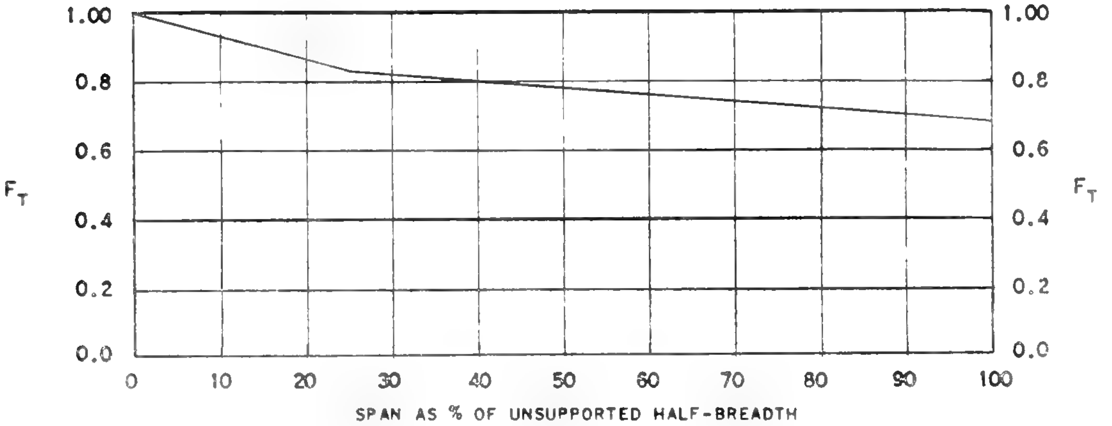
75' WATERLINE LENGTH PT BOAT
MAX. $V = 35$ KNOTS $= 40.3$ MPH
$V \times \sqrt{L} = 349$

MAXIMUM IMPACT PRESSURE
$p_I = 36$ PSI

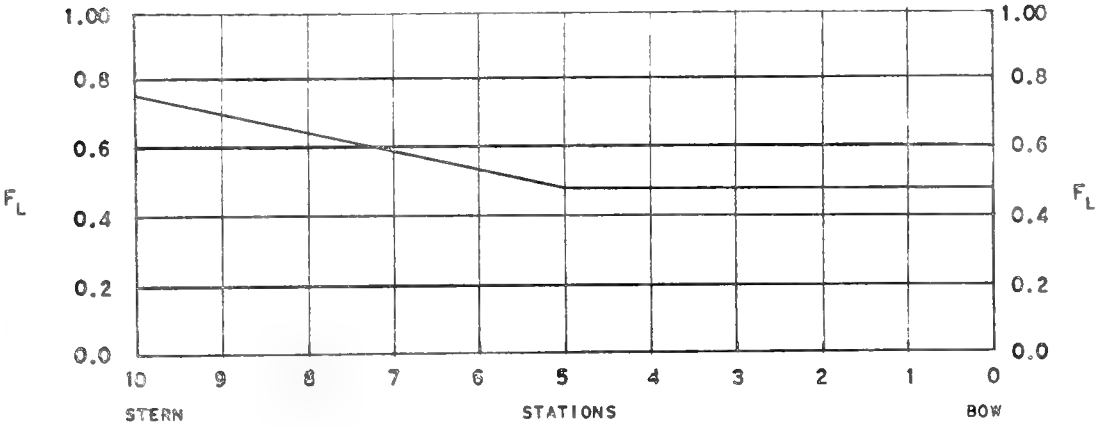
Fig. 2-14. Maximum bottom pressure for high speed planing boats



a. FACTOR F_1 VERSUS LONGITUDINAL LOCATION FOR SHELL



b. FACTOR F_T VERSUS SPAN FOR TRANSVERSES



c. FACTOR F_L VERSUS LONGITUDINAL LOCATION FOR LONGITUDINALS

Fig. 2-15. Pressure distribution factors time. This pressure will occur only under the most severe sea conditions, which must be judged in relation to the size of the boat. The intention here is that severe conditions are those in which the operator of the boat is subjected to acute discomfort. It is recognized that this does not represent a normal operating condition, but rather one due to some emergency, such as an approaching storm, when the boat must be driven as hard as the operator is physically capable of driving it.

The pressure given by the nomograph will not occur, at any one time, over a large area of the bottom, and there are areas of the bottom, both forward and aft where it will never occur. The pressure to be used for design purposes will vary with the type of member being designed and its location in the boat. These pressure variations with location and extent of area loaded were investigated during the PT boat tests (13), and the results, with some modifications, are summarized in Fig. 2-15.

For the design of the bottom shell the pressure to be used is the full pressure varied only for longitudinal location. The formula is:

$$p_D = p_H + p_I \times F_1 \tag{2.3}$$

p_D = design pressure

p_H = pressure due to the normal static head of water taken in the at-rest position

p_I = impact pressure from the nomograph, Fig. 2-14

F_1 = a factor for the shell impact pressure, depending on location along the length of the hull shown in the top graph of Fig. 2-15

It can be seen from the figure that one-half of the maximum impact pressure may be expected at the bow, the maximum may be reached anywhere between the forward one-quarter point and midships, and that the impact pressure drops off to zero at the stern. For practical construction, the whole bottom laminate forward of station 6 or 7 may be designed for the maximum impact pressure, and the laminate aft for the impact pressure at station 6 or 7. In this manual reference to station numbers is based on the water line length being divided into ten stations from forward.

For the design of transverse members the variation in pressure depends on the longitudinal location of the member in the boat, and on the span of the member in the transverse direction. The formula is:

$$p_D = p_H + p_I \times F_1 \times F_T \tag{2.4}$$

p_D = design pressure considered acting as a uniform pressure on the shell area supported by the transverse

p_H = static water pressure as previously defined

p_I = pressure from nomograph, Fig. 2-14

F_1 = factor taken from the top graph on Fig. 2-15

F_T = factor taken from the second graph on Fig. 2-15

The factor F_T varies with the length of span expressed as a function of the half-breadth of the boat at the transverse. This means that for a boat with a center keel and transverse framing spanning the entire half-breadth, the design load is a uniform pressure equal to 0.68 times the maximum pressure at the longitudinal position of the transverse in question. This reduction is due to the fact that only a portion of the shell area supported by the transverse will be subjected to the maximum pressure at any one time.

For the design of longitudinals the variation in pressure is dependent on the longitudinal location of the member. The formula is:

$$p_D = p_H + p_I \times F_1 \times F_L \qquad (2.5)$$

p_D = design pressure considered acting as a uniform pressure on the portion of the shell area supported by the longitudinal

p_H = static water pressure as previously defined

p_I = pressure from the nomograph, Fig. 2-14

F_1 = factor taken from the top graph on Fig. 2-15

F_L = factor taken from the bottom graph on Fig. 2-15

To obtain the design pressure for a longitudinal with a particular span, or distance between transverse supports, calculate the design pressure p_D at the ends of the span and use the average of these two values as a uniform load on the portion of the shell supported by the longitudinal.

In designing the components of the bottom structure using the pressures obtained by the methods just described, a factor of safety of 1.5 on the ultimate wet strength of the material is suggested. This low factor of safety is permissible because the pressure used is for an extreme loading condition.

An alternative criterion which should be checked on all runabout designs is the deflection of the bottom. The assigning of an allowable deflection is a difficult problem since it depends on the reaction of the passengers in a boat. People who are accustomed to wood hulls sometimes regard the flexing of a fiberglass boat as a sign of weakness. The reasons that fiberglass hulls may flex more than wood hulls are that the hull thickness is reduced because of the higher strength of the fiberglass laminate, and that the number of transverses is reduced compared to that required for a wood hull to prevent working and leaking at the seams.

From a structural point of view, limited deflection of the shell in a boat hull is not, in itself, a major problem. However, the passenger reaction previously mentioned can be a serious one from the standpoint of customer acceptance. For guidance, it is recommended that the deflection of bottom structure under the maximum bottom pressure be limited to 1/100 of the span.

The side thickness of the planing boat is usually sized on the basis of the required bottom thickness to provide a balanced hull laminate. From a study of a number of existing designs which are believed to represent good current practice, the side laminate thickness may be taken as 75 to 80 per cent of the thickness of the bottom hull laminate with a minimum thickness of 1/8 inch. If a boat is intended to be used in service where frequent dockings are required, such as a club launch, or a passenger ferry, the side laminate should be increased to the same thickness as the bottom laminate.

Side framing for runabouts may be designed to withstand a pressure equivalent to a head of water six inches above the deck edge. If several side frames are used, they are usually made the same size throughout. A factor of safety of 4 is suggested for this loading. Side framing designed to the above criterion will usually support a lower maximum load than the shell laminate can support. The reason for this difference is that the side laminate thickness, selected as explained above, is chosen partially to resist effectively local impact loads due to striking docks, partially to reduce torsional deflection of the hull, and partially to prevent side panel vibration. The side framing in the forward end of a boat should be designed as bottom framing especially when a Vee form is used since it is subject to similar impact loadings.

The next shell design to be considered is for displacement type boats. These boats do not travel fast enough in a seaway to have the large impact pressures experienced by a high speed planing boat. The shell is therefore designed for a static water pressure.

In the case of the cruising sailboat, the shell and framing should be designed to withstand a head of water corresponding to that experienced when the boat is heeled to the point where the cockpit starts to flood. Depending on the height of the cockpit coaming this height will vary from 6 inches to a foot or more above the deck edge. Since this is a normal loading condition a factor of safety of four is suggested. Deflection is not normally a problem with boats of this type.

The displacement type power boat occupies a position midway between the planing power boat and the cruising sailboat, as far as the shell load is concerned. The shell design load for this type of boat cannot be taken from the empirical formulation presented for planing boats, but should be greater than the static pressure existing on the bottom with the boat at rest because of the additional loading experienced in a seaway. For these boats a bottom design pressure equivalent to a water head of 2 feet above the main deck forward of Station 7 and 6 inches above the main deck aft of Station 7 is recommended for the shell and framing.

In designing the framing for displacement boats no reduction factors for location and span, as are used for planing boats, should be applied. The pressures used here are not local transient impact pressures, such as those that occur on the planing hull, but are considered as a uniform load over the entire bottom of the boat. A factor of safety of four is recommended for use with this design loading. As in cruising sailboats, deflection is not normally a problem with this type of boat.

As with planing hulls, the side shell is proportioned on the basis of the bottom shell. For normal service this thickness may be taken as approximately 80 per cent of the bottom thickness. The side framing is designed to withstand a water head to a height six inches above the deck edge, as in planing boats.

To assist the designer in making preliminary estimates for the bottom laminate of a cruising sailboat, Fig. 2-16 has been compiled from existing designs. The Figure indicates required section modulus and stiffener spacing as a function of the cube root of the displaced volume. The Figure is for guidance only and in the detail design stage the laminate and the stiffener spacing must be determined for the particular boat by the detailed design methods. Fig. 2-16, in conjunction with the unit weights given in Fig. 2-12, will aid the designer in making preliminary weight calculations.

Transom: The vast majority of fiberglass boats built so far are powered by outboard motors. Even rowboats and small sailboats are generally arranged so that a small outboard motor can be used as a means of propulsion. The transom must therefore, be designed to support a motor of a size suitable for the boat. The designer should always remember the trend toward ever increasing power and size in outboard motors, and that boat owners all too often use motors of higher power than the designer considers necessary or even safe. In estimating the horsepower to be used in designing a transom the designer should be generous, particularly for a stock boat which will be widely distributed.

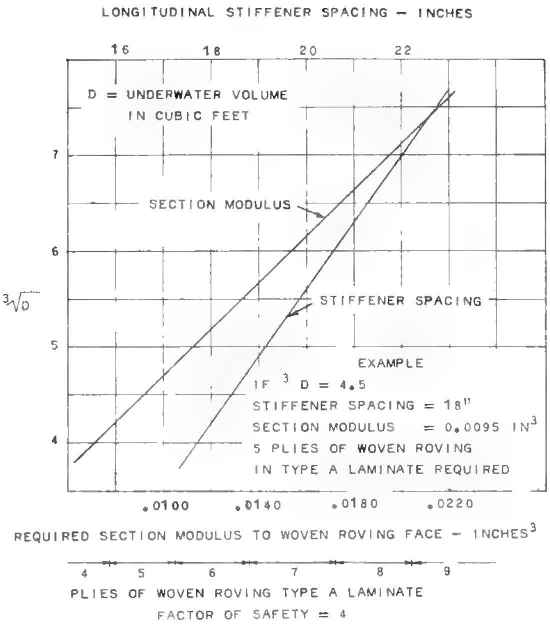


Fig. 2-16. Bottom shell laminate for fiberglass polyester cruising sailboats based on current designs

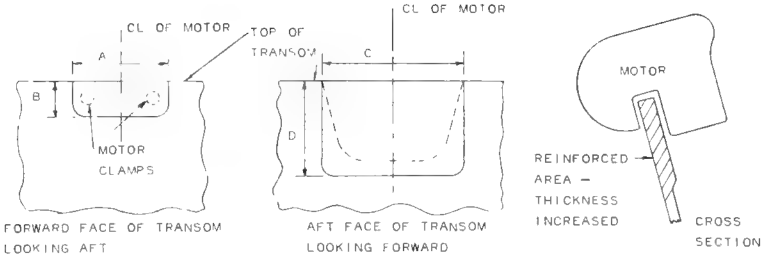
As a guide in selecting the transom thickness and in determining the dimensions of the area of increased thickness for the motor clamps, minimum standards have been set up by the Outboard Boating Club of America(14). These standards call for a minimum transom thickness of 1-3/8 inches for motors, totaling 40 horsepower and less, and 1-1/2 inches for motors totaling more than 40 horsepower. The maximum thickness in way of the engine clamping bracket is 1-3/4 inches for a single motor of 40 horsepower and less, and 2-1/4 inches for a single motor over 40 horsepower. In actual practice the entire transom is sometimes made the thickness required in way of the engine clamping bracket. Alternatively, the minimum thickness may be used throughout and steel plates added in way of the clamping bracket.

The over-all dimensions for the area and the increased thickness are given in Table 2-1 below.

TABLE 2-1

DIMENSIONS OF MOTOR SUPPORT AREA

OBC HP Rating	A	B	C	D	Thickness
Under 12	8-1/2	4-3/4	8-1/4	7-1/4	1-3/4
12-40	15-1/4	5-1/2	14-1/2	10-1/2	1-3/4
Over 40	10-1/8	3-5/8	12-1/2	11-1/2	2-1/4



For boats with high power, the transom design should be checked to insure that the minimum dimensions given above are adequate. To aid the designer, Fig. 2-17 has been prepared. This Figure provides the means of determining the required section modulus of the transom. It has been prepared based on the following assumptions:

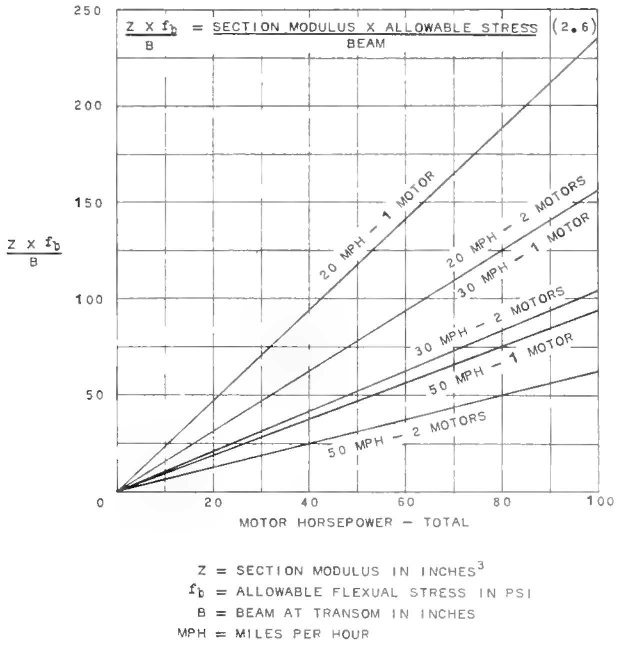


Fig. 2-17. Transom section modulus as a function of speed and power

The upper portion of the transom is considered to be a simply supported beam loaded with the thrust required to move the boat.

The thrust used in developing the Figure was determined by taking the effective horsepower equal to 1/2 the motor horsepower (1).

To use Fig. 2-17, enter the graph at the total horsepower to be used, read up to the appropriate line for the speed and number of motors, and read across to the value of the parameter

$$(Z \times f_b)/B \qquad (2.6)$$

By using the known values of allowable flexural stress, f_b, and the beam of the transom B, the required section modulus, Z, may be obtained. A factor of safety of 6 is recommended in determining the allowable stress. It should be noted that a stronger transom is required to support one 40 horsepower motor than to support two 20 horsepower motors mounted side by side.

The most common and practicable method of construction for transoms is a sandwich arrangement with a plywood core and fiberglass facings. In computing the effective section modulus of the transom, it is recommended that the following assumptions be used:

> The effective width of the transom should be taken as the maximum vertical dimension of the motor clamping area as given in Table 2-1.
>
> Only the plies of plywood whose grain is horizontal, that is parallel to the span being considered, should be taken as effective. These will normally be the face plies, and alternating "center" plies within the plywood. This procedure is recommended by Ref. 15.
>
> Where a seat or motor well is made an integral part of the transom, this should be included in the section modulus.

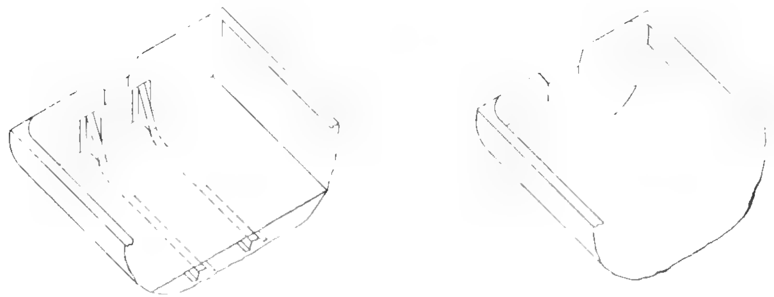
For an example of the use of Fig. 2-17, see Design Example 2-3 for the 19 foot runabout.

Resonant vibration does not normally occur at the transom. The vibration felt there is a forced vibration excited by the motor, but the fundamental frequency of the transom is so far from any normal operating range of the motor that resonance with this frequency is not a problem.

The unsupported transom is used for boats with low power, but this not usually satisfactory for boats in the high power range. Several methods of support are used, singly or

a. UNSUPPORTED TRANSOM

b. INNERBOTTOM FLANGED UP
TO SUPPORT TRANSOM.
BOAT SHOWN CUT ALONG
CENTERLINE



c. VERTICAL BRACKETS TO BE
SUPPORTED BY LONGITUDINALS.
NOTE: GUNWALE CARRIED INBOARD
ON TRANSOM

d. HORIZONTAL SHELF SUPPORTING
TRANSOM.
NOTE: GUNWALE CARRIED INBOARD
ON TRANSOM

Fig. 2-18. Transom configurations

in combination as illustrated in Fig. 2-18. Normally, in boats intended for higher power, a narrow side deck or heavy gunwale strip will exist which may be carried around the corner to reduce the span of the transom. If a permanent inner bottom is provided, this may be given a radius at the stern, and carried up the transom for support. The use of vertical brackets, which is common in wood construction, should be avoided in fiberglass construction unless there are corresponding stiffening members on the bottom. This is because the toe of a bracket landing on unsupported shell constitutes a definite "hard spot" as discussed in Chapter 3. One of the most common and most effective means of support for the transom is the horizontal shelf located as close to the top of the transom as the depth of the mounting bracket of the motor will permit. This horizontal shelf is usually used as a seat, or as the bottom of a watertight well. Another method of increasing transom rigidity is to curve the transom aft. The effect of any normal curvature is comparatively small, and it is felt that the possible reduction in the transom thickness should not be considered.

Decks: For structural design purposes, decks are divided into two types: weather decks which may be subject to water loading and interior flats and cabin tops which are subject to loads from personnel and equipment.

For weather decks, including watertight open cockpits, a uniform load corresponding to 2 feet of water is considered a good design value for most pleasure boats. For work boats and fishing boats designed to operate at sea, a higher figure should be used. In boats with small partial decks, as in runabouts and small sailboats, an alternative design loading may be used, assuming the weight of a man concentrated at the center of the deck. A factor of safety of four is suggested with either of the above loadings.

For interior decks, non-tight cockpits, and cabin tops, the design load depends on the intended use of the boat. The load for the interior deck of a privately owned vessel may be taken as 40 pounds per square foot, while the passenger deck for a high speed ferry such as a service craft for offshore drilling rig should be designed for approximately 60 pounds per square foot. The above loadings are for the at-rest condition. The increase for accelerations due to pounding in a seaway depends on the requirements of the service, and on the arrangements. In high speed offshore ferry service, where it may be necessary to maintain high speed in rough seas, a "g" or gravity factor of two should be applied to the above loads for flats in the forward portion of the vessel; that is the loads given above should be doubled.

An important design consideration for decks, particularly in walking areas, is deflection. The allowable deflection, as previously discussed in the section on shell design, is a subjective matter. An allowable deflection of 1/200th of the span under the design loads discussed above is recommended.

Decks, particularly interior flats, are usually constructed of plywood or of sandwich construction with a lightweight core and fiberglass faces. For maximum economy with fiberglass construction, a single molding including deck, seats, and any other interior accommodation is recommended where feasible.

In small boats, with single skin construction, the use of contour, i.e. raised areas, in lieu of stiffeners is very common.

Gunwale: For open or partially decked boats, some form of gunwale must be provided to strengthen the upper edge of the side. The most severe loading likely to occur on a gunwale will vary according to the size of the boat. However all gunwales are subject to impact at docks and from other boats. In a boat small enough to be man-handled, it is possible that the boat will be rolled over on its gunwale for cleaning or storage. The gunwale should therefore be able to withstand the weight of the boat concentrated at the center of the longest span between gunwale supports. The factor of safety for this loading condition may be quite small, say 2 on the ultimate wet strength, since it is not a normal service load.

For larger boats, the gunwale will be used, in many cases, as a step when boarding or leaving the craft. The stability of the boat should, of course, be checked for this condition and if found inadequate, the shape of the gunwale should discourage passengers from attempting to step on it. In the event that the gunwale is intended for use as a step, the necessary width, approximately 3 or 4 inches, should provide ample strength for boats with conventional arrangements. For common gunwale types, see Chapter 3.

Bulkheads: Transverse bulkheads in small pleasure boats are not usually intended to withstand water pressure, as is the case in larger vessels. In some cases Coast Guard Regulations (16) require bulkheads to resist water pressure. In the case of small commercial vessels carrying more than six passengers the bulkhead must be able to withstand a head of water to the top of the bulkhead.

In addition to the possible requirement for withstanding a waterhead, bulkheads are generally required to support the weight of equipment mounted on them, the loads imposed by the deck and side framing and any local loads, as from a mast. A factor of safety of 4 on the ultimate wet strength is recommended.

All of the foregoing may sound very difficult, but fortunately it is not usually necessary to perform a detailed analysis on bulkheads except for special cases where large local loads are to be supported. Usually unstiffened 1/2 to 3/4 inch thick plywood for cruising boats and 1/4 to 3/8 inch thick plywood for smaller craft, or lightweight sandwich construction of equal rigidity may be used. This equivalent rigidity is considered necessary since one of the most important functions of a transverse bulkhead is to provide sufficient stiffness to maintain the shape of the hull.

Ballast Attachment: The attachment of localized heavy ballast occurs in some sailboats. This ballast, usually in the form of lead or grey cast iron is attached to the bottom of the hull. The attachment is normally made with bolts cast into the ballast and passing through the heavy laminate at the bottom of the boat. The design loading used to check the attachment and the surrounding structure is generally taken as twice the weight of the ballast to allow for acceleration due to heave and pitch. The effect of buoyancy is ignored as an added safety factor. Since conservative design of this attachment costs very little and provides added safety at a vital point, a factor of safety of 4 on the ultimate wet strength of the materials involved is recommended.

For ready reference a summary, Table 2-2, of the design loadings and factors of safety recommended in this Chapter has been prepared.

TABLE 2-2 SUMMARY OF DESIGN LOADS AND FACTORS OF SAFETY

Boat Type	Shell		Framing		Decks		Transom	Gunwale	Bulkhead
	Bottom	Side	Bottom	Side	Weather and *W.T. Cockpit	Interior and **N.T. Cockpit			
Small Open Boat (Low Power)	Use Std Laminate p 2-13	Use Std Laminate p 2-13	Nominal-use with flat bottom only p 2-14	None	None	40 psf F. S. =4. 0	OBC Std Table 2-1	Weight of Boat on center of long span F. S. =2. 0	None
High Power Planing	Impact Pressure (Figs. 2-14 & 2-15) F. S. =1. 5	75-80% Bottom Thickness	Impact Pressure (Figs. 2-14 & 2-15) F. S. =1. 5	Water-head 6" above deck edge F. S. =4. 0	Waterhead 2' of water F. S. =4. 0	Same as above	OBC Std Table 2-1 and Fig. 2-17 F. S. =6. 0	Same as above	Nominal Size and Local Load F. S. =4. 0
Cruising Sail	Waterhead to Coaming in heeled condition F. S. =4. 0	Same as Bottom	Same as Shell	Same as Shell	Same as above	Same as above	Same as Shell	None	Same as above
Cruising Displacement Low Power	Waterhead 2' above Deck Fwd Sta. 7. 6" above Deck Aft Sta. 7 F. S. =4. 0	Waterhead 6" above Deck F. S. =4. 0	Waterhead same as Shell F. S. =4. 0	Water-head same as Shell F. S. =4. 0	Same as above	Same as above	Same as above for outboard power, same as shell for inboard	None	Same as above

* W. T. denotes watertight.

** N. T. denotes non-tight.

DESIGN EXAMPLES

The design loadings and methods explained and illustrated in this Chapter can be used for guidance by the designer in determining the scantlings of major structural components and other important details for fiberglass boats. A study of Chapter 3, "Design Details" is strongly recommended before beginning a fiberglass boat design, since this material, like wood and other laminated materials, requires proper structural arrangement of panels and framing members.

Examples of typical structural calculations are given for five different boat types as follows: rowboat, open sailboat, high speed runabout, cruising sailboat, and power cruiser. The calculations are based on the design loads and factors of safety summarized in Table 2-2. The physical properties values used for the various types of fiberglass reinforcement are the low average values given in Tables 5-6 to 5-14. These values have been selected for consistency in the design examples and are suggested when test data are not available. When it is desired to use higher values to save weight, cost and building time, it is necessary that tests be made of the actual production laminate to justify these higher values.

Since the purpose of this manual is to guide the designer in the selection and application of fiberglass laminates, the calculations are based on simplifying assumptions, both for the loads applied and the methods of analysis. These simplifications are also justified to some extent by the uncertainty regarding actual service loads which may occur, particularly for the boats of the sizes discussed.

The methods of calculation used in these design examples are standard methods of analysis which are readily available in many standard texts, and are therefore not referenced. Those calculations which are different from the standard methods because of the characteristics of the material, such as section modulus calculations, are similar to the methods developed and explained in Chapter 6.

Because the design examples are intended to illustrate structural calculations, details are not indicated except where necessary to provide structural arrangement for analysis. Selection of a particular detail or method of construction for analysis does not imply that the detail chosen is the only one which may be used.

In all the design examples, unless otherwise noted, reinforcement weights are:

Cloth - 10 ounces per square yard
Woven Roving - 25-27 ounces per square yard
Mat - 2 ounces per square ft.

DESIGN EXAMPLE 2-1. ROWBOAT

This rowboat is a common type suitable as a tender for a large yacht, or for fishing and general pleasure and is usually used in protected waters. If used as a work boat or a utility tender for a large commercial fishing vessel the scantlings should be suitably increased. This design allows for the use of a 5 horsepower outboard motor.

Principal Dimensions - See Fig. 2-19 for details.

Length Over-all:	13 ft. - 0 in.
Beam:	4 ft. - 6 in. maximum

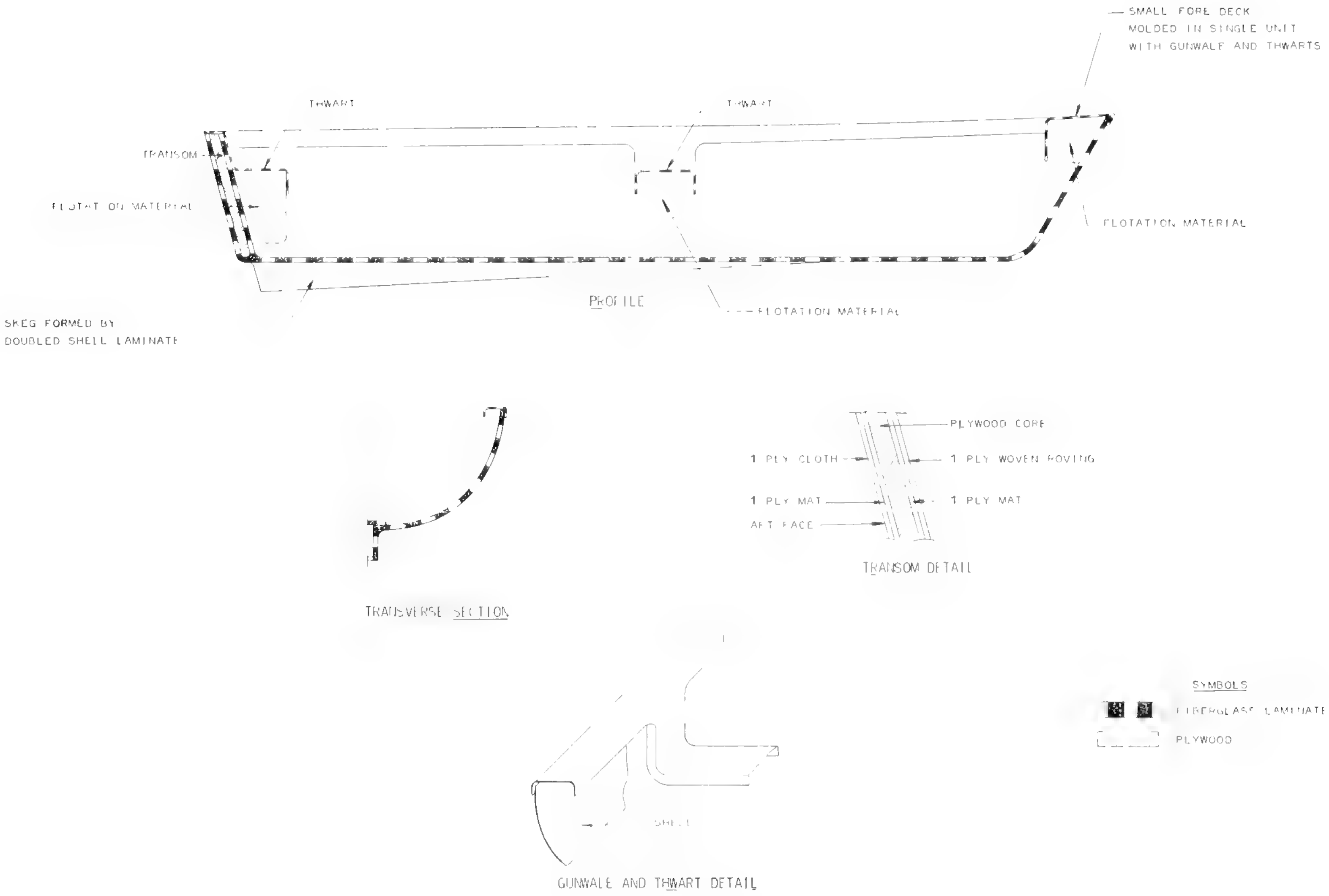


Fig. 2-19. Rowboat

Summary of Scantlings

Shell Laminate: 1 ply cloth on outboard face, 1 ply mat and 1 ply woven roving.

Transom: 1-3/8 in. thick, as required by OBC Standards (14). Sandwich construction - 1-1/4 in. thick waterproof Douglas fir plywood core, 1 ply cloth and 1 ply mat on aft face; 1 ply mat and 1 ply woven roving on forward face. Mat plies placed next to plywood for maximum bond and to reduce porosity.

Gunwale, Thwart and Fore Deck: Molded in a single unit of 1 ply cloth and 2 plies mat. Gunwale to be a channel section with 2 in. flanges and web; similar to Fig. 3-17. Thwart to be a channel section with a 12 in. web and 3-1/2 in. flanges with an additional ply of mat on the flanges, Fig. 2-20.

Design

Gunwale: Design Loading - Assume weight of boat as a concentrated load at the center of the longest span.

Factor of Safety = 2.0

Weight of Boat; estimated = 150 lbs.

Maximum Span = 6.5 ft.

$$\text{Bending Moment, } M = \frac{PL}{4} \qquad (2.7)$$

$$M = \frac{150 \times 6.5 \times 12}{4} = 2925 \text{ in.-lbs.}$$

Use a premolded U-shaped gunwale, similar to Fig. 3-17, with a 2 in. horizontal web and 2 in. vertical flanges. The laminate should consist of 1 ply cloth on top and 2 plies mat.

By separate calculations, not shown, the critical stress is found to occur at the inboard flange of the gunwale.

Section Modulus, Z, at the cloth = 0.265 in.^{3}

$$\text{Stress} = \frac{\text{Bending Moment}}{\text{Section Modulus}} \;;\; f_t = \frac{M}{Z} \qquad (2.8)$$

$$f_t = \frac{2925}{0.265} = 11{,}038 \text{ psi}$$

Ultimate Stress, cloth in tension, F_{tu} = 24,100 psi (Table 5-6)

$$\text{Factor of Safety} = \frac{\text{Ultimate Stress}}{\text{Calculated Stress}} \;;\; \text{F.S.} = \frac{F_{tu}}{f_t} \qquad (2.9)$$

$$\text{F.S.} = \frac{24{,}100}{11{,}038} = 2.18 \text{ Satisfactory}$$

Thwarts: Consider as a simply supported beam loaded by two 200 pound men, sitting at one-third of the span from each end.

Factor of Safety = 4.0

$$\text{Bending Moment, } M = F \times \frac{L}{3} \qquad (2.10)$$

$$M = \frac{200 \times 54}{3} = 3600 \text{ in.-lbs.}$$

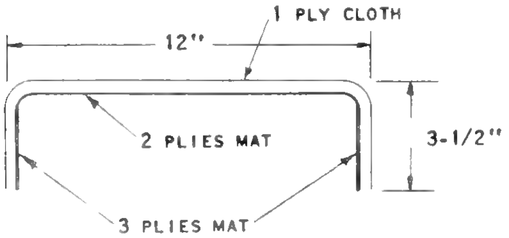


Fig. 2-20. Thwart cross-section

Consider a channel shaped thwart integrally molded with the gunwale as shown in Fig. 2-19. The cross-section and laminate construction shown in Fig. 2-20 gives the following results: Ultimate tensile stresses from Table 5-6.

Stress in Cloth - tension at bottom edge of flange = 5350 psi

$$\text{Factor of Safety} = \frac{24{,}100}{5350} = 4.5 \quad \text{Satisfactory}$$

Stress in Mat - tension at bottom edge of flange = 2250 psi

$$\text{Factor of Safety} = \frac{11{,}000}{2250} = 4.9 \quad \text{Satisfactory}$$

Tensile and compressive stresses are used instead of the flexural stresses given in Chapter 5 because the flexural stresses are obtained from tests of bending in a plane perpendicular to the plane of the laminate. No experimental information is available regarding flexural stresses when the bending is in the plane of the laminate.

DESIGN EXAMPLE 2-2. OPEN SAILBOAT

This sailboat is intended for use as a day sailer and for class racing. It is a sloop rigged, centerboard boat and similar in size, rig, and general layout to many classes in widespread use. The transom is to be suitable for a 5 horsepower outboard motor.

Principal Dimensions - See Fig. 2-21 for details.

Length Over-all:	14 ft. - 0 in.
Beam:	5 ft. - 2 in. maximum
Sail Area:	131 sq. ft.

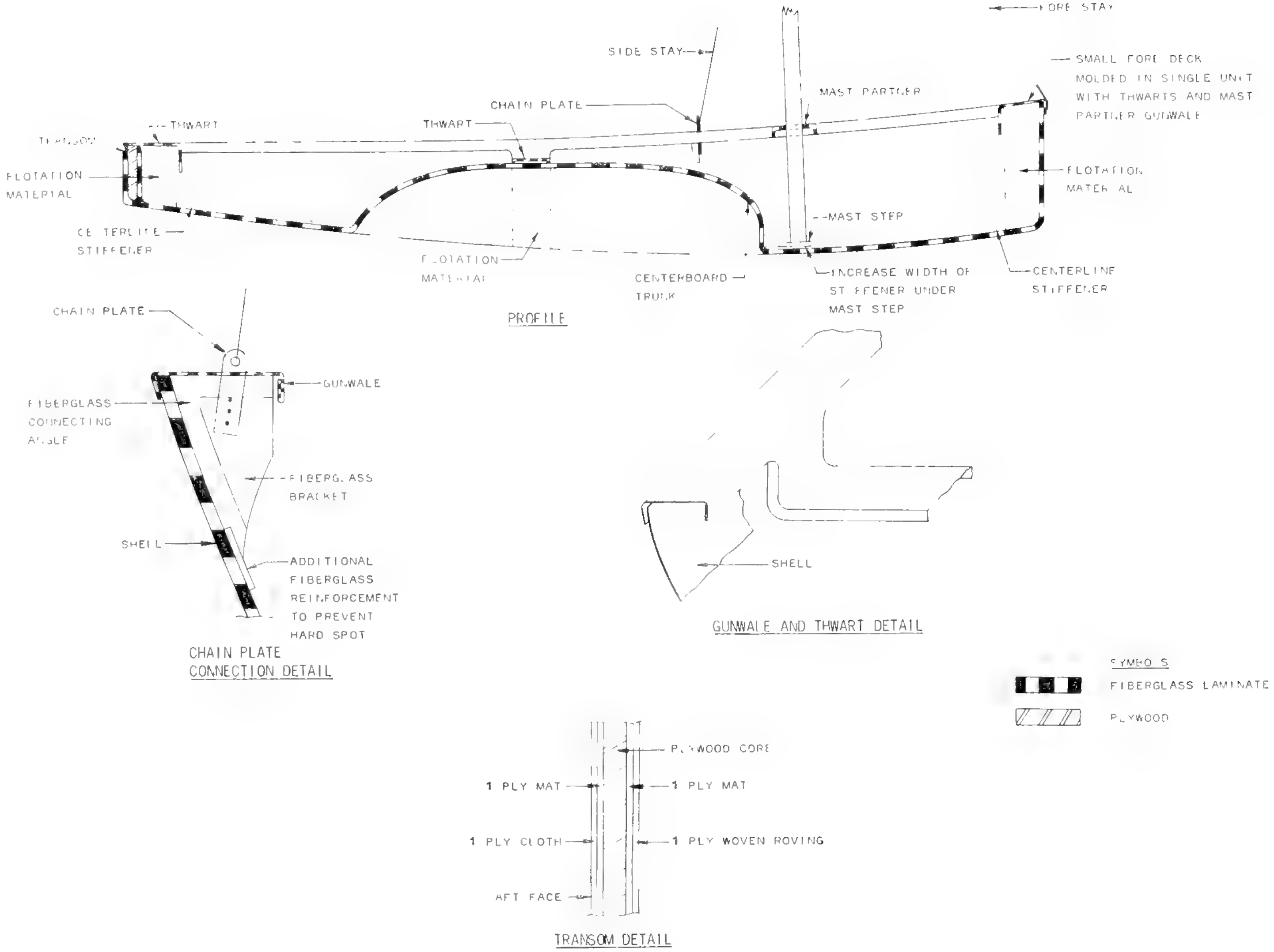


Fig. 2-21. Open sailboat

Summary of Scantlings

Shell Laminate: 1 ply cloth on outboard face of laminate, 1 ply mat, and 1 ply woven roving.

Centerboard Trunk: Same laminate as shell.

Centerline Stiffener: 1/2 in. deep x 1-1/2 in. wide, parallel roving stiffener in lieu of keel forward and aft of centerboard trunk.

Thwart and Gunwale: molded in single unit of 1 ply cloth and 2 plies mat. Gunwale to be channel shaped with 2 in. flanges and web. Thwart to be 8 in. wide with 2-1/2 in. vertical legs with additional 2 plies of mat on each leg.

Chain Plate: to be 1-1/8 in. wide x 3/16 in. thick stainless steel, connected to a 5 ply woven roving fiberglass bracket by three 1/8 in. stainless steel bolts.

Mast Step: to be 12 in. x 12 in. and made of mat.

Mast Partner: to be similar to the thwart except for a local increase in way of the mast, and to be molded in single unit with thwarts, gunwale and fore deck.

Design

Thwart: Consider supported at side, and on centerline by centerboard trunk; loaded by a 200 pound man at the center of the unsupported span. Except for the bending moment equation, the calculation is similar to that for the rowboat, Design Example 2-1, and is not shown.

Use an 8 in. wide, channel shaped thwart with 2-1/2 in. vertical legs. Use 1 ply of cloth and 2 plies of mat on the seat, 1 ply of cloth and 4 plies of mat on the vertical legs.

Gunwale: The gunwale of a boat of this type must be wide enough for the crew to sit on and is assumed to be 4 inches wide. By comparison with the design example for the rowboat, this will obviously be strong enough. The construction adopted, shown in Fig. 2-21, is similar to that used for the rowboat except that the laminate is doubled under at the inboard edge. This is to provide a "hiking" hand grip without a rough edge for the crew members. Vertical loading due to a person stepping on the gunwale need not be checked, since the boat is not stable to permit such use.

Transom: Since the use of the 5 horsepower outboard motor is contemplated, the transom may be designed the same as for the rowboat transom. The motor will be mounted on a bracket attached to the aft face of the transom

This will result in the following:

OBC Standard thickness = 1-3/8 in., from Table 2-1.

Use 1-1/4 in. plywood core; 1 ply cloth, 1 ply mat on aft face; 1 ply mat, 1 ply woven roving on forward face.

Rigging Supports: The size of the stays on a sailboat is selected to resist the loads imposed by the sails to cause an overturning moment equal to the maximum heeling moment available. For illustrative purposes, it is assumed that this calculation has been made and the stays chosen are 3/32 in. diameter, 1 x 19 stainless steel wire rope with a breaking strength of 1200 pounds (17). The chain plates are designed to the yield stress of the material and the supporting fiberglass laminate to a factor of safety of 2.

Stay Connection:

Stainless steel chain plate and pin;

Tensile Yield Stress, F_{ty} = 40,000 psi (Reference 18)

Shear Yield Stress, $F_{sy} = 0.6 \times F_{ty} = 24{,}000$ psi

Consider pin in double shear and load P = 1200 lbs.:

Required pin area, $A_p = \dfrac{P}{2 \times F_{sy}}$ (2.11)

$$A_p = \frac{1200}{2 \times 24{,}000} = 0.025 \text{ sq. in.}$$

Use 3/16 in. pin diameter; Area = 0.035 sq. in.

Chain Plate:

Thickness required for bearing of pin;

Bearing Yield Stress, $F_{By} = 1.6 \times 24{,}000 = 38{,}400$ psi

Bearing load, P = 1200 lbs.

$$t = \frac{P}{F_{By} \times D} \qquad (2.12)$$

$$t = \frac{1200}{38{,}400 \times 0.1875} = 0.1665 \text{ in.}$$

Use 0.1875 or 3/16 in. thick plate

Chain Plate Fastening to Hull: The chain is passed through the gunwale and fastened to a transverse bracket, which is connected with bonding angles to the shell. The bracket is used in lieu of bolting directly through the shell for appearance.

Assume the bracket is made of 5 plies of woven roving, and the bolts are 1/8 in. diameter stainless steel. Design for the wire to fail without permanent deformation of the laminate:

Total load, P = 1200 lbs.

Laminate thickness, t = .185 in. (Table 5-2)

Bearing area per bolt = Bolt diameter x Laminate thickness

$$A_B = D \times t \qquad (2.13)$$

$$A_B = 0.125 \times 0.185 = 0.023 \text{ sq. in.}$$

Allowable Bolt Bearing Stress - from Table 3-2 and for no permanent deformation:

F_{Ba} = .641 x Laminate ultimate tensile strength

F_{Ba} = .641 x 32,900 = 21,070 psi - Table 5-6 for Ultimate Tensile Stress

Allowable bearing load per bolt = Bearing area x Allowable bearing stress

$$P_{Ba} = A_B \times F_{Ba} \tag{2.14}$$

$$P_{Ba} = 0.023 \times 21,070 = 488 \text{ lbs.}$$

Required number of bolts ; $N = \dfrac{P}{P_{Ba}}$ (2.15)

$$N = \frac{1200}{488} = 2.46 \text{ bolts}$$

Use three bolts.

Chain Plate Width:

$$\text{Total Width} = \text{Diameter of pin} + \frac{\text{Load}}{\text{thickness of plate} \times \text{tensile yield stress}}$$

$$b = D + \frac{P}{t \times F_{ty}} \tag{2.16}$$

$$t = \frac{3}{16} \text{ in.} = 0.1875 \text{ in.}$$

$$b = 0.1875 + \frac{1200}{0.1875 \times 40,000} = 0.3475 \text{ in.}$$

Use a 1-1/8 in. wide x 3/16 in. thick plate minimum.

Required Vertical Length of Bracket: Assume load carried in shear by shell to bracket connection, which is made of two 2 in. x 2 in. fiberglass polyester resin angles. The angles are made of one ply of 1-1/2 ounce mat against the bracket and shell and two plies of woven roving. The connection between the angles and the shell and bracket is in secondary bond with polyester resin.

Ultimate Bond Shear Stress, F_{Bsu} = 1000 psi

Factor of safety, F.S. = 2.0

$$\text{Vertical length of bracket, } L = \frac{P \times F.S.}{\text{Bond Width} \times F_{Bsu}} \tag{2.17}$$

$$L = \frac{1200 \times 2}{2 \times 2 \times 1000} = 0.60 \text{ in.}$$

The shear connection is obviously not critical so the bracket is made 8 inches long to accommodate the length of the chain plate and provide a reasonable taper at the bottom as described in Chapter 3.

Hull Support for Chain Plate: The slope of the side stay places a horizontal load on the gunwale causing bending and local compression.

The horizontal load is 210 pounds, and the distance between the mast partner and thwart is about 4 ft. 6 in. Following the same procedure as for the gunwale for the rowboat:

Bending Moment, $M = \frac{PL}{4} = \frac{210 \times 54}{4} = 2840$ in.-lbs. (2.7)

Factor of Safety = 2.0

Ultimate Stress of Mat in Tension, F_{tu} = 11,000 psi (Table 5-6) *

Allowable Tensile Stress $= \frac{\text{Ultimate Stress}}{\text{Factor of Safety}}$; $f_{tu} = \frac{F_{tu}}{F.S.}$ (2.9a)

$F_{tu} = \frac{11000}{2} = 5500$ psi

Required Section Modulus $= \frac{\text{Bending Moment}}{\text{Allowable Stress}}$; $Z = \frac{M}{f_t}$ (2.8a)

$Z = \frac{2840}{5500} = 0.516$ in.^{3}

Section Modulus of Gunwale, Figure 2-21, $Z = 1.568$ in.^{3} Satisfactory

* For an explanation of the use of tensile rather than flexural stress, see Design Example 2-1, gunwale and thwart design.

Finally, a check must be made of the shear loading on the horizontal web of the gunwale. Consider the horizontal load of 210 pounds to be applied by the bracket to the web.

Ultimate Shear Stress of Woven Roving, F_{su} = 7500 psi (Table 5-14)

Factor of Safety = 2.0

Allowable Shear Stress, f_s = 3750 psi

Area = Thickness of Laminate x depth of gunwale x 2

$A = 0.113 \times 4.0 \times 2 = 0.904$ in.^{2}

Stress, $f_s = \frac{P}{A}$ (2.18)

$f_s = \frac{210}{0.90} = 232$ psi Satisfactory

Mast Support: The mast is subjected to loading from two sources. Loads in the horizontal plane from the sail and boom, and vertical and horizontal loads applied by the stays. The stay loads are of two types; the forestay being loaded primarily by the jib and the side stay being loaded by the horizontal load at the top of the mast.

The mast is supported by the mast step at the bottom of the hull which resists the vertical compression in the mast, and also by the mast partner which is a horizontal support reducing transverse bending in the mast. The horizontal load at the mast partner is relatively small and may be ignored. The vertical load may be approximated by assuming the forestay and one of the side stays to be at the breaking point.

Taking the vertical components of the 1200 lbs. breaking load, the following vertical loads are found:

From the side stay, P_s = 1180 lbs.

From the forestay, P_f = 1160 lbs.

Total P_t = 2340 lbs.

Considering the built-up mast step to be of mat laminate:

Base of mast assumed 2 in. x 2 in. Mast base periphery, L_p = 8 in.

$$\text{Compressive Stress, } f_c = \frac{2340}{2 \times 2} = 585 \text{ psi} \quad \text{Satisfactory}$$

$$\text{Shear Stress} = \frac{\text{Load}}{\text{thickness of shell x mast base periphery}} \; ; \; f_s = \frac{P_t}{t \times L_p} \qquad (2.19)$$

Use Factor of Safety = 2.0

For discussion of Factor of Safety see chain plate support.

$$\text{Allowable Shear Stress, } F_s = \frac{9900}{2} = 4950 \text{ psi} \qquad \text{(Table 5-14)}$$

$$\text{Required shear area, } A_s = \frac{2340}{4950} = 0.47 \text{ in.}^2$$

Minimum thickness of bottom of hull:

$$t = \frac{.47}{8} = .059 \text{ in.}$$ This is less than the shell thickness previously specified and is satisfactory

In order to avoid creation of local hard spots, see Chapter 3, the centerline stiffener will be widened immediately under the base of the mat mast step. This extra width is tapered off to the normal width to form a 12 in. wide reinforced area.

The Mast Partner: The mast partner is made of the same scantlings as the thwart, with a local increase in thickness to about 1/2 in. in way of the mast.

DESIGN EXAMPLE 2-3. 19 FT. RUNABOUT

This runabout is representative of the type of boat which has had the most widespread application of fiberglass construction. It is intended for pleasure use, including day trips in relatively open water, and for towing water skiers. The boat is somewhat larger than the majority of its type, but the design principles illustrated are, of course, applicable to the smaller sizes.

Principal Dimensions - See Fig. 2-22 for details.

Length, Over-all: 19 ft. - 0 in.

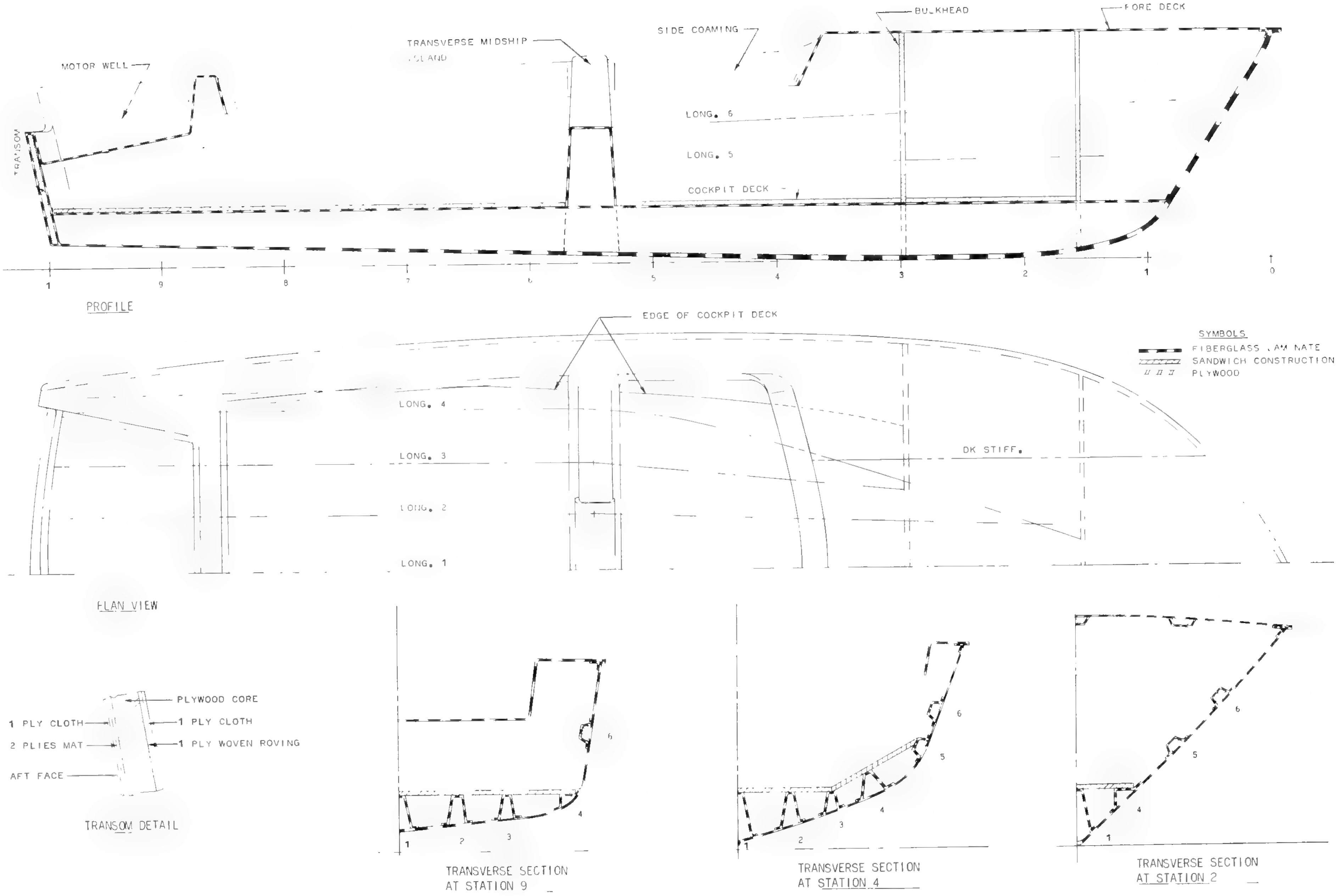


Fig. 2-22. 19 Ft. Runabout

Length, Water Line: 18 ft. - 6 in.
Beam: 7 ft. - 0 in. maximum
Draft, at rest: 8 in.

Speed = 38 miles per hour
Power = 2 outboard motors at 50 horsepower each

Summary of Scantlings

Shell Laminate: Bottom forward of Station 7 and side forward of Station 4-1/2; 1 ply cloth on outboard face of shell, 3 plies 1-1/2 ounce mat and 1 ply woven roving.

Note: For rugged service, where maximum impact strength is required, a higher strength laminate of 1 ply cloth, 1 ply 2 ounce mat, and 3 plies of woven roving could be used with a slight change in longitudinal size.

Bottom aft of Station 7 and side aft of Station 4-1/2; 1 ply cloth on outboard face of shell, 2 plies 1-1/2 ounce mat, and 1 ply woven roving.

Note: Same note as above applies except use 2 plies of woven roving.

Shell Framing: Longitudinals No. 1, 2, 3 and 4 - Size as shown on Fig. 2-22. Forward of midship transverse, 5 plies of woven roving. Aft of midship transverse, 6 plies of woven roving.

Longitudinals No. 5 and 6: 2 in. deep x 2 in. wide with 4 plies woven roving.

Deck Laminate: Fore Deck, Side Coaming, Motor Well and Transverse Midship Island: 1 ply cloth on top of deck, 2 plies 1-1/2 ounce mat, and 1 ply woven roving.

Deck Framing: Fore Deck, 1 in. deep x 4 in. wide. 2 plies woven roving.

Cockpit Deck: Sandwich construction, core 1/4 in. thick. 1 ply woven roving top and bottom; 1 ply cloth on top, optional - for appearance.

Transom: Sandwich construction; 1-1/2 in. Douglas fir waterproof plywood core. Laminate; after face, 1 ply cloth, outboard, 2 plies 1-1/2 ounce mat; forward face, 1 ply woven roving, inboard, 1 ply 1-1/2 ounce mat against plywood. Increase thickness at motor support area as specified by OBC standards, Table 2-1.

Bulkheads: 1/2 in. thick core, 1 ply cloth each side, 1 ply 1-1/2 ounce mat each side against core.

Deck Connecting Angles: 2 in. x 2 in. angle, 5 plies of woven roving with polyester resin.

Design

Bottom Shell Laminate: The bottom shell design loads are taken from Figs. 2-14 and 2-15. An example of the calculation for maximum design pressure is given, and the computation for the shell laminate are arranged in tabular form for convenience, Table 2-3.

The bottom shell laminate is given for two types of laminates, Type A and Type B. As explained previously, the Type A laminate is the more expensive, but has higher impact resistance to floating objects than the Type B. Since the service requirement of this boat is for normal pleasure use, the Type B laminate as specified above is considered satisfactory.

Typical Design Loads:

Impact pressure from Fig. 2-14

Waterline Length, $L = 18.5$ ft.

Speed, $V = 38$ miles per hour

$V \times L = 163.4$

$p_I = 25.0$ psi

Determine Design Pressure At Station 7

$$p_D = p_H + p_I \times F_1 \qquad (2.3)$$

$$p_H \text{ at 8 in. draft } = \frac{8}{12} \times \frac{64}{144} = 0.3 \text{ psi}$$

Where: $\frac{8}{12}$ = head of water in ft.

64 = weight per cubic ft. of salt water

144 = sq. in. per sq. ft.

F_1 = .60 from Fig. 2-15

$p_D = 0.3 + 25.0 \times 0.60 = 15.3$ psi

Laminate Design: Table 2-3. The panels of shell laminate formed by the longitudinal and transverse supports are long and narrow, and the laminate is considered as a 1 inch wide beam spanning between the longitudinals. Due to the continuity of laminate and the uniform pressure loading, the beam is considered to have fixed ends. The maximum moment occurs at the ends of the span, i. e. at the longitudinal, and places the inboard face of the laminate in compression as indicated in Fig. 2-10b.

A typical deflection calculation is also shown.

$$\text{Deflection; } d = \frac{p_D L^4}{384\ EI} \quad \text{Shear deflection not considered} \qquad \textbf{(2.20)}$$

Assumed allowable $d = \frac{L}{100}$; $E_{WR} = 1.81 \times 10^6$ **(Table 5-10)**

Type A Laminate - Forward Station 5

$$d = \frac{25.3\ (5.3)^4}{384 \times 1.81 \times 10^6 \times .00046} = 0.06 \text{ in.}$$

$$\text{Allowable } d = \frac{5.3}{100} = .053 \text{ in.}$$

Calculated deflection is high, but acceptable because of innerbottom.

TABLE 2-3. BOTTOM SHELL

Location	Max. Clear Dist. Betw. Long'ls. L (In.)	p_D (psi)	Bending Moment $M = \frac{p_D \times L^2}{12}$ (2.21) (In. -Lb.)	Section Modulus $Z = \frac{FSxM}{F_{bu}} = \frac{1.5M}{F_{bu}}$ ** ($In.^3$) (2.22)	Laminate (Figs. 6-31 and 6-32)
Fwd of Station 5	5. 3	25. 3	59. 4	$Z_{wr} = 0.0038$ $Z_{cl} = 0.0029$ $Z_m = 0.0043$	Type A - 3 plies of woven roving or Type B - 4 ounces of mat - use 3 plies of 1-1/2 ounce mat
At Station 7	6	15. 3	45. 9	$Z_{wr} = 0.0029$ $Z_{cl} = 0.0022$ $Z_m = 0.0034$	Type A - 2 plies of woven roving or Type B - 3 ounces of mat - 2 plies of 1-1/2 ounce mat
At Station 8	7	10. 3	42. 1	$Z_{wr} = 0.0027$ $Z_{cl} = 0.0021$ $Z_m = 0.0032$	Type A - Same as above or Type B - Same as above
At Station 9	8	5. 3	28. 3	$Z_{wr} = 0.0018$ $Z_{cl} = 0.0014$ $Z_m = 0.0021$	* Type A - 2 plies of woven roving or * Type B - 2 ounces of mat - 1 ply 2 ounce mat

* For practical reasons, carry the laminate required at Station 7 all the way aft to the transom.

** F_{bu} = 23,700 psi for woven roving
= 31,100 psi for cloth = Table 5-9
= 20,500 psi for mat

Side Shell Laminate: Table 2-4. The side shell laminate is determined on the basis of the bottom laminate thickness, except in the area forward of Station 4-1/2. Forward of this point the chine disappears, the laminate is in an area of high impact and the bottom laminate is carried to the deck edge.

TABLE 2-4. SIDE SHELL

Location	Bottom Thickness at this Location (In.)	Side Thickness = 0.75 x Bottom Thickness (In.)	Laminate Selected	Actual Thickness (In.)
Forward of Station 4-1/2	This is in the impact area, and is considered as bottom laminate		Same as bottom laminate	
Stations 4-1/2 to 7	0.179	0.134	Type B - 2 plies 1-1/2 ounce mat	0.137
Aft Station 7	0.137	0.103	Reduction to 1 ply mat results in insufficient thickness - use Type B - 2 plies 1-1/2 ounce mat	0.137

Framing: Bottom Longitudinals, Table 2-5. The bottom longitudinals are considered as fixed ended beams, due to continuity. The design load is obtained from Fig. 2-15, and is considered as a uniform load applied to the width of shell supported; that is a width equal to the longitudinal spacing. A typical design pressure calculation is shown and the calculations for the longitudinals are given in Table 2-5. The maximum moment occurs at the support point and places the inboard face of the longitudinal in compression. As noted in the description of the design data sheets giving stiffener properties, Chapter 6, the woven roving at the inboard compression face is the critical material.

Typical Design Loads: For longitudinals No. 3 and 4 between the bulkhead at Station 3 and the transverse island at Station 5-1/2, Fig. 2-22.

$$p_D = p_H + p_I \times F_1 \times F_L \qquad (2.5)$$

p_I = 25.0 psi - See bottom shell calculation

p_H = 0.3 psi - See bottom shell calculation

F_1 and F_L are from Fig. 2-15

At Bulkhead, Station 3

$F_1 = 1.00$

$F_L = 0.38$

$p_D = 0.3 + 25.0 \times 1.0 \times 0.38 = 9.8$ psi

At Transverse

$F_1 = 0.93$

$F_L = 0.40$

$p_D = 0.3 + 25.0 \times 0.93 \times 0.40 = 9.6$ psi

Average Design Pressure $p_D = \frac{9.8 + 9.6}{2} = 9.7$ psi

TABLE 2-5. BOTTOM LONGITUDINALS

Longitudinal Number	Location	Max. Clear Distance Between Transverses L (In.)	Width of Shell Supported s (In.)	p_D (psi)	Bending Moment $M = \frac{p_D x s L^2}{12}$ (2.21) (In.-Lb.)	Section Modulus $Z = \frac{1.5 \times M}{15,800}$ ¶ (In.^{3}) (2.22)	Required Stiffener (Fig. 6-37)		
							Depth (In.)	Width at Top (In.)	No. of plies of woven roving
3	Bulkhead to Transverse Island	51	7.5	9.7	15,800	1.50	3	1-1/2	5 **
3	Transverse Island to Transom	91.5	9.5	4.9	32,500	3.09	4	1-1/2	6 **
1, 2 and 4		Similar to No. 3							
6 *	Between Bulkheads	31	12	9.0	8,700	0.83	2	2	4 **
5 *		Similar to No. 6							

* These longitudinals are considered bottom longitudinals in this area because they are subject to impact loading.

** Fig. 6-37 does not have the proper stiffener laminate to shell laminate ratio for these stiffeners. When height limitations make this necessary, the stiffener laminate should be considered as controlling and a margin allowed in selecting a stiffener. The section modulus for the proposed stiffener - shell combination should be calculated separately.

¶ Ultimate compressive stress, F_{cu}, from Table 5-11.

The longitudinal stiffener sizes determined from the bending moments must be checked for shear. A typical calculation is shown. The remaining stiffeners have been checked and found satisfactory.

Maximum shear, $f_s = \frac{VQ}{Ib}$ (2.23)

For longitudinal number 3 between the bulkhead and the transverse island:

$V = \frac{P_D \times s \times L}{2} = \frac{9.7 \times 7.5 \times 51}{2} = 1852$ lbs (2.24)

Stiffener Properties:

Size: 3 in. deep x 1-1/2 in. wide x 5 plies of woven roving, from Fig. 6-37

Thickness of 5 plies of woven roving = 0.185 in. (Table 5-2)

I_{WR} = 3.6 in.^{4} This value is based on woven roving equivalence and all material inboard of the neutral axis is woven roving. Therefore no modulus connections are necessary.

Z_{WR} = 1.75 in.^{3}

Distance to neutral axis $y = \frac{I}{Z} = \frac{3.6}{1.75} = 2.06$ in. (2.25)

Q = Moment of area inboard of neutral axis about neutral axis

$= 1.5 \times 0.185 \times (2.06 - \frac{0.185}{2}) + 2 \times 2.06 \times 0.185 \times \frac{2.06}{2} = 1.33$ in.

b = 2 x 0.185 = .370 in.

Maximum shear, $f_s = \frac{1852 \times 1.33}{3.6 \times .370} = 1852$ psi

Ultimate Parallel Shear Stress for Woven Roving, F_{su} = 7500 psi (Table 5-14)

Factor of Safety = 1.5

Allowable Parallel Shear Stress, $f_s = \frac{7500}{1.5} = 5000$ psi Satisfactory

Finally the stiffener must be checked to ensure that the allowable deflection is not exceeded. A typical calculation is shown; the remaining stiffeners have been checked and found satisfactory.

Deflection, $d = \frac{P_D \times s \times L^4}{384\ EI}$ Shear deflection not considered (2.20a)

For longitudinal number 3 between the bulkhead and the transverse island:

$d = \frac{9.7 \times 7.5\ (51)^4}{384 \times 2.06 \times 10^6 \times 3.6} = 0.173$ in.

Allowable deflection, $d = \frac{L}{100} = 0.51$ in. Satisfactory

Side Longitudinals: The side longitudinals are designed to support a pressure equivalent to a head of water to 6 in. above the deck. The longitudinals are designed as uniformly loaded, fixed ended beams.

Consider Longitudinal No. 6 between the transverse and the bottom of the motor well.

Stiffener Spacing = 10.5 in.

Load = head of water to 6 in. above the deck at side

Factor of Safety = 4 ; F_{cu} = 15,800 psi (Table 5-11)

Pressure = Head x Density of Sea Water

$$p = \frac{1.58 \times 64}{144} = .703 \text{ psi}$$

Load per inch = .703 x 10.5 = 7.38 ppi

$$\text{Bending Moment, } M = \frac{pL^2}{12} \qquad (2.21)$$

$$M = \frac{7.38 \times (81)^2}{12} = 4034 \text{ in.-lbs.}$$

$$\text{Required Section Modulus, } Z = \frac{F.S. \times M}{F_{cu}} \qquad (2.22)$$

$$Z = \frac{4 \times 4034}{15{,}800} = 1.02 \text{ in.}^3$$

From Fig. 6-37, use 1-1/2 in. wide x 2-1/2 in. deep stiffeners with 5 plies of woven roving.

Decks: Fore Deck - Laminate: Similar to shell laminate; Framing: 3 equally spaced deck longitudinals, Loading: Head equivalent to 2 ft. of water = 0. 89 psi, Factor of Safety = 4. 0.

Laminate Design: The panel is considered fixed ended due to the continuous load and continuity of the laminate.

Stiffener spacing = 19 in.

Stiffener width = 4 in.

Unsupported span of laminate = 15 in.

$$\text{Bending moment, } M = \frac{0.89\ (15)^2}{12} = 16.7 \text{ in.-lbs.} \qquad (2.21)$$

$$\text{Required Section Modulus, } Z = \frac{F.S. \times M}{F_{bu}} \qquad (2.22)$$

Ultimate Flexural Stress, F_{bu} from Table 5-9

$$Z = \frac{4.0 \times 16.7}{20{,}500} = 0.0033 \text{ in.}^3 \quad \text{Mat}$$

$$Z = \frac{4.0 \times 16.7}{23{,}700} = 0.0028 \text{ in.}^3 \quad \text{Woven Roving}$$

$$Z = \frac{4.0 \times 16.7}{31{,}100} = 0.0021 \text{ in.}^3 \quad \text{Cloth}$$

From Fig. 6-32, Type B laminate with 2 plies of 1-1/2 ounce mat.

Framing:

Spacing = 19 in.

Length = 31 in.

Load per inch = 0.89 x 19 = 16.91 lbs. per in.

$$\text{Bending moment,} \quad M = \frac{pL^2}{12} = \frac{16.91\ (31)^2}{12} = 1354 \text{ in.-lbs.} \qquad (2.21)$$

$$\text{Required Section Modulus,} \quad Z = \frac{1354 \times 4}{15{,}800} = .343 \text{ in.}^3 \qquad (2.22)$$

From Fig. 6-37, use 1 in. x 4 in. stiffener with 2 plies of woven roving.

The deflection of the Fore Deck is not checked since it is not a normal walking area in a boat this size.

Cockpit Deck:

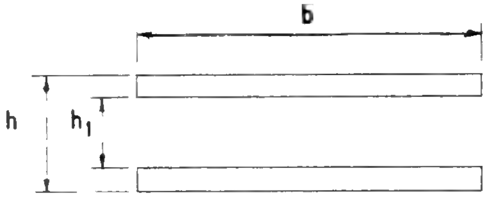


Fig. 2-23. Cockpit deck sandwich cross-section

Design Load = 40 psf = 0.28 psi

Maximum Span = 8 in.

Construction - Use sandwich construction for lightness and rigidity.

Try a 1/4 inch thick core with one ply of woven roving on each face.

For 1 in. strip bending moment:

$$M = \frac{pL^2}{12} = \frac{0.28 \times (8)^2}{12} = 1.49 \text{ in.-lbs.} \qquad (2.21)$$

The dimensions for the cross section indicated in Fig. 2-23 are:

b = 1 in.

h_1 = 0.25 in.

h = 0.25 + 0.074 = 0.324 in.

Assume adequate bond between core and faces and that core is not effective in flexure, the section modulus is:

Section Modulus, $$Z = \frac{b \times (h^3 - h_1{}^3)}{6\ h} \qquad (2.26)$$

$$Z = \frac{1 \times [0.324^3 - 0.25^3]}{6 \times 0.324} = \frac{.018}{1.944} = .009 \text{ in.}^3$$

Stress in facings, $$f_c = \frac{1.49}{.009} = 165.6 \text{ psi}$$

Maximum Shear; $$V = \frac{pL}{2} \qquad (2.24)$$

$$V = 0.28 \times 8 = 2.24 \text{ lbs.}$$

Shear Stress in Core, $$f_s = \frac{3}{2} \times \frac{V}{A} \qquad (2.27)$$

$$f_s = \frac{3}{2} \times \frac{2.24}{1 \times .25} = 13.5 \text{ psi}$$

Required ultimate core shear stress $= f_s \times$ F.S.

$= 13.5 \times 4 = 54.0$ psi Satisfactory

The 1/4 in. thickness is chosen as the minimum for workability. The core material may be of any of those discussed in Chapter 4, with preference given to a solid material which will be able to resist the shear loads and high local impact loads as would be caused by a person jumping into the boat, or heavy objects being dropped on deck.

If desired for appearance reasons, a ply of 10 ounce cloth may be added to the top of the deck sandwich. Caution should be exercised to avoid too smooth a surface in walking areas for safety reasons.

Deflection Check: As explained in Chapter 6, a conservative estimate of the deflection of a sandwich section is the sum of the bending deflection of the faces alone plus the shear deflection of the core alone.

Deflection, $$d = \frac{pL^4}{384\ E_f I_f} + \frac{6pL^2}{5G_c A_c} \qquad (2.28)$$

Assume a cellular cellulose acetate (CCA Foam) core of 6 lbs per cubic ft. density

Shear Modulus, $G_c = 1.25 \times 10^3$ psi (Table 5-17)

Area of Core, $A_c = 1 \times 0.25 = 0.25 \text{ in.}^2$

$$d = \frac{0.28 \times 8^4}{384 \times 2.06 \times 10^6 \times .009 \times \frac{.324}{2}} + \frac{6 \times 0.28 \times 8^2}{40 \times 1.25 \times 10^3 \times 0.25}$$

$$= 0.001 + 0.016 = 0.017 \text{ in.}$$

Allowable deflection, $d = \frac{L}{200} = \frac{8}{200} = 0.04$ in. Satisfactory

Side Deck and Deck Edge or Gunwale:

Vertical Loading - Assume a 200 lb. man at the center of the longest span - Factor of Safety = 4.

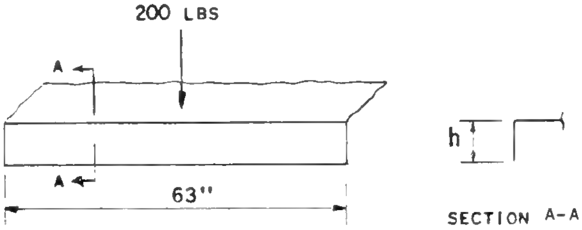


Fig. 2-24. Gunwale - assumed section for vertical loading

Bending Moment, $M = \frac{PL}{4} = \frac{200 \times 63}{4} = 3150$ in.-lbs. (2.7)

Consider the same laminate as the Fore Deck.

From a detailed calculation the cloth in tension is critical and controls the strength of the section.

Ultimate tensile strength $F_{tu} = 24{,}100$ psi. (Table 5-6)

Consider only the vertical flange to be effective:

Section Modulus, $Z = \frac{t\,h^2}{6}$ (2.29)

Required, $Z = \frac{3150 \times 4}{24{,}100} = 0.523$ in.^{3} (2.22)

To find required depth, h, where t is the equivalent thickness if the laminate were all cloth

$h^2 = \frac{6Z}{t} = \frac{6 \times 0.523}{0.100} = 31.4$ sq. in. (2.29a)

h = 5.60 in.; use 5-5/8 in. deep coaming; Fig. 2-25

Horizontal Loading: Assume weight of boat concentrated at center of longest span; island to motor well.

From a detailed calculation the cloth in compression is the critical material. For an explanation of the use of tensile and compressive stresses, rather than flexural stresses, see Design Example 2-1; Gunwale and Thwart Design.

Factor of Safety = 2.0

Weight of Boat; estimated = 2000 lbs.

Bending Moment, $M = \frac{pL}{4} = \frac{2000 \times 63}{4} = 31{,}500$ in.-lbs. (2.7)

Ultimate Compressive Stress, $F_{cu} = 18900$ psi from Table 5-11

Required Section Modulus, $Z = \frac{31500 \times 2}{18900} = 3.33$ in.^{3} (2.22)

Actual Section Modulus of section shown in Fig. 2-25; from detailed calculation, $Z = 4.65$ in.^{3} Satisfactory

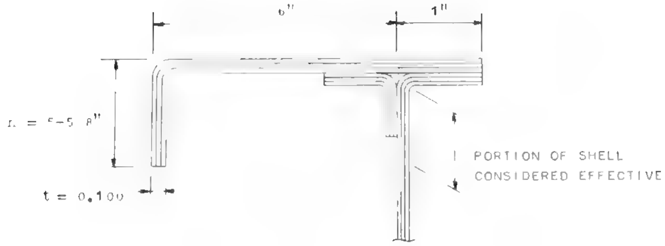


Fig. 2-25. Gunwale - assumed cross-section for horizontal loading

Transom: As a first trial use the dimensions recommended by the OBC for the over 40 horsepower range, Table 2-1.

Thickness = 1-1/2 in. minimum for entire transom

Reinforcing at motors
Thickness = 2-1/4 in.
Inboard Area - 10-1/8 in. horizontal dimension
- 3-5/8 in. vertical dimension

Outboard Area - 12-1/2 in. horizontal dimension
- 11-1/2 in. vertical dimension

Use a sandwich construction.

Plywood core - 1-1/2 in. thick Douglas fir

Outboard Laminate - 1 ply 10 ounce cloth on aft face
2 plies 1-1/2 ounce mat against plywood

Inboard Laminate - 1 ply woven roving on forward face
1 ply 1-1/2 ounce mat against plywood

Design on a Strength Basis: For 38 miles per hour - 2 motors at 50 horsepower = 100 horsepower.

$$\frac{\text{Section modulus x Allowable stress}}{\text{Transom Beam}} = \frac{Z \times f_b}{B} \qquad (2.6)$$

$$\text{From Fig. 2-17;} \quad \frac{Z \times f_b}{B} = 87$$

$$\text{Beam at transom} = 66 \text{ in.}$$

$$\text{Required } Z \times f_b = 87 \times 66 = 5742 \qquad (2.6a)$$

The portion of the transom considered effective is: The plywood core - parallel horizontal grain plies only; 11-1/2 in. wide; the fiberglass covering for the above width, and the motor well - a strip adjacent to the transom of width equal to 30 times its own thickness.

The allowable stresses based on a factor of safety of 6, for the various materials are as follows:

Plywood

Basic working stress - Douglas fir plywood in bending = 2000 psi

Ultimate stress, F_{bu} for long term loading = basic working stress x factor of safety on which basic working stress is based (19)

$F_{bu} = 2000 \times 2.25 = 4500$ psi

Allowable stress, $f_b = \frac{4500}{6} = 750$ psi (2.9a)

Mat in tension at motor well

Ultimate stress, $F_{tu} = 11{,}000$ psi (Table 5-6)

Allowable stress, $f_t = \frac{11{,}000}{6} = 1830$ psi (2.9a)

Multiplying the section modulus, from detailed calculations not shown, of each material by its allowable stress:

Mat - tension on motor well bottom:

$Z \times f_t = 6.26 \times 1830 = 11{,}456$ which is greater than 5742 (2.6a)

Plywood - compression on aft side:

$Z \times f_b = 10.10 \times 750 = 7545$ which is greater than 5742 (2.6a)

Satisfactory

Bulkheads: The critical loading on the bulkheads in this boat is the shear load in way of the cutout under the forward deck.

Check for shear at Section A-A, Fig. 2-26.

Use a 1/2 in. core nominal for rigidity.

Consider all shear load carried by laminate, i. e. core is nonstructural.

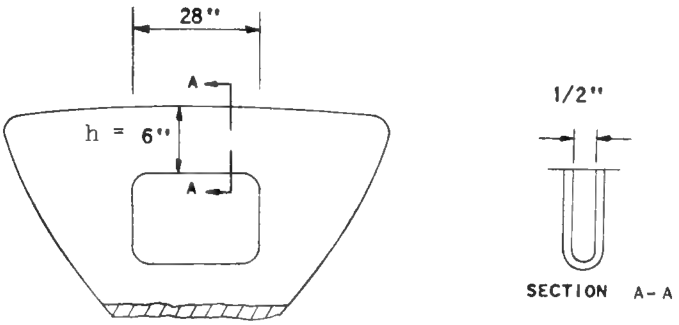


Fig. 2-26. Transverse bulkhead

Deck area supported = 28 in. x 30 in. = 840 sq. in.

Deck loading = 0.89 psi

Shear load, $V = \frac{840 \times 0.89}{2} = 374$ lbs. (2.24)

Assume cloth laminate:

Ultimate shear stress, $F_{su} = 9000$ psi (Table 5-14)

Allowable shear stress, $f_s = \frac{9000}{4} = 2250$ psi (2.9)

Area required $= \frac{374}{2250} = 0.166$ in. (2.19a)

Thickness of laminate faces, $t = \frac{\text{Area}}{2 \times h}$

$t = \frac{.166}{2 \times 6} = .014$ in.

Use 1 ply of cloth, t = .016 in. on each side. (Table 5-1)

Add 1 ply of 1-1/2 oz. mat on each side for added resistance to local impact and to improve the core to face bond.

Deck Edge Connecting Angle: This connection is required to carry the same ultimate shear loading as the deck laminate.

Reinforcement woven roving for high impact resistance.

Deck Laminate: 1 ply cloth, 2 plies 2 ounce mat and 1 ply woven roving.

Ultimate shear strength per running in.:

$$F'_{su} = A_{cl}F_{scl} + A_mF_{sm} + A_{wr}F_{swr} \qquad (2.30)$$

Where A = area

F'_{su} = ultimate shear strength, lbs. per in. (Table 5-14)

cl,m,wr = subscripts referring to cloth, mat, and woven roving respectively

$$F_{sc} = F_{swr} \times \frac{G_c}{G_{wr}} = F_{swr} \times \frac{.52 \times 10^6}{.45 \times 10^6} = F_{swr} \times 1.16 \qquad (2.31)$$

$$F_{sm} = F_{swr} \times \frac{G_m}{G_{wr}} = F_{swr} \times \frac{.40 \times 10^6}{.45 \times 10^6} = F_{swr} \times 0.89 \qquad (2.31)$$

G = shear modulus, psi (Table 5-14)

Ultimate shear strength, $F'_{su} = (1 \times .016)\ 7500 \times 1.16 + (1 \times .116)\ 7500 \times .89 + (1 \times .037)\ 7500 = 139 + 775 + 278 = 1192$ lbs. per in.

Required thickness of angle, $t = \frac{F'_{su}}{F_{swr}} = \frac{1192}{7500} = .159$ in. (2.32)

Use 5 plies of woven roving, $t = .185$ (Table 5-2)

Width of angle legs should be sufficient to transmit this same shear load, i.e., 1192 lbs. per in.

Ultimate shear stress, secondary bond, $F_{bsu} = 800$ psi

Width of leg, $b = \frac{F'_{su}}{F_{bsu}} = \frac{1192}{800} = 1.49$ in. (2.32a)

Use 2 in. x 2 in. for ease in handling.

DESIGN EXAMPLE 2-4. CRUISING SAILBOAT

This cruising sailboat represents a very popular size and type, providing reasonably comfortable accommodations for four to six people. It is intended for cruising in unprotected waters and for ocean racing with similar boats.

Principal Dimensions - See Fig. 2-27 for details.

Length, Over-all: 33 ft. - 0 in.
Length, Water Line: 23 ft. - 2 in.
Beam: 9 ft. - 10 in. maximum
Draft: 4 ft. - 0 in.
Rig: Sloop
Auxiliary Power: 6 horsepower engine

Summary of Scantlings

Shell Basic Laminate: 1 ply cloth on outside of hull, 1 ply 2 ounce mat and 4 plies woven roving.

Bottom shell forward of Station 7 below longitudinal No. 2 similar to basic laminate except use 5 plies woven roving.

Bottom shell aft of Station 7, from 12 in. below longitudinal No. 1 to keel: similar to basic laminate except use 6 plies woven roving.

Framing: All stiffeners are hat type.

		Depth In.	Width In.	Plies of Woven Roving
Longitudinal No. 1	Bow to Second Bulkhead	3	3	4
	Second Bulkhead to Stern	4	3	4
Longitudinal No. 2	Forward of Bulkhead 5	5	4	4
	Aft of Bulkhead 5	4	4	6
Longitudinal No. 3		5	3	5
Longitudinal No. 4		5	3	5

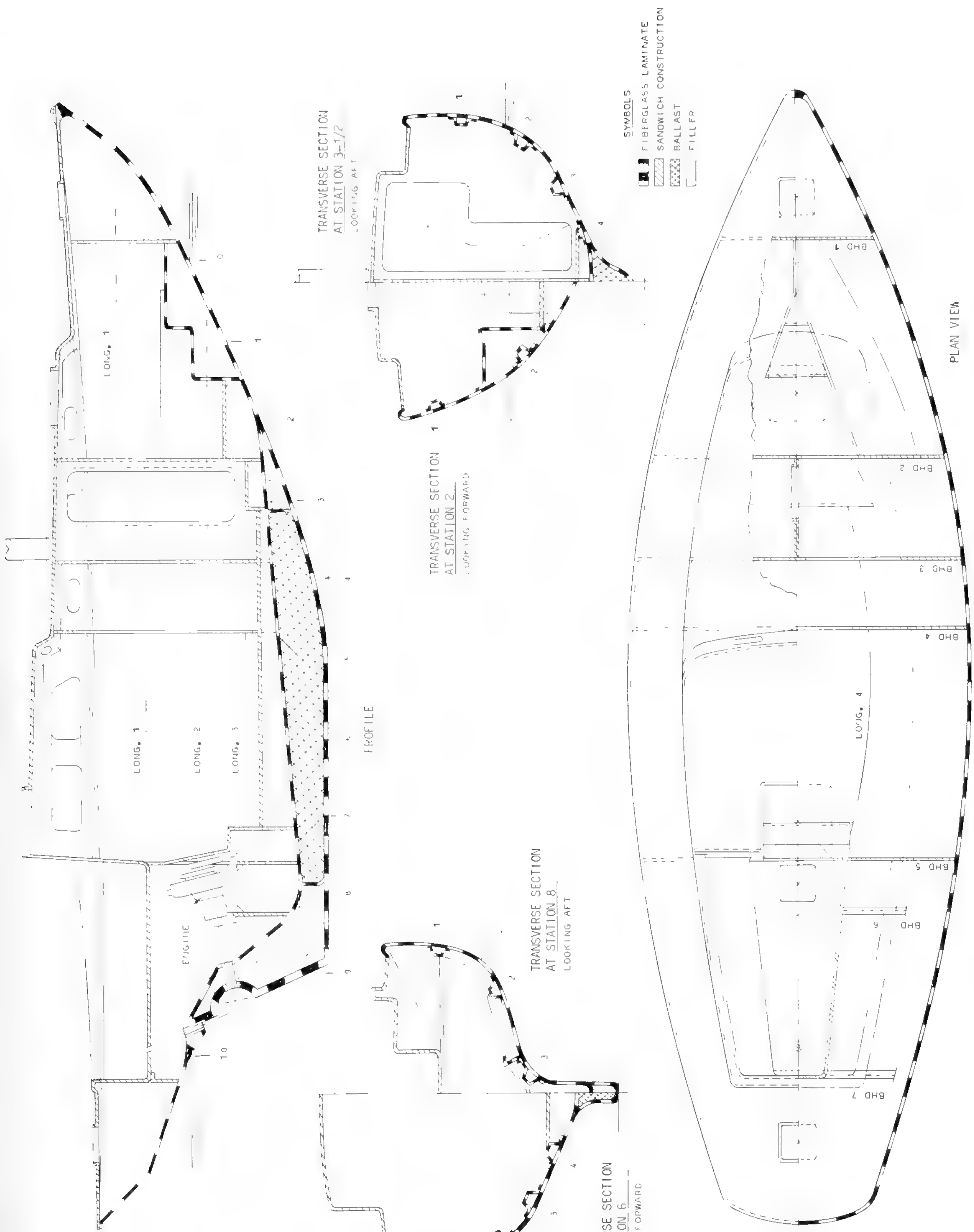


Fig. 2-27. Cruising sailboat

Decks: Sandwich construction; 2 plies cloth on top face, 1 ply 1-1/2 ounce mat, nonstructural core of variable thickness, 1 ply 1-1/2 ounce mat and 1 ply woven roving.

Location	Core Thickness
Main Deck - Forward	3/4 in.
Main Deck - Cabin Sides	3/8 in.
Main Deck Aft of Cockpit	1-1/4 in.
Cabin Top - Lower Level	1 in.
Cabin Top - Upper Level	1 in.
Cockpit	1 in.
Interior Decks	1 in.

Built-in Bunks and Lockers in Forward Compartment: 4 plies woven roving.

Bulkheads: 3/4 in. core with 1 ply cloth and 1 ply 1-1/2 ounce mat each side; 4 additional plies of cloth each side locally under mast.

Design

Shell Laminate: The laminate chosen is that referred to as Type A in this manual and consists of: 1 ply cloth on the outboard face, 1 ply mat, and a varying number of plies of woven roving.

The laminate selection is based on the excellent laminate impact resistance to floating objects as previously explained.

The design head of water is taken to 12 in. above the deck edge measured from the center of the panel, Table 2-2.

Since the panels involved are all relatively long and narrow, the bending moment and section modulus used are in each case taken for a 1 in. wide strip. This strip is considered to act as a uniformly loaded, fixed ended beam of span equal to the distance between longitudinals.

Because of the number of areas which must be checked, a tabular arrangement is used for the calculations; Table 2-6.

Shell Longitudinals: The shell longitudinals are designed as fixed ended beams to withstand the same design load as the shell they support. Hat section stiffeners are chosen because of their greater efficiency due to the high section moduli required. The calculations have been arranged in tabular form for convenience, Table 2-7. The stiffeners shown have been checked for shear and are adequate. For a typical shear calculation see Design Example 2-3.

Decks: All decks are to be of sandwich construction for rigidity. Type B sandwich is used; Fig. 6-53b. Each deck is checked for stress in the various elements, and for deflection. The core thickness required is determined for each criterion and the maximum required is used.

Forward Portion of Main Deck: The largest panel is between bulkhead No. 1 and the forward end of the cabin trunk.

Panel Dimensions: length = 5 ft.-6 in.; width = 2 ft. -9 in.

TABLE 2-6. SHELL LAMINATES

Location	Max. Clear Distance Between Long'ls L (In.)	Head to 12 in. Above Deck h (ft.)	$p = h \times \frac{64}{144}$ psi	Bending Moment $M = \frac{pL^2}{12}$ (2.21) (In.-Lbs.)	Section Modulus $Z = \frac{F.S. \times M}{F_{bu}}$ $= \frac{4M}{F_{bu}}$ * (2.22) Req'd. Z in.^{3}	Type A Laminate Required Plies of Woven Roving (Fig. 6-31)
Between						
Deck Edge and Long'l No. 1	18	2.0	0.89	24.03	Z_{wr} = 0.0061 Z_{cl} = 0.0046 Z_m = 0.0071	4
Long'l No. 1 and Long'l No. 2 Fwd of Sta. 7	15	3.58	1.59	29.81	Z_{wr} 0.0075 Z_{cl} = 0.0057 Z_m = 0.0087	4
Same - Aft of Sta. 7	23	3.67	1.63	71.86	Z_{wr} = 0.0122 Z_{cl} = 0.0093 Z_m = 0.0142	6
Long'l No. 2 and Long'l No. 3 Fwd Sta. 7	14	5.0	2.22	36.26	Z_{wr} = 0.0092 Z_{cl} = 0.0070 Z_m = 0.0108	5
Same - Aft Sta. 7	19	5.5	2.44	73.40	Z_{wr} = 0.0124 Z_{cl} = 0.0095 Z_m = 0.0143	6
Long'l No. 3 and Long'l No. 4	14	5.92	2.63	42.96	Z_{wr} = 0.0109 Z_{cl} = 0.0083 Z_m = 0.0126	5
Long'l No. 4 - and Keel at Centerline	13	6.25	2.78	39.15	Z_{wr} = 0.0099 Z_{cl} = 0.0075 Z_m = 0.0114	5

* F_{bu} = 23,700 psi for woven roving
= 31,100 psi for cloth
= 20,500 psi for mat

TABLE 2-7. SHELL LONGITUDINALS

Long'l No.	Location	Length L (In.)	Width of Shell Supported s (In.)	Head to 12 In. Above Deck h (Ft.-In.)	$p = \frac{n \times s \times 64}{144}$ p (No.-In.)	$M = \frac{pL^2}{12}$ (2.21) (In.-Lbs.)	$Z = \frac{4M}{15,800}$ (2.22) (in.^{3})	Required Stiffener (Fig. 6-37) Depth x Width (In.)	Required Stiffener (Fig. 6-37) No. of Plies Woven Roving
1	Bhd 1 to 2	80	14-1/2	2-1	13.41	7,152	1.81	3 x 3	4
1	Bhd 4 to 5	81	18	2-6	19.98	10,924	2.77	4 x 3	4
1	Bhd 5 to 7	77	22	2-6	24.42	12,066	3.05	4 x 3	4
2	Bhd 4 to 5	81	18	4-3	33.97	18,573	4.70	5 x 4	4
2	Bhd 5 to 7	77	21	4-3	39.69	19,610	4.97	4 x 4	6
3	Bhd 4 to 5	81	15	5-3	34.95	19,109	4.84	5 x 3	5
4	Bhd 4 to 5	81	15	5-9	38.40	20,995	5.32	5 x 3	5

Shell above Longitudinal No. 1 has 4 plies of woven roving.

Shell Forward of Station 7:

> Between Longitudinals Nos. 1 and 2 has 4 plies of woven roving.
> Below Longitudinal No. 2 has 5 plies of woven roving.

Shell Aft of Station 7, Below Longitudinal No. 1, has 6 plies of woven roving.

Design Load: p = 2 ft. of water = 0.89 psi

Flexure:

Considering a 1 in. strip as a fixed ended beam.

Bending Moment, $$M = \frac{pL^2}{12} = \frac{0.89 \times 33^2}{12} = 80.7 \text{ in.-lbs.} \qquad (2.21)$$

Ultimate Stresses, F_u from Tables 5-6 and 5-11

Cloth; top face in tension $$Z = \frac{4 \times 80.7}{24{,}100} = 0.0134 \text{ in.} \qquad (2.22)$$

1/4 in. deep core required. (Fig. 6-53b)

Woven Roving; bottom face in compression $$Z = \frac{4 \times 80.7}{13{,}900} = 0.0232 \text{ in.}^3 \qquad (2.22)$$

3/8 in. deep core required. (Fig. 6-53b)

Mat; top face in tension $$Z = \frac{4 \times 80.7}{11{,}000} = 0.0294 \text{ in.}^3 \qquad (2.22)$$

1/4 in. deep core required. (Fig. 6-53b)

Shear Stress:

Maximum Shear Load, $$V = \frac{pL}{2} \qquad (2.24)$$

$$V = \frac{0.89 \times 33}{2} = 14.7 \text{ lbs. per in.}$$

Assuming the core carries all the shear load.

Shear stress, $$f_s = \frac{3}{2}\,\frac{V}{A} \qquad (2.27)$$

$$f_s = \frac{3}{2} \times \frac{14.7}{1 \times 0.75} = 29.4 \text{ psi}$$

Allowable Shear Stress, $$f_{sa} = \frac{\text{Ultimate Shear Stress}}{\text{Factor of Safety}} \qquad (2.9a)$$

$$f_{sa} = \frac{185}{4} = 46.3 \text{ psi}$$ Satisfactory (Table 5-17)

This shear stress calculation is approximate and over estimates the shear stress in the core. A more accurate stress value may be obtained by the methods explained in Chapter 6.

Deflection:

Allowable Deflection, $$d = \frac{1}{200} = \frac{33}{200} = 0.165 \text{ in.}$$

Maximum Deflection, $$d = \frac{pL^4}{384\, E_f I_f} + \frac{pL^2}{8\, G_c A_c} \qquad (2.28)$$

Try a 3/4 in. thick core of cellular cellulose acetate; 7 lbs. per cu.ft. density.

$$E_fI_f = 2.06 \times 10^6 \times 0.0172 = 0.036 \times 10^6 \qquad \text{(I from Fig. 6-53b)}$$

$$G_cA_c = 2.0 \times 10^3 \times 1 \times 0.75 = 1500 \qquad \text{(G from Table 5-17)}$$

$$\text{Maximum Deflection, } d = \frac{0.89 \times 33^4}{384 \times 0.036 \times 10^6} + \frac{0.89 \times 33^2}{8 \times 1500}$$

$$= 0.076 \text{ in.} + 0.081 = 0.157 \text{ in.}$$

Therefore deflection is the controlling criterion and a 3/4 in. deep core is required.

By similar calculations the remainder of the decks may be checked. The results of these calculations are given below in tabular form, Table 2-8.

TABLE 2-8. DECKS

Deck	Location	Panel Size	Edge Condition	Load (psi)	Critical Design Criterion	Req'd. Core Thickness	Req'd. Core Ult. Shear Stress ** (psi)
Cabin Top	Upper Level	5'-10" x 6'-8"	Fixed	0. 28	Deflection	1" *	147
Cabin Top	Lower Level	3'-0" x 4'-6"	Fixed	0. 89	Deflection	1"	24
Main Deck	Forward	2'-9"x5'-6"	Fixed	0. 89	Deflection	3/4"	46
	Cabin Side	18" Span	Fixed	0. 89	Deflection	3/8"	48
	Aft of Cockpit	4' x 5'-3"	Fixed	0. 89	Deflection	1-1/4"	137
Cockpit	-	2'-2" x 6'-2'	Simply Supported	0. 89	Deflection	1"	22
Interior Decks	Main Cabin	3' x 5'-8"	Simply Supported	0. 28	Deflection	1"	30

* The deflection of this deck is slightly in excess of the allowable, but is considered acceptable since this is not a normal walking space.

** Ultimate Shear Stress of 7 lb. per ft^3 density CCA = 185 psi (Table 5-17).

Built-in Bunks: Design Loading - 40 lb. per ft^2 (0. 28 psi) on horizontal surface.

Design Criteria: Horizontal surface to be checked as a plate in bending. Vertical surface to be checked for column loading.

Factor of Safety = 4. 0 in bending; 2. 0 on buckling stress in compression.

Laminate: Use a solid woven roving laminate.

Horizontal Surface:

Load = 0.28 psi

Span = 22 in. (panel length to width ratio is greater than 3 - design as a 1 in. wide beam simply supported at the ends)

Bending Moment, $M = \frac{pL^2}{8}$ (2.33)

$$= \frac{0.28\ (22)^2}{8} = 16.95 \text{ in.-lbs.}$$

Required Section Modulus, $Z = \frac{4 \times 16.95}{23{,}700} = 0.0029 \text{ in.}^3$ (2.22)

Ultimate flexural strength woven roving, $F_{bu} = 23{,}700$ psi (Table 5-9)

Deflection is neglected, since the bunk will be covered by a mattress.

Section Modulus; $Z = \frac{bt^2}{6}$ (2.29)

$$t^2 = \frac{6 \times Z}{b} = \frac{6 \times .0029}{1} = .0174 \text{ in.}^2 \quad (2.29a)$$

$t = 0.132$ in.

Use 4 plies of woven roving, t = 0.147 in. (Table 5-2)

Vertical Surface:

Load per inch on loaded edge $P = \frac{pL}{2} = \frac{0.28 \times 22}{2}$ (2.24)

$$= 3.08 \text{ lbs.}$$

Length of Loaded Edge = 60 in. = A

Length of Unloaded Edge (taken at Station 2) = 24 in. = B

Load per inch for critical buckling = 8.8 lbs. by interpolation in Table 6-8 for simply supported edges

Allowable Compressive Load $= \frac{8.8}{2} = 4.4$ lbs. per in. Satisfactory (2.9)

Bulkheads:

Standard Construction - 5/8 in. Mahogany Plywood

Sandwich Construction with fiberglass laminate facings:

Design Criterion - Equivalent Rigidity (EI)

Moment of Inertia, I plywood - parallel plies only

$I_p = .014 \text{ in.}^4$ for 1 in. strip. (15)

Modulus of Elasticity, E mahogany = 1.6×10^6 psi

Rigidity (EI) sandwich = Rigidity (EI) plywood

From Fig. 6-53a for a Type A sandwich

Modulus of Elasticity, E sandwich = 1.95×10^6

Required Moment of Inertia, I sandwich = $\frac{\text{E plywood}}{\text{E sandwich}} \times \text{I plywood}$ (2.34)

Required I = $.0115$ in.^{4}

Sandwich Section 3/4 in. core, 1 ply cloth and 1 ply
1-1/2 oz. mat on each face.

Check longitudinal bulkhead for local load from mast.

Assumed vertical mast load = 15,000 lbs. - at breaking strength of stays.

Assume 9 in. width of bulkhead must withstand load.

A factor of safety of 2 is used since the load is based on the breaking strength of the stays.

Consider load on laminate only; core not effective.

Area of cloth = $2 \times .016 \times 9 = .288$ in.^{2}

Area of mat = $2 \times .042 \times 9 = .756$ in.^{2}

Cloth area equivalent to mat area = area mat x $\frac{Ec(\text{mat})}{Ec\ (\text{cloth})}$ (2.35)

Cloth area = $.756 \times \frac{.93 \times 10^6}{2.46 \times 10^6} = .286$ in.^{2} (Table 5-12)

Total equivalent area = $.288 + .286 = .574$ in.^{2}

Compressive Stress, $f_c = \frac{15,000}{.574} = 26,132$ psi (2.18)

Cloth Ultimate Compressive Stress $F_{cu} = 18,900$ psi (Table 5-11)

This is obviously not satisfactory, and cloth reinforcement should be added locally. To determine the required reinforcement:

Allowable Stress $f_c = \frac{18,900}{2} = 9,450$ psi (2.9a)

Required Area = $\frac{15,000}{9,450} = 1.537$ in.^{2} (2.11)

Required Additional Area = $1.537 - .574 = 1.013$

Required additional thickness each side, $t = \frac{1.013}{2 \times 9} \doteq .056$ in.

From Table 5-2 - 4 plies of 10 ounce cloth; t = .064 in.

Add 4 plies of cloth to each side of the bulkhead in way of the mast.

Check bond so that the faces will not break away from the core.

Critical stress for face buckling f_{cr}

$$= \frac{1}{2}\sqrt[3]{E_{Face} \times E_{Core} \times G_{Core}} \qquad \text{(See Chapter 6)} \qquad (2.36)$$

$$= \frac{1}{2}\sqrt[3]{1.95 \times 10^6 \times 1.0 \times 10^4 \times 2 \times 10^3}$$

(For 8 lb. per cubic ft. CCA)

$= 17000$ psi. Satisfactory

Buckling of the panel itself in way of the mast is not a problem due to the close proximity of transverse bulkhead No. 3.

Fittings: The chain plate calculation is similar to that for the open sailing boat (Design Example 2-2).

Typical cleat attachment: Consider a jib sheet cleat intended to handle a 1/4 in. diameter manila line. The cleat is a standard item and is provided with holes for 2 fasteners.

Design the fasteners for the breaking strength of the 1/4 in. diameter manila line = 550 lbs. (17).

Consider two loading directions, a horizontal pull and a vertical pull (see Fig. 2-28).

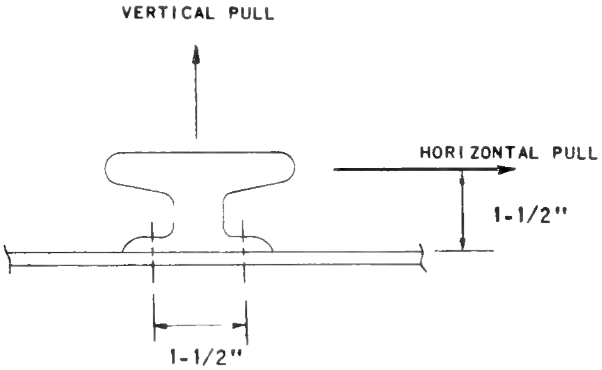


Fig. 2-28. Loading of cleat

Axial Load on Fastener - From vertical pull $= \frac{550}{2} = 275$ lbs.

From horizontal pull - to resist overturning moment = 550 lbs.

Transverse Load on Fastener - assuming equal distribution $= \frac{550}{2} = 275$ lbs.

Factor of Safety = 2.0

Use a threaded fastener of the self-tapping, thread cutting type with a mat insert in place of the nonstructural core of the deck. The fastener should not go all the way through the deck.

Thickness of deck - 3/8 in. core = .375
- 2 plies cloth = .032 in. (Table 5-2)
- 2 plies 1-1/2 oz. mat = .084 in.
- 1 ply woven roving = .037 in.
.528 in.

For 550 x 2 = 1100 lb. axial load

From Table 3-4 Try No. 10 - 32 self-tapping thread cutting fastener.

Required penetration:

4/16 in. gives 400 lb. minimum holding force

Each additional 1/16 in. gives $\frac{2500-400}{8} = 263$ lbs.

Required additional sixteenths $= \frac{1100-400}{263} = 2.66$ - say 3

Total Required Penetration $= \frac{4}{16} + \frac{3}{16} = 7/16$ in.

For 275 x 2 = 550 lb. lateral load

From Table 3-4 a No. 10-32 self-tapping thread cutting screw is satisfactory at 3/16 in. penetration.

The controlling penetration is 7/16 in. which is satisfactory.

DESIGN EXAMPLE 2-5. CABIN CRUISER

This cruising power boat represents a type commonly used for pleasure cruising with accommodations for four to six people. It is of the displacement type, with a cruising speed of about 12 knots.

Principal Dimensions - See Fig. 2-29 for details.

Length, Over-all: 29 ft. - 3 in.
Length, Water Line: 27 ft. - 5 in.
Beam: 9 ft. - 2 in.
Draft: 2 ft. - 4 in.
Speed: 15 miles per hour
Engine: 135 horsepower

Summary of Scantlings

Shell Including Transom - Basic Laminate: 1 ply cloth on outside of hull, 1 ply 2 ounce mat, 2 plies woven roving.

Bottom shell from the bow to Station 7 below Longitudinal No. 3: similar to basic laminate except 4 plies of woven roving.

Side shell from the bow to Station 7 above Longitudinal No. 3: similar to basic laminate except 3 plies of woven roving.

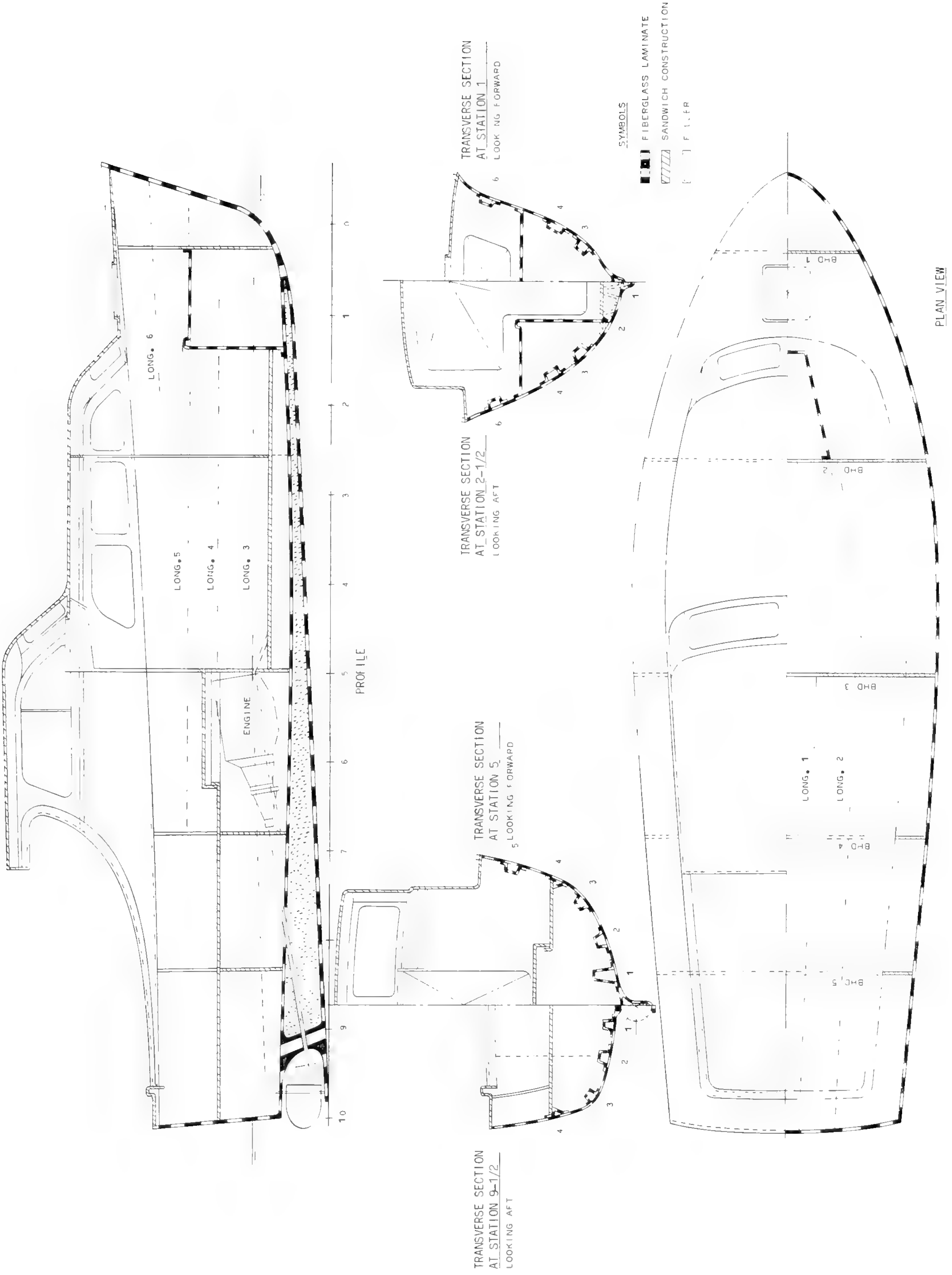


Fig. 2-29. Cabin cruiser

The number and arrangement of stiffeners used aft of Station 7 results in a very thin laminate. A better balanced laminate-stiffener combination could be achieved by dropping one stiffener and respacing the others, using a Type A laminate with 3 plies of woven roving as the basic laminate.

Framing: All stiffeners are hat type.

		Depth In.	Width In.	Plies of Woven Roving
Longitudinal No. 1 -	Bulkhead 2 to 4	To suit Engine and Cabin Floor	2	5
	Bulkhead 5 to Transom	3	3	2
Longitudinal No. 2 -	Bulkhead 2 to 3	4	4	8
	Bulkhead 3 to Transom *	4	3	4
Longitudinal No. 3 -	Bow to Bulkhead 2	5	4	4
	Bulkhead 3 to Transom	4	2	4
Longitudinal No. 4 -	Bow to Bulkhead 3	5	4	3
Longitudinal No. 5 -	Bulkhead 2 to Bulkhead 4	4	4	3
Longitudinal No. 6 -	Bow to Bulkhead 2	4	3	3

* Carried up transom to deck.

Decks: Sandwich construction - 2 plies cloth on top face, 1 ply 1-1/2 ounce mat, non-structural core - variable thickness, 1 ply 1-1/2 ounce mat, 1 ply woven roving.

Location	Core Thickness
Main Deck	1/2 in.
Cabin Top - Lower Level	1-1/4 in.
Cabin Top - Upper Level	1-1/4 in.
Cockpit	5/8 in.
Interior Decks	1/4 in.

Built-in Bunks and Lockers Forward: 4 plies woven roving.

Bulkheads: 3/4 in. core with 1 ply cloth and 1 ply 1-1/2 ounce of mat on each face.

Design

Shell Laminate: The laminate chosen is that referred to as Type A in this manual and consists of: 1 ply cloth on the outboard face, 1 ply mat and a varying number of plies of woven roving.

The laminate selection is based on the excellent impact resistance of this type of laminate.

The design head of water is taken to 24 in. above the deck edge forward of Station 7; and to 6 in. above deck edge aft of Station 7, Table 2-2.

Since the panels involved are all relatively long and narrow, the bending moment and section modulus used are in each case taken for a one in. wide strip. This strip is considered to act as a uniformly loaded, fixed ended beam of span equal to the distance between longitudinals.

The calculations have been arranged in tabular form for convenience, Table 2-9.

TABLE 2-9. SHELL LAMINATE

Location	Max. Clear Distance Between Longitudinals L (In.)	Head to 24" Abv. Dk. Fwd. Sta. 7 6" Abv. Dk. Aft Sta. 7 h (Ft.)	$p = h \times \frac{64}{144}$ p = psi	Bending Moment $M = \frac{pL^2}{12}$ (2.21) M = in.-lbs.	Section Modulus $Z = \frac{F.S. \times M}{F_{bu}}$ (2.22) $= \frac{4\,M}{F_{bu}}$ Req'd Z * - in.^{3}	Type A Laminate Req'd Plies of Woven Roving (Fig. 6-31)
Deck Edge & Long'l #6 Forward Station 7	10	2.5	1.11	9.25	Z_{cl} = .0012	2 Use 3
Deck Edge & Long'l #5 Forward Station 7	14.5	2.8	1.24	21.75	Z_{wr} = .0037	3
Deck Edge & Long'l #4 Aft Station 7	20	1.3	0.58	19.33	Z_{wr} = .0033	2
Long'l #6 & Long'l #5 Forward Station 7	10	3.4	1.51	12.58	Z_{wr} = .0021	2 Use 3
Long'l #5 & Long'l #4 Forward Station 7	11-3/4	4.3	1.91	22.00	Z_{wr} = .0037	3
Long'l #4 & Long'l #3						
Forward Station 7	9	5.3	2.36	15.93	Z_{wr} = .0027	2 (Use 3)
Aft Station 7	12	3.0	1.33	15.96	Z_{wr} = .0027	2
Long'l #3 & Long'l #2						
Forward Station 7	12	6.4	2.84	34.08	Z_{wr} = .0058	4
Aft Station 7	10	3.9	1.73	14.42	Z_{wr} = .0024	2
Long'l #2 & Long'l #1						
Forward Station 7	10	6.9	3.07	25.58	Z_{wr} = .0043	3 **
Aft Station 7	10	4.2	1.87	15.58	Z_{wr} = .0026	2
Long'l #1 & Centerline						
Forward Station 7	8	6.2	2.76	14.72	Z_{wr} = .0025	2 **
Aft Station 7	10	4.3	1.91	15.92	Z_{wr} = .0027	2 ***

* Due to space limitations only the critical Z is shown.

** Forward of Station 7 use 4 plies of woven roving, as required between Long'ls. #2 and #3, for consistency and ease of construction.

*** Between Stations 9 and 10 inboard of Long'l. #2, a local increase to 4 plies of woven roving is recommended because of the pressure from the propeller.

Shell Longitudinals: The shell longitudinals are designed as fixed ended beams to withstand the same design load as the shell they support. The calculations have been arranged in tabular form for convenience, Table 2-10. Hat section stiffeners have been used throughout.

The stiffener sections indicated have been checked for shear and found satisfactory. For a typical shear stress calculation see Design Example 2-3.

TABLE 2-10. SHELL LONGITUDINALS

Long'l No.	Location	Length L (In.)	Width of Shell Supported s (In.)	Head to 24" Abv. Dk. Fwd Sta. 7 6" Abv. Dk. Aft Sta. 7 h (Ft.)	$p = h \times s \times \frac{64}{144}$ p - Lbs.-In.	$M = \frac{pL^2}{12}$ (2.21) In.-Lbs.	$Z = \frac{4M}{15{,}800}$ (2.22) $in.^3$	Required Stiffener (Fig. 6-37) Depth x Width (In.)	No. of Plies of Woven Roving
1	Bhd #5 to Transom	52	10	4.3	19.11	4,306	1.09	3 x 3	2
2	Bhd #3 to #4	57	15	5.8	38.67	10,470	2.65	4 x 3	4
3	Bhd #1 to #2	78	15	5.8	38.67	19,606	4.96	5 x 4	4
3	Bhd #3 to #4	57	15	5.2	34.66	9,384	2.38	4 x 2	4
4	Bhd #1 to #2	78	13	4.8	27.73	14,069	3.56	5 x 4	3
5	Bhd #2 to #3	77	14	3.4	21.15	10,450	2.65	4 x 4	3
6	Bhd #1 to #2	78	13	2.9	16.76	8,497	2.15	4 x 3	3

Shell below Longitudinal No. 4 Forward of Station 7 has 4 plies of woven roving.

Shell Forward of Station 7 from Longitudinal No. 4 to deck edge has 3 plies of woven roving.

Shell elsewhere has 2 plies of woven roving.

Shell Longitudinal No. 2 - Supporting Cabin Flooring: Bulkhead No. 2 to Bulkhead No. 3.

$L = 77$ in., $s = 12$ in., $h = 5.9$ ft., $p = 5.9 \times 12 \times \frac{64}{144} = 31.47$ lbs.-in.

$$M = \frac{pL^2}{12} = 15.770 \text{ in.-lbs.} \qquad (2.21)$$

$$\text{Required, } Z = \frac{4M}{15{,}800} = 3.99 \text{ in.}^3 \qquad (2.22)$$

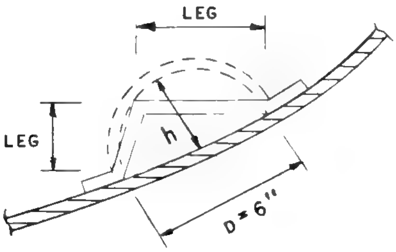


Fig. 2-30. Longitudinal No. 2

As an approximation, assume half-round stiffener with $\frac{D}{2} = h$; $Z = 3.99$ in.^{3}

From Fig. 6-39 D = 6 in., h = 3 in., 8 plies woven roving

Minimum leg 4 in.

Assume difference between Z of half-round and Z of angle is provided by support of the angle by the cabin deck.

Longitudinal No. 1 - Engine Support

Engine Weight: 850 lbs.
Thrust: 1615 lbs. at 15 knots assuming EHP = 1/2 SHP
Engine Mounting: 4 bolting pads on engine
Engine Support: 4 steel angle clips bolted to fiberglass hat stiffeners

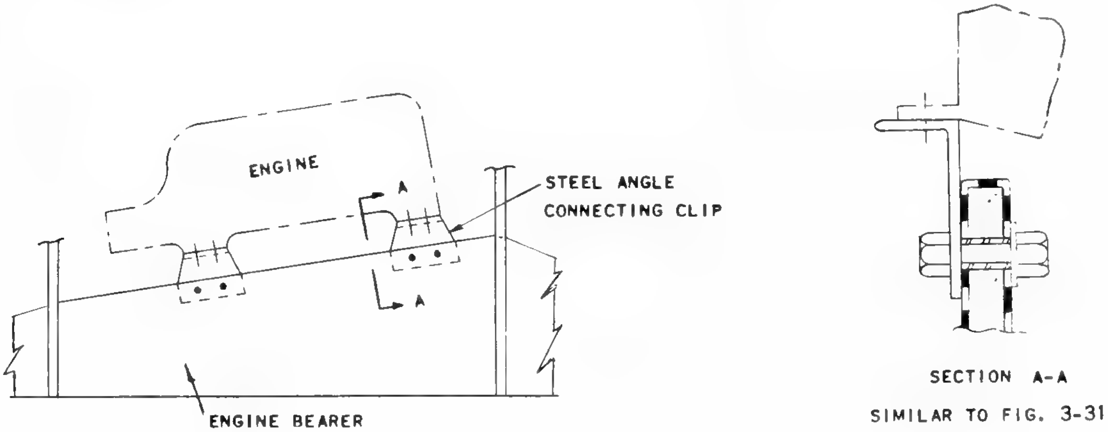


Fig. 2-31. Engine foundation

Assume engine weight is doubled by acceleration forces -

Factor of Safety = 6 (Chosen because of the long term nature of the loading and the vibration).

Using standard methods of vector analysis, assuming the weight and thrust forces equally distributed among the four connections and including the force required to resist the moment introduced by the fact that the line of action of the thrust does not pass through the bolts the maximum load per attachment P = 700 lbs.

Assume only two bolts per attachment.

Load per bolt $P_b = 350$ lbs.

Using a bolt and spacer combination with a 1/2 in. outside diameter D, determine the required thickness of woven roving, to give an acceptable bearing stress, considering all the load taken by one web of the longitudinal.

Ultimate tensile strength, $F_{tu} = 30{,}100$ psi (Table 5-6)

Factor = .914 (Table 3-2)

Bearing stress at failure, $F_{Bu} = .914 \times 30{,}100 = 27{,}500$ psi

Allowable bearing stress, $f_{Ba} = \frac{27{,}500}{6} = 4583$ psi (2.9a)

The required thickness, $t = \dfrac{P_b}{D \times f_{Ba}}$ (2.12)

$$t = \frac{350}{0.5 \times 4583} = 0.153 \text{ in.}$$

Use 5 plies of woven roving, t = .185 in. (Table 5-2)

Use a stiffener width of 2 in. for ease in molding. This stiffener is carried forward to support the cabin floor.

Decks: All decks are to be of sandwich construction for rigidity. Type B sandwich is used Fig. 6-53b. Each deck is checked for stress in the various elements, and for deflection.

The required core thickness for each criterion, stress or deflection, is determined and the thickest core is used.

Cabin Top - Lower Level:

Design Load; p = 2 ft. of water = 0.89 psi
Dimensions: Length = 6 ft. - 5 in., width = 7 ft. - 0 in.
Edge Connection: Fixed

Flexure: Consider a 1 in. strip as a fixed ended beam.

Bending moment, $M = \dfrac{pL^2}{12} = \dfrac{0.89 \times 48^2}{12} = 171$ in.-lbs. (2.21)

Required section modulus $= Z = \dfrac{F.S. \times M}{f}$ (2.22)

Ultimate stresses, Fu, from Tables 5-6 and 5-11

Cloth; top face in tension, $Z = \dfrac{4 \times 1.71}{24{,}100} = 0.028 \text{ in.}^3$

1/2 in. deep core required (Fig. 6-53b)

Woven roving; bottom face in compression, $Z = \dfrac{4 \times 1.71}{13{,}900} = 0.049 \text{ in.}^3$

7/8 in. deep core required (Fig. 6-53b)

Mat; top face in tension, $Z = \dfrac{4 \times 1.71}{11{,}00} = 0.062 \text{ in.}^3$

1/2 in. deep core required (Fig. 6-53b)*

* By extrapolation.

Shear Stress:

$$\text{Shear load, } V = \frac{p \times L}{2} \qquad (2.24)$$

$$= \frac{0.89 \times 48}{2} = 21.4 \text{ lbs. per in.}$$

Assuming the core material carries all the shear load, the maximum shear stress for a rectangular block is for a 1-1/4 in. core:

$$f_s = \frac{3}{2}\frac{V}{A} \qquad (2.27)$$

$$f_s = \frac{3}{2} = \frac{21.4}{1 \times 1.25} = 25.7 \text{ psi}$$

$$\text{Allowable shear stress, fsa} = \frac{\text{Ultimate Shear Stress}}{\text{Factor of Safety}} \qquad \text{(Table 5-17)(2.9a)}$$

$$f_{sa} = \frac{185.0}{4} = 46.3 \text{ psi} \quad \text{Satisfactory}$$

See Design Example 2-4 for notes regarding this shear calculation.

By similar calculations the remainder of the decks may be checked. The results of these calculations are given below in tabular form, Table 2-11.

Deflection:

$$\text{Allowable deflection, } d = \frac{L}{200} = \frac{48}{200} = 0.24 \text{ in.}$$

Assume a cellular cellulose acetate core weighing 7.0 lbs. per cubic ft.

$$G_c = 2.0 \times 10^3 \text{ psi} \qquad \text{(Table 5-17)}$$

Ultimate shear strength = 185 psi

Try a 1-1/4 in. core

$$\text{Maximum deflection, } d = \frac{pL^4}{384\ E_f I_f} + \frac{pL^2}{8\ G_c A_c} \qquad (2.28)$$

$$d = \frac{0.89 \times 48^4}{384 \times 2.06 \times 10^6 \times .046} + \frac{0.89 \times 48^2}{8 \times 2000 \times 1 \times 1.25} \text{ (Fig. 6-53b)*}$$

$$= 0.130 \text{ in.} + 0.103$$

$$= 0.233 \text{ in.} \quad \text{Satisfactory}$$

* By extrapolation.

TABLE 2-11. DECKS

Deck	Location	Panel Size	Edge Connection	Load psi	Critical Design Criterion	Req'd Core Thick-ness	Req'd Ult. Core Shear Stress psi
Main Deck	Deck Fwd of Cabin Trunk Out-board of Hatch	32" x 24"	Fixed Edges	0.89	Deflection	1/2"	128.4
Main Deck	Between Coaming & Cabin Side Aft of Bhd #2	12" (Treat as beam)	Simply Supported	0.89	Deflection	3/8" Use 1/2"	86.0
Cabin Top	Upper Level	81" x 80"	Fixed Edges	0.28	Deflection	1-1/4"	53.7
Cockpit	-	98" x 49"	Fixed Edges	0.28	Deflection	5/8"	49.7
Interior	Main Cabin	15" (Treat as beam)	Fixed Ends	0.28	Deflection	1/8" Use 1/4"	50.4

Built-in Bunks: See similar calculation for Cruising Sailboat, Design Example 2-4.

Use 4 plies woven roving.

Bulkheads: See similar calculation for Cruising Sailboat, Design Example 2-4.

Use 3/4 in. core with 1 ply cloth and 1 ply 1-1/2 ounce mat each face.

Fittings: Similar to cleat attachment calculation for Cruising Sailboat, Design Example 2-4.

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3

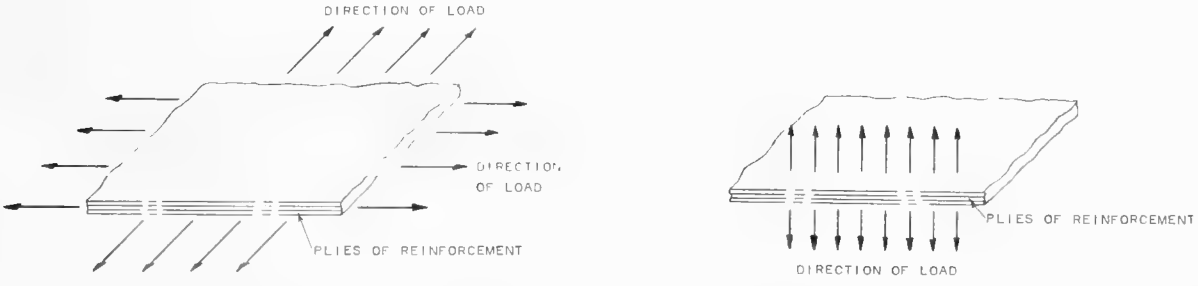
Design Details

The use of good details in fiberglass construction is of vital importance in producing a successful design. It is the purpose of this Chapter to indicate recommended methods of construction, and to provide guidance for avoiding trouble causing details. Because of the variety of details possible, the number covered has been held to a minimum and the details chosen illustrate principles which are applicable regardless of the exact means by which they are applied. This approach should guide the designer in solving particular problems and developing successful details, even though the exact situation is not covered here.

APPLICATION OF LOADS

In any structural design work an understanding of the basic properties of the material used is essential. The basic property of fiberglass laminates which must be clearly understood is the difference between its tensile strength perpendicular to the plies of the laminate and its tensile strength parallel to these plies. The tensile strength perpendicular to the plies is very much less than that parallel to the plies. For this reason there are right and wrong directions of loading, which are illustrated in Fig. 3-1. The variation in strength with direction of reinforcement, which is characteristic of cloth and woven roving reinforced laminates and which is discussed in Chapter 6, has nothing whatever to do with the "wrong" loading direction mentioned here. Those directions are all "right" directions since the loading is parallel to the laminate.

The reason for this right and wrong direction is simple. As explained in Chapter 5, the properties of fiberglass reinforced laminates are due to the two basic components, fiberglass and resin. Of these, the fiberglass provides the strength and the plastic or



a. RIGHT – LOAD PARALLEL TO PLIES

b. WRONG – LOAD PERPENDICULAR TO PLIES

Fig. 3-1. Right and Wrong Directions of Loading with Respect to Laminate Reinforcement resin provides the means of holding the fiberglass in place. Loading a laminate in the wrong direction places the load on the resin, and the glass reinforcement cannot act. Therefore, when a load is applied in the wrong direction, as with cleats secured to a deck, mechanical fasteners completely through the laminate should be used. The only exception to this rule may be in the case of very light loads.

Assuming the loads are applied in the right direction or parallel to the plies, the next consideration is the orientation of the reinforcement to suit the loading. This is particularly important with cloth and woven roving reinforcements. The designer should be familiar with the strong and weak directions, and make every attempt to place the laminate reinforcement with the strong or warp direction in line with the direction of the principle stress. This principle applies both to the lay up of the over-all laminate and to local increases in thickness in way of local loading.

LAMINATE CONNECTIONS

One of the major advantages of fiberglass construction is that, in many cases, the basic material may be used to form the connection between two parts, in a manner analogous to welding in steel construction. The basic requirement for all joints is that the laminate be loaded in a direction that will not tend to delaminate it; that is, pull it apart.

In secondary bonded joints, i.e. joints using an adhesive to connect cured laminates, subjected to shear tending to slide one laminate past the other, it is recommended that a layer of resin impregnated fiberglass mat reinforcement be placed between the joining surfaces since it acts as the adhesive carrier and as a reinforcement. Fiberglass mat is preferred since it retains the adhesive and its random distribution of glass fibers provides reinforcement in the joint opposing the shear force.

Deck to Shell

One of the most common connections which must be made is the deck to the shell. There are many possible means of making this connection and the final selection of a detail must be based on satisfying a number of requirements. These requirements will sometimes conflict and some compromise must be decided upon. The following basic principles will guide in the design of a good joint:

> A joint should develop maximum efficiency or the full strength of the weaker of the two pieces being joined. This is the most important criterion of a proposed design; the one which overrides all other considerations. The exterior reinforcement shown in a number of the following figures will create a condition where good exterior appearance will be difficult to obtain. If, however, sufficient strength cannot be obtained without this exterior reinforcement, the effect on appearance must be accepted or the joint design modified if possible.
>
> A joint must be easily made by the fabricators. Quality control in fiberglass construction is all important, and a joint that the workman can do well will often be stronger than a joint which appears stronger on paper but cannot be easily made and inspected.

A joint should be compatible with the molding method used, the speed of construction desired, and the size and type of boat being built. A joint which has adequate strength and can easily be made with minimum mold accuracy for small boats, may not be suitable for use with larger boats with higher strength requirements. These larger boats are not rapidly produced, and therefore justify the extra cost of using one of the more complex joints requiring more accurate molds. The parts to be joined should never be forced into place, since this introduces stresses not contemplated in the design and may drastically reduce the strength of the structure.

Normal loads on the deck and shell produce either shear loading, or tension loading on the outside of the hull at the joint. It is the tension on the outside of the hull which makes exterior reinforcement so effective when compared to interior reinforcement. With interior reinforcement only, this type of loading tends to peel the pre-molded laminate away from the bonding reinforcement as shown in Fig. 3-2. For this reason, this connection must be very carefully made. It is recommended that the bond lap be at least 2 inches in small boats, and be adequately increased for larger hulls with thicker laminates.

When joints are used which leave an edge of a laminate that is not tapered or butted to an adjacent piece, this edge should be sealed with resin to prevent water absorption and delamination.

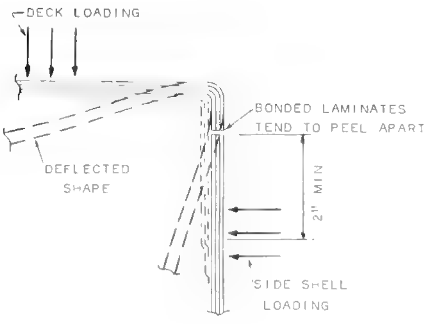


Fig. 3-2. Deck Edge Connection - Normal Deck and Shell Loading Produces Tension at the Joint

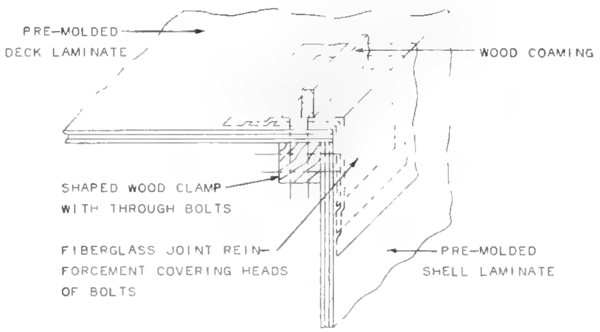


Fig. 3-3. Deck Edge Connection - Shaped Wood Gunwale Clamp

Figs. 3-3 through 3-12 indicate several deck to shell connections.

Fig. 3-3 indicates the use of a shaped wood gunwale clamp. This was common practice in past years, and was adapted from wood boat construction, but the current trend is to the all fiberglass boat. Several reasons for this have been given in the discussion of composite construction, Chapter 2.

Fig. 3-4 indicates a connection with a vee or scarf joint in the deck. Fig. 3-5 indicates the same basic connection with a vee or scarf joint in the shell rather than the deck, but incorporates a molded in deck edge coaming. Usually, joint selection depends on the molding procedure. The joint shown in Fig. 3-4 may be used when the shell is molded in two halves, while that in Fig. 3-5 may be used when the shell is molded in one piece. Although this is not recommended, the joints in Figs. 3-4 and 3-5 may be made without the additional exterior fiberglass reinforcement. If this is done, the vee joint is preferred since a better bond will be obtained. In any case, the total joint reinforcing laminate should be at least equal in strength to the weaker of the laminates joined.

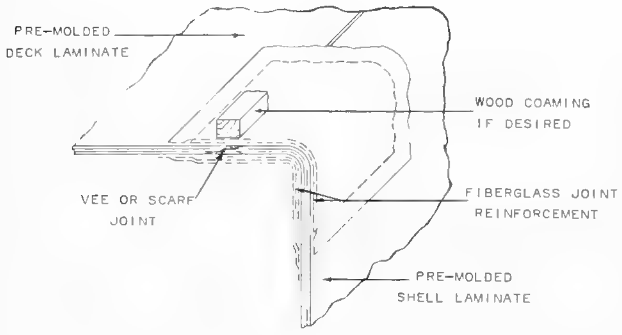


Fig. 3-4. Deck Edge Connection - Wood Coaming and Joint in Deck

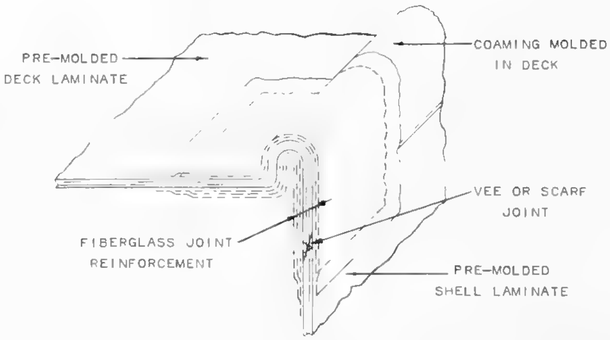


Fig. 3-5. Deck Edge Connection - Molded in Deck Edge Coaming with Joint in Shell

Fig. 3-6 indicates a shell to deck connection commonly used in small boats. It has the advantage of minimizing requirements for dimensional accuracy and provides an easy means of attaching a rubbing strip. The through bolts in this joint may be eliminated by clamping the deck and shell edges together until the ply of resin impregnated mat in the joint is cured. The edges are then ground flush and, if necessary, interior reinforcement placed, and finally the snap-on rubbing strip is added. This strip may be of metal or plastic.

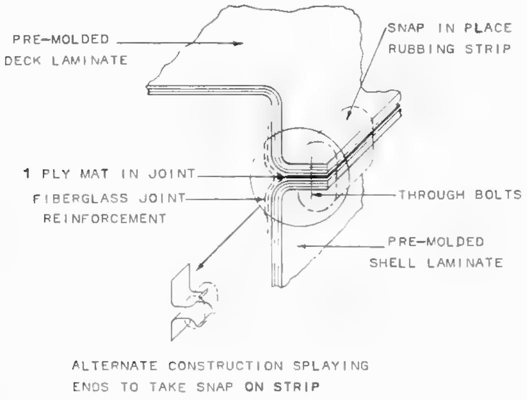


Fig. 3-6. Deck Edge Connection - Small Boat Type with Snap in Place Rubbing Strip

Fig. 3-7 indicates the use of a lap joint combining bonding with through fastening. The hull and deck molds may be easily made so that the faying or connecting surfaces of the joint are vertical. The small strip shown may be added to provide a ready positioning means.

Fig. 3-8 illustrates a connection utilizing a prefoamed resin or a troweled in place filled resin, described in Chapter 4. This type of joint maintains the rigidity and strength of the sandwich construction deck right to the deck edge. In making this joint, the shell and deck laminates are joined in a manner similar to that shown in Fig. 3-4. A filled resin is then troweled in place, or a prefoamed resin is shaped and set in place and the second reinforcing laminate is added. The advantage of this joint is its high rigidity and strength without the addition of exterior layers of reinforcement which disturb the molded-in gel coat finish. Fig. 3-9 indicates the same basic joint with a molded-in coaming and the joint in the shell, rather than the deck. As previously mentioned, choice of joint location depends on molding procedure.

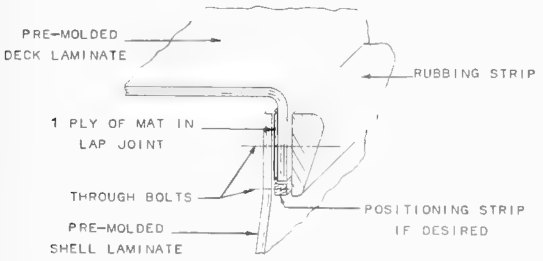


Fig. 3-7. Deck Edge Connection - Combining Bonding and Mechanical Fastening

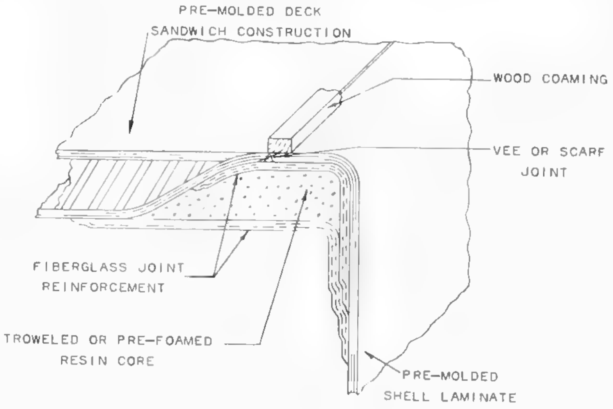


Fig. 3-8. Deck Edge Connection - Sandwich Deck with Wood Coaming and Joint in Deck

Figs. 3-10, 3-11 and 3-12 indicate three connections which have been successfully used, and which have the advantage of simplicity of construction.

Fig. 3-13 indicates a method of connecting a sandwich construction interior deck, such as a cockpit deck or cabin sole, to the shell. Notice that the connection is a temporary one, so that the deck may be removed for inspection and cleaning of the bilges.

Gunwale

Gunwale connections on small open boats vary considerably with molding method and designer's preference. Four common methods are shown in Figs. 3-14 through 3-17.

Fig. 3-14 indicates a common detail for gunwale and shell as one continuous piece. The edge of the laminate is dressed after removal from the mold. Depending on the molding method used, the gunwale may be flanged inboard or outboard. This is considered the simplest and best of the details shown, when flanged outboard.

Fig. 3-15 indicates, in effect, a conventional wood construction applied to a fiberglass hull. It is chosen partly on an appearance basis and partly because the wood rubbing strip may be easily replaced. This construction will, however, increase maintenance problems on what should be a relatively maintenance free boat.

Fig. 3-16 indicates two types of aluminum extrusions bolted to the shell to serve as a gunwale. The cross-sectional shape of the aluminum may, of course, vary widely.

Fig. 3-17 indicates an all fiberglass construction suitable for a shell molded in one piece. The gunwale piece is molded separately and bonded or bolted to the completed hull.

Shell at Keel

In some instances the main hull laminate is made in two parts and is then joined together. This connection is of such importance that some designers use a combination of mechanical fastening and resin bonding. Special care must be taken when using through bolting in the shell below the waterline, since this is a possible source of annoying leakage.

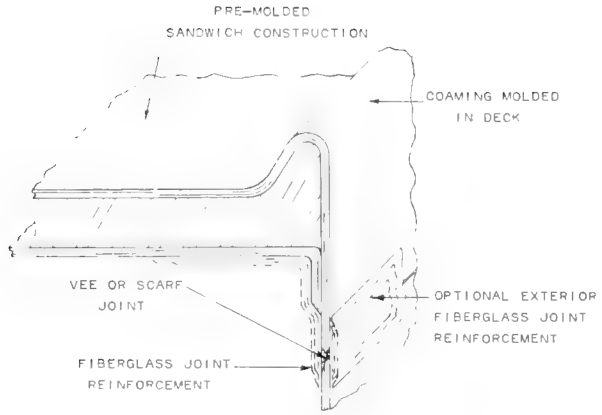


Fig. 3-9. Deck Edge Connection - Sandwich Deck with Molded-in Coaming and Joint in Shell

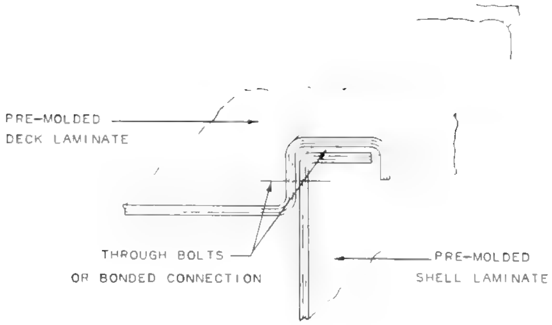


Fig. 3-10. Deck Edge Connection - Simple Molded-in Coaming with Mechanical Fastenings

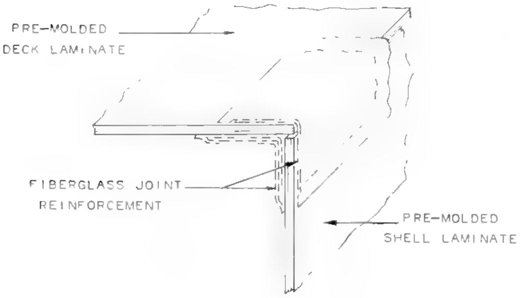


Fig. 3-11. Deck Edge Connection - Simple Butt Joint

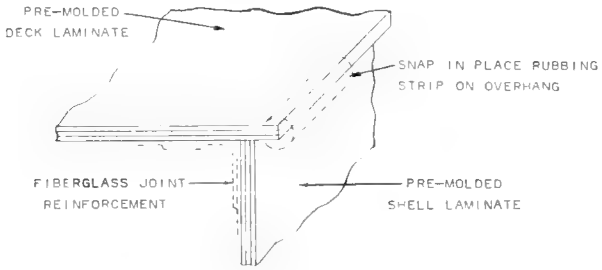


Fig. 3-12. Deck Edge Connection - Modified Butt Joint with Overhang for Snap in Place Rubbing Strip

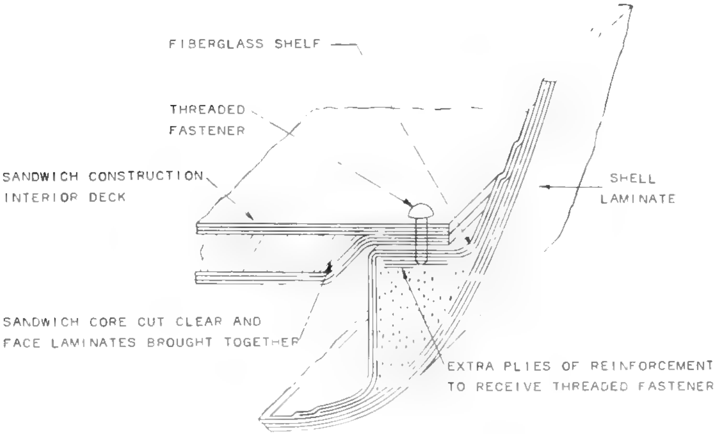


Fig. 3-13. Deck Edge Connection - Interior Deck to Shell

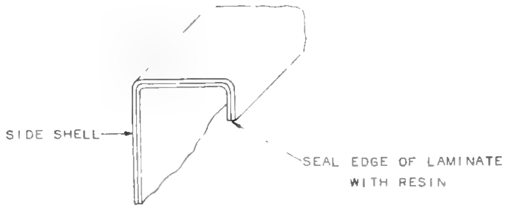


Fig. 3-14. Integrally Molded Gunwale

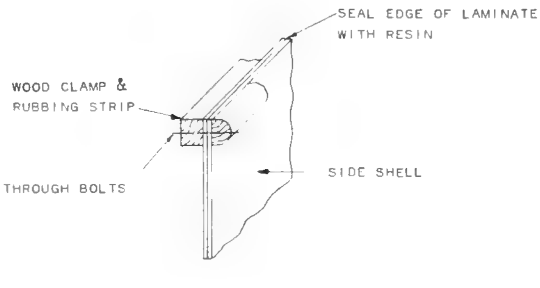


Fig. 3-15. Wood Gunwale

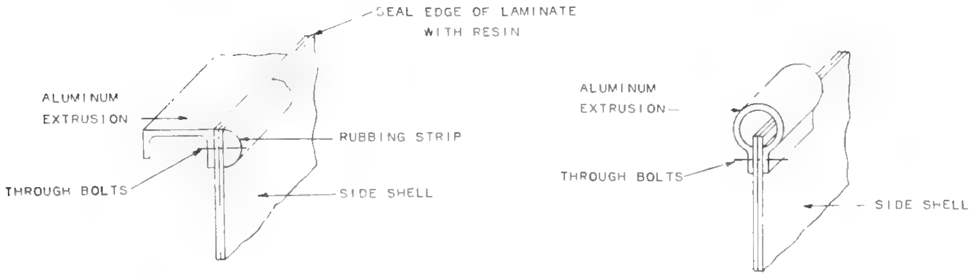


Fig. 3-16. Aluminum Gunwales

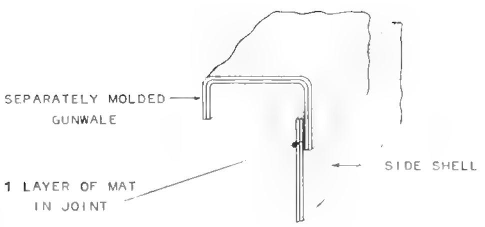


Fig. 3-17. Separately Molded Fiberglass Gunwale

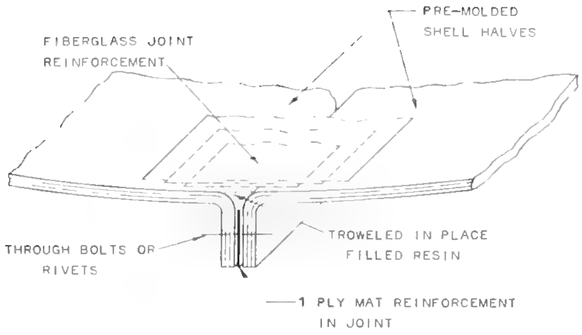


Fig. 3-18. Connection of Shell Halves - Centerline Skeg

Fig. 3-18 indicates a detail suitable for boats such as lifeboats, cruising power boats and small open boats where a small keel is desirable for directional stability. The joint reinforcement as shown, also prevents leakage. If a flat bottom is desired, the joining flanges may be turned inboard and the joint reinforcement placed outside.

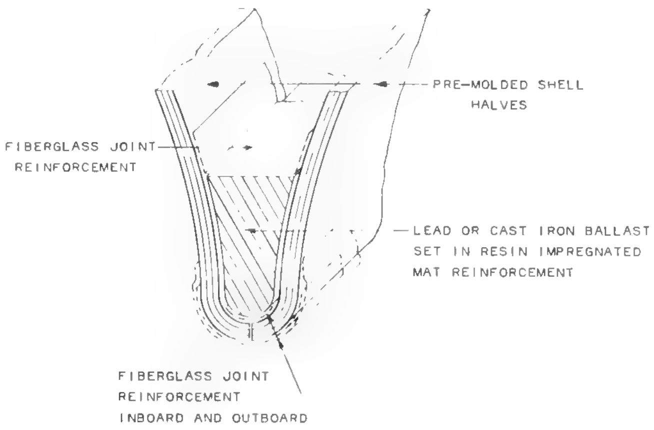
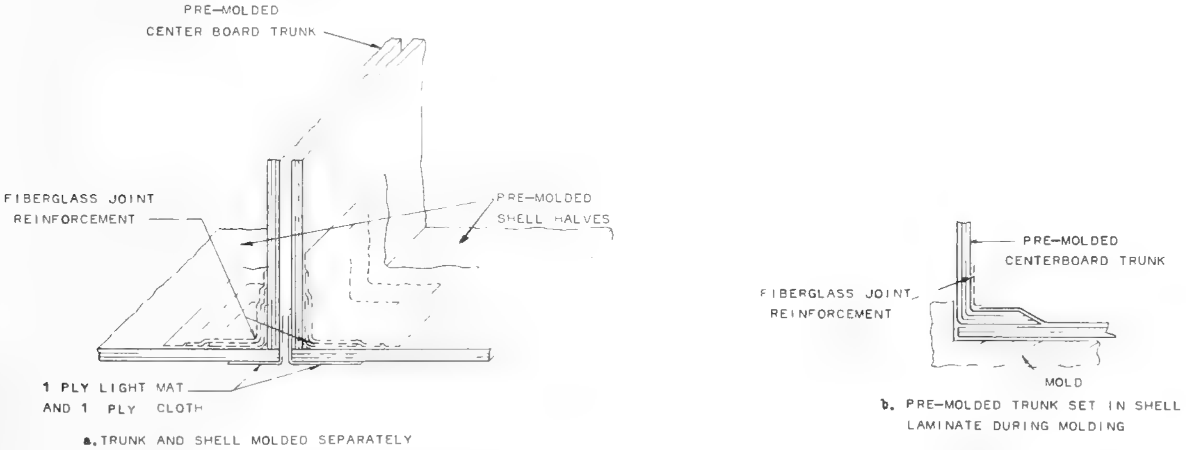


Fig. 3-19. Connection of Shell Halves - Cruising Sailboat with Ballast

Figs. 3-19, 3-20 and 3-21 indicate various means of forming a similar connection for a sailboat. Note that where heavy ballast is required in these boats, it is set in wet mat reinforcement during or after joining the shell halves. The ply of mat covered by a layer of cloth indicated outboard at the joint in Figs. 3-20 and 3-21, is intended to keep water out of these secondary bonded joints which are susceptible to delamination under water pressure. The joint at the base of the centerboard trunk shown in Fig. 3-20a is used when the shell is molded in one piece and the centerboard trunk added later. The alternate construction shown in Fig. 3-20b is used when the centerboard trunk is premolded and set in the wet laminate during the molding of the shell. The lower flange of the trunk is covered by the inner layers of the shell laminate. The use of a



a. TRUNK AND SHELL MOLDED SEPARATELY

b. PRE-MOLDED TRUNK SET IN SHELL LAMINATE DURING MOLDING

Fig. 3-20. Connection of Shell and Centerboard Trunk mold extending slightly up into the centerboard trunk provides a means of locating the trunk and a smooth mold face surface which will minimize the secondary bond leakage problem mentioned above.

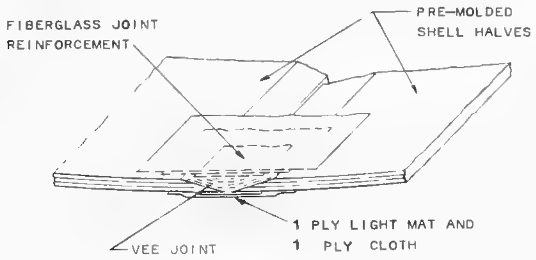


Fig. 3-21. Connection of Shell Halves - For Small Boats Only

Keel Ballast to Hull

Fig. 3-22 indicates a common means of attaching outside ballast to the hull. The large washer shown is essential to prevent the securing nut from crushing the laminate. The local reinforcement is necessary to prevent the washer from shearing through the laminate, and to provide bearing for the bolt to enable it to resist sidewards thrust.

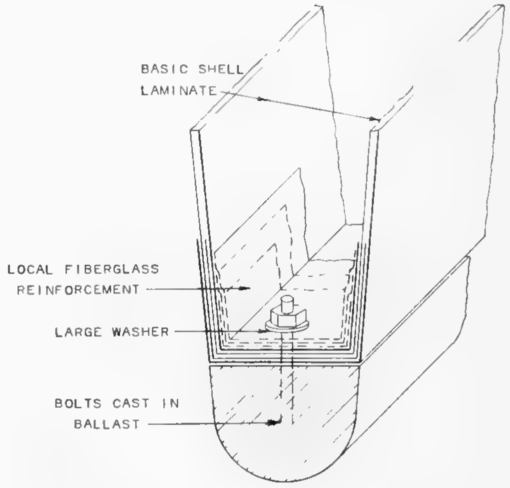
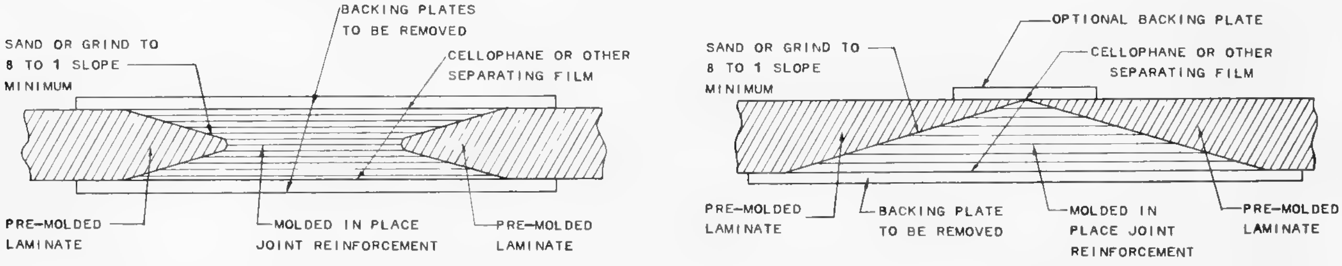


Fig. 3-22. Ballast to Hull Connection

Repair Joint

Fig. 3-23 shows a type of connection commonly used in repair work and which may be used anywhere a butt joint requires surface appearance combined with strength. The joint reinforcement should be equivalent to the basic laminate for continuity of strength.



a. PREFERRED CONSTRUCTION

b. ACCEPTABLE ALTERNATE

Fig. 3-23. Butt Joints

Bulkhead or Frame to Deck or Shell

Fig. 3-24 shows one of the most common connections, particularly in larger boats having accommodations. This basically is a connection between the shell or deck and any member perpendicular to it. This connection performs the dual function of making the joint and reinforcing the shell at a rigid support. The fillet pieces indicated are to ease the hard spot caused by the connected member. A detailed discussion of hard spots is given later in this Chapter. The fillets also prevent resin richness in the corner. The fillets may be made of balsa, foamed plastic or a filled resin troweled in place and allowed to set before the joint reinforcement is added.

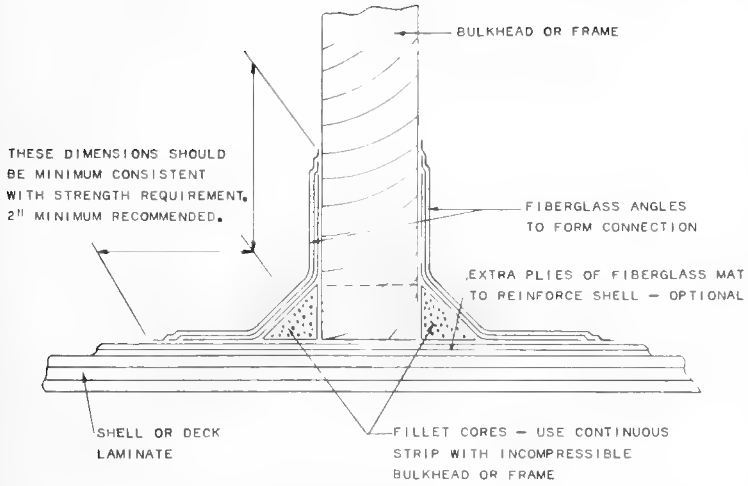


Fig. 3-24. Connection - Bulkheads and Framing to Shell or Deck

Where incompressible bulkheads and frames, such as, plywood or hard woods are connected to thin shell or deck laminates, the length of the fiberglass connecting angles should be determined by test to insure that unfairness in the hull or deck will not occur. Shrinkage during cure of the connecting angles tends to pull the bulkhead or frame through the laminate, causing a slight bump. Experience has shown that this is particularly noticeable when incompressible frame cores are completely encased in the laminate. This effect can be minimized by replacing the separate low density fillet cores with a continuous strip inserted between the framing member and the shell.

Cabin Trunk to Deck

In wooden construction, the joint between the cabin trunk and the deck causes considerable difficulty. In many fiberglass boats the problem is avoided completely by molding the cabin trunk and the deck in one unit and eliminating this connection entirely. A typical example of this construction is shown in Fig. 3-25. If this desired one piece construction is not possible, the connection shown in Figs. 3-26 or 3-27 may be used. The joint between the cabin trunk and the decks is an important one from a strength viewpoint, and reinforcing of both sides as shown is considered essential.

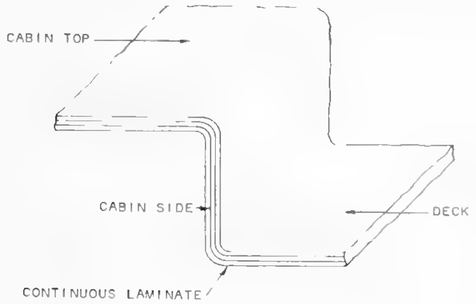


Fig. 3-25. Cabin and Deck Molded as a Single Unit

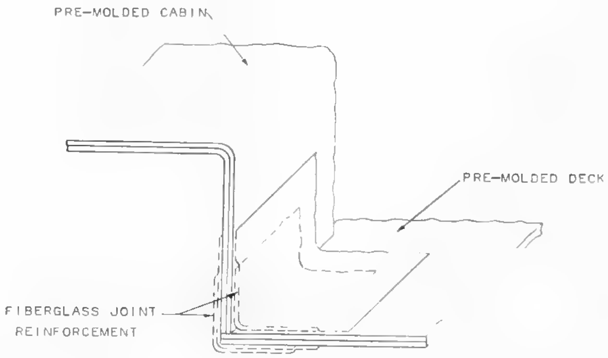


Fig. 3-26. Cabin to Deck Connection - Pre-molded Cabin and Deck - Single Skin Construction

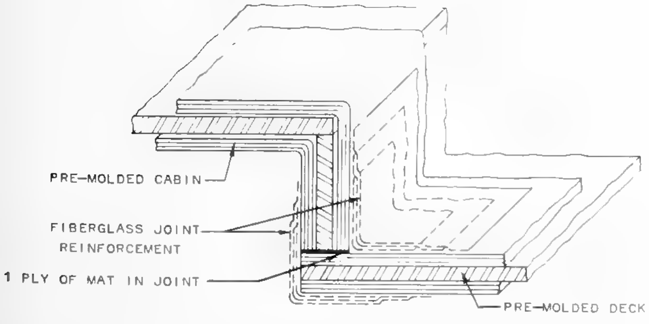


Fig. 3-27. Cabin to Deck Connection - Pre-molded Cabin and Deck - Sandwich Construction

FITTING CONNECTIONS

All boats have various attachments and fittings which do not affect the over-all strength of the hull, but are vital for operation. This includes engine mountings, chain plates, bitts, chocks, cleats, etc. Certain fittings can put severe local loads on the hull, and these loads must be carefully considered in designing the necessary reinforcement. Loads induced by fittings generally push down on the boat, such as engines and masts; or pull away from the boat, such as rigging attachments and cleats. Horizontal thrusts in one or more directions may also be induced simultaneously.

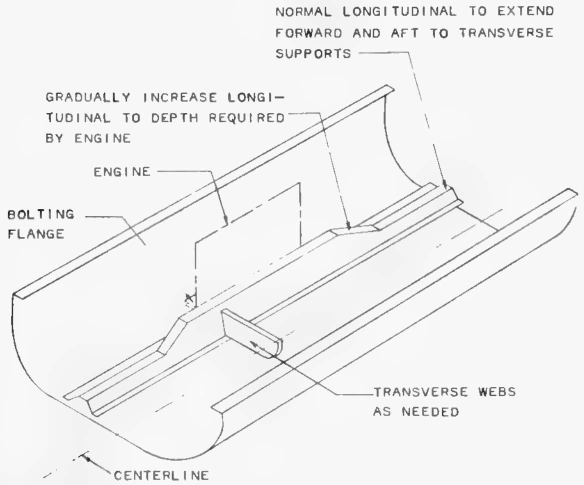
Pushing Loads

The design of engine mounts, mast steps and similar items is basically a problem of providing adequate strength directly under the load to prevent local failure, and spreading the load over a sufficient supporting area. Supports should, wherever possible, be tied into the main structure of the boat, such as, transverse and longitudinal frames, bulkheads, etc.

Engine Mounts: A number of typical mountings for inboard engines are shown in Figs. 3-28 through 3-33. In each case the longitudinal supports are carried a substantial distance away from the engine, sometimes stopping at a transverse frame or bulkhead, and sometimes tapering down to a normal longitudinal frame. The engine bearers themselves may be of steel or fiberglass angles as shown in Figs. 3-31, 3-32 and 3-33. The loading from the engine is always considered as being supported by the fiberglass laminate, without assistance by the stiffener core, if any. It is recommended that a thin layer of neoprene or some similar material be placed between the steel engine bolting supports and the fiberglass laminate bearers as a means of insulation. Transverse frames are added where necessary to help distribute the engine thrust and weight to the shell, and to reduce shell panel sizes compared to the normal size in the area to avoid excessive vibrations.

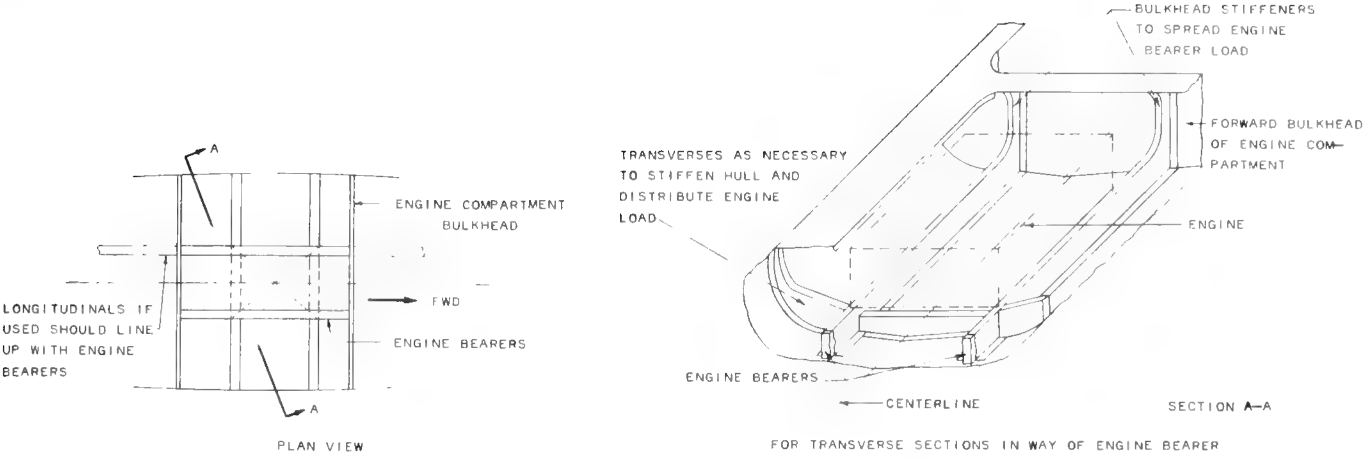
The mounting of outboard engines has been covered in Chapter 2 under transom design since this mounting constitutes a major structural portion of the whole craft.

Mast Steps: Masts exert major concentrated loads on the boat. Masts may be divided, for purposes of design, into those which step on the deck and those which step on the keel. In wooden construction the keel is a major structural member and can receive the mast,



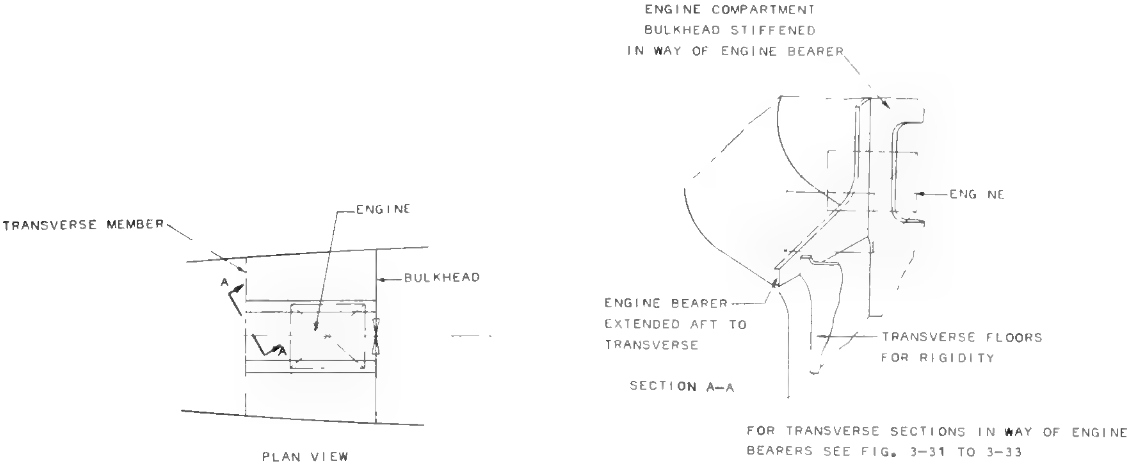
FOR TRANSVERSE SECTIONS IN WAY OF ENGINE BEARER, SEE FIG. 3-31 TO 3-33.

Fig. 3-28. Engine Mount for Inboard Runabout - Suitable for Low Horsepower Installations Only



FOR TRANSVERSE SECTIONS IN WAY OF ENGINE BEARER SEE FIG. 3-31 TO 3-33.

Fig. 3-29. Engine Mount for High Powered Inboard Runabouts and Larger Boats. Note Bulkheads and Additional Stiffening for Greater Strength and Rigidity.



FOR TRANSVERSE SECTIONS IN WAY OF ENGINE BEARERS SEE FIG. 3-31 TO 3-33

Fig. 3-30. Engine Mount for Cruising Sailboat - Longitudinal or Transverse Stiffening of Shell Outboard may be required to prevent excessive vibration

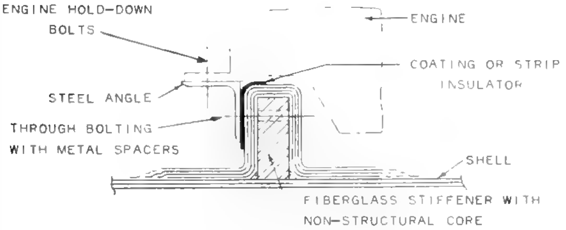


Fig. 3-31. Engine Bearer - Steel Angle Bolted to Hat Stiffener

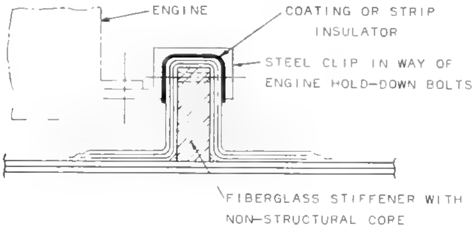


Fig. 3-32. Engine Bearer - Steel Clip Bolted to Hat Stiffener

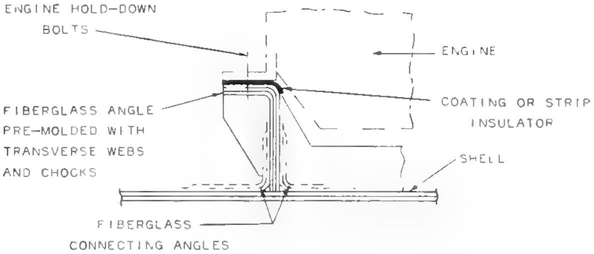


Fig. 3-33. Engine Bearer - Pre-molded Fiberglass Angle Bonded to Shell

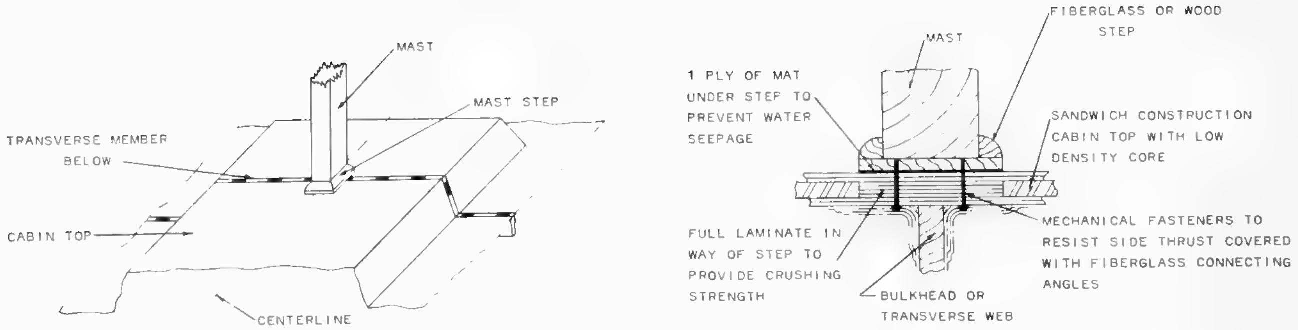


Fig. 3-34. Cabin Top Mast Step - Fiberglass or Wood

but in fiberglass construction this heavy member is not necessary and a substantial step or hull reinforcement must be added. Since definite advantages are gained in accommodation arrangement, many fiberglass cruising sailboats have the mast stepped on the cabin top or deck. The support under the cabin top must, however, be very carefully determined. The most satisfactory solution is to locate the mast directly over a bulkhead. If this cannot be done, then a heavy transverse beam with adequate end supports must be provided. Figs. 3-34 through 3-37 illustrate recommended details of mast steps.

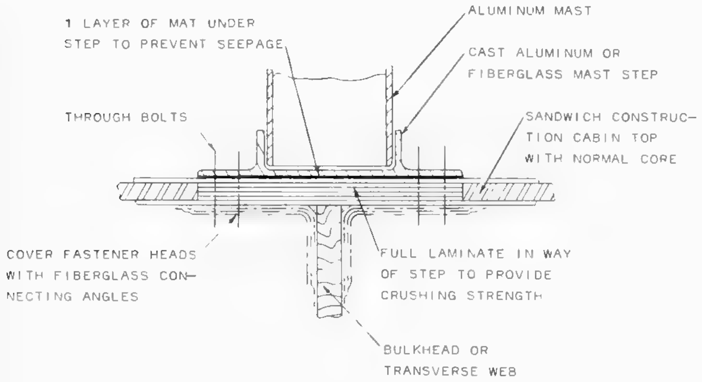


Fig. 3-35. Alternate Cabin Top Mast Step - Aluminum

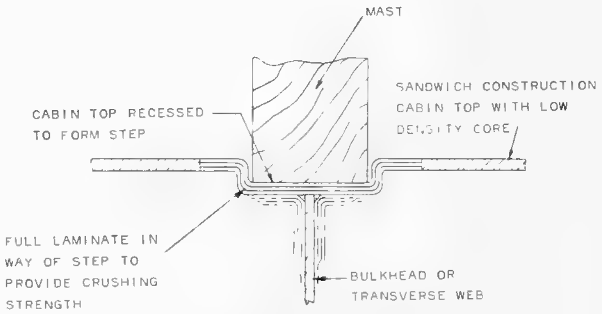


Fig. 3-36. Alternate Cabin Top Mast Step with Recess

Pulling Loads

The principles involved in developing foundations to resist pulling loads are, in some respects, similar to those discussed for the pushing loads. The load must be spread over a large area to avoid high local stress. The direction in which the load will be applied is very important. In some cases, particularly standing rigging connections, this can be very accurately established. In other cases, such as, mooring cleats and so on, it is dangerous to assume that the loading direction will always be the sensible or obvious one. Granted that lines should run from the cleat to the chock and from there over the side, they may not always do so. The foundation should therefore be designed on the basis of line directions which are physically possible, rather than those which are considered customary. The amount of load to be applied to a foundation of this type may be considered on one of two bases. Either the normal line pull is arrived at by some service or operational criterion and the foundation designed to withstand this load with a substantial factor of safety, or the breaking strength of the line is applied and the foundation is designed to withstand this load with a small factor of safety. The basic requirement is that the loading line should break without causing permanent deformation of the supporting hull structure. Considering this, the use of the breaking strength of the line is preferred and is the most commonly used design criterion.

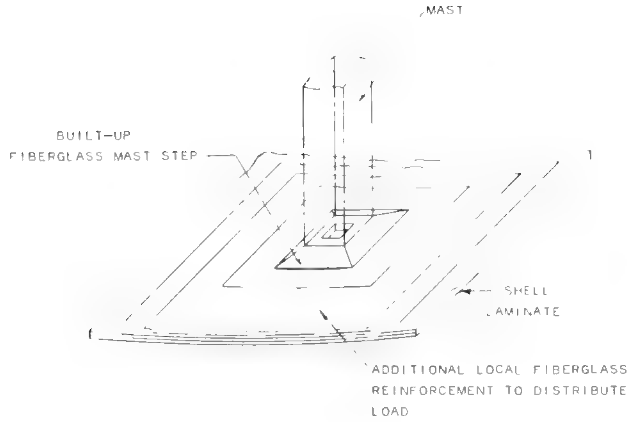
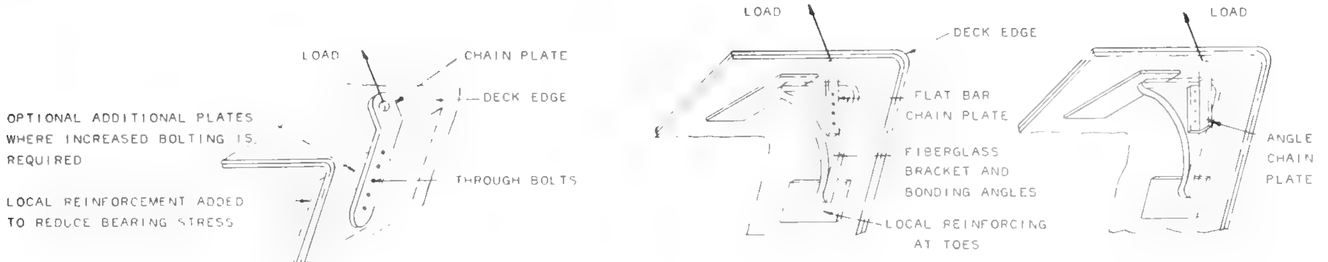


Fig. 3-37. Mast Step at Bottom of Boat
Note Taper of Fiberglass Mast Step to
Reduce Hard Spot

Figs. 3-38 through 3-41 indicate a number of different attachments. Note that, wherever possible, the fittings should be located near a structural strong point in the boat such as, a frame, bulkhead or the deck edge. These locations simplify the design of a satisfactory foundation and avoid interferences with the arrangement of the boat.

The detail design of bolted and threaded fastener connections is discussed later in this Chapter. Where attachments become a permanent part of the structure, the bolt heads and nuts may be sealed with resin or covered with a ply of reinforcement.



a. SIMPLE EXTERIOR SIDE STAY CHAIN PLATE. SIMILAR DETAIL IS USED AT THE BOW FOR FORE STAY CHAIN PLATES

b. INTERIOR SIDE CHAIN PLATE. CHAIN PLATES MAY BE CONNECTED TO A TRANSVERSE BULKHEAD, OR THE BOTTOM OF THE BRACKET MAY BE CONNECTED TO A LONGITUDINAL FRAME. BOTH ARE IMPROVED CONSTRUCTIONS. CONSTRUCTION SHOWN IS CONSIDERED THE MINIMUM ACCEPTABLE. A SIMILAR DETAIL IS USED ON THE TRANSOM FOR BACK STAY CHAIN PLATES.

Fig. 3-38. Chain Plate Attachments

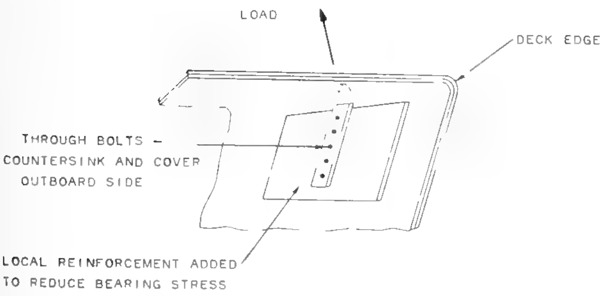


Fig. 3-39. Chain Plate Attachments -
Simple Interior Side Stay Chain Plate

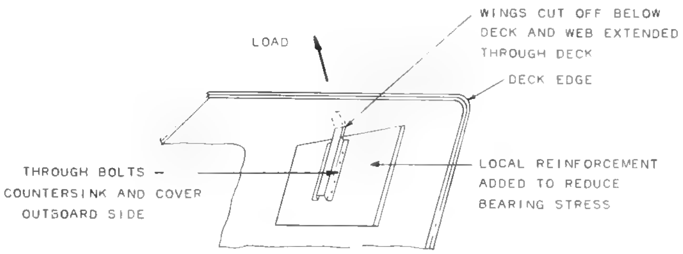


Fig. 3-40. Chain Plate Attachment -
Wing Channel Side Stay Plate

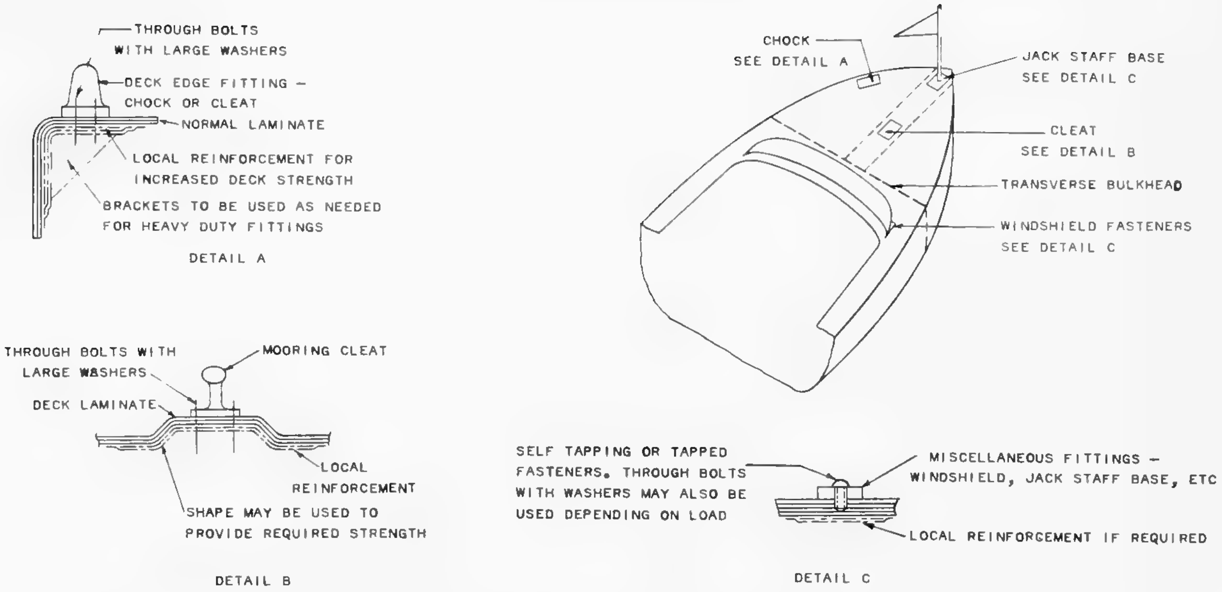


Fig. 3-41. Attachment of Fittings

APPENDAGE CONNECTIONS

Rudder

The attachment of the rudder to the hull is one of the most important connections which must be made, and an extremely conservative design is recommended. Consequences of failure are so serious that the additional cost and weight for an excessively strong joint is more than justified. The loading on the rudder may be determined by standard formulas contained in the usual naval architectural texts. In the case of rudder configurations using gudgeons and pintles, which are often standard pieces, it is recommended that the attachment to the hull be designed so that the pintle will fail before permanent damage is done to the hull. Figs. 3-42 and 3-43 indicate standard methods for these connections.

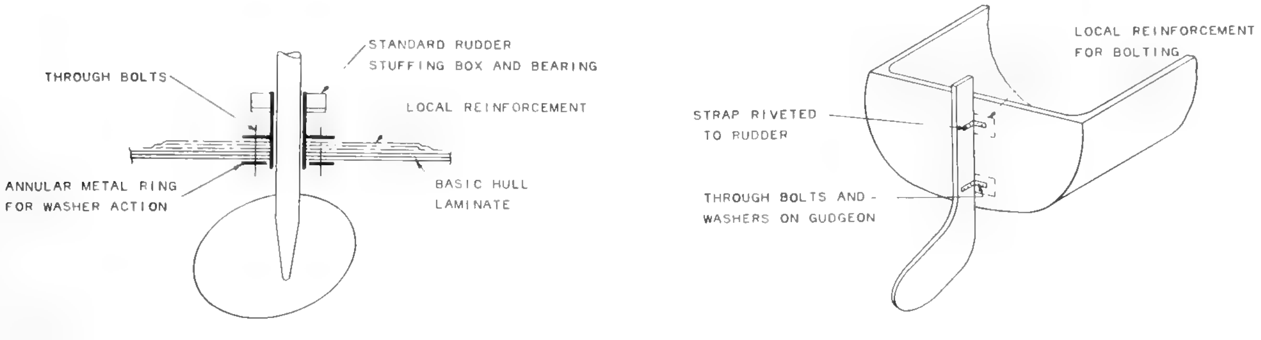
Shaft

One of the most frequent causes of annoying leakage and excessive noise in small boats is the passing of the propeller shaft through the shell. The problems associated with this connection usually arise from poor workmanship, rather than structural inadequacy. The designer can help insure proper workmanship, however, by providing a design for the shaft support and connection to the hull which is simple and easy to install.

The shaft passes through the hull in the conventional manner in a standard type bearing. Normally, the shell laminate is completed, the hole for the bearing drilled out and the bearing bonded in place with an adhesive. Some epoxy resins, because of their greater strength and higher resistance to water penetration, are recommended, but polyester resins have been successfully used. If required, local reinforcement can be added to build up the laminate for proper seating of the bearing flange.

OUTFIT CONNECTIONS

On any small boat there are many small miscellaneous items which primarily contribute to the usefulness or appearance of the craft. These items include windshields, windows, flagstaff fittings, rubber treads, floor boards, etc. The common fastener for attaching these items is the self-tapping screw. The only requirement for most of these fittings is that the laminate be thick enough to retain the screw. In the case of windows, the fastenings should be designed so that the window will withstand the same loadings as the area to which it is attached. This is particularly important where shell ports are used.



a. SPADE RUDDER – ORDINARY SKEG RUDDER SIMILAR

b. SMALL SAILBOAT – GUDGEON AND PINTLE

Fig. 3-42. Rudder Connections

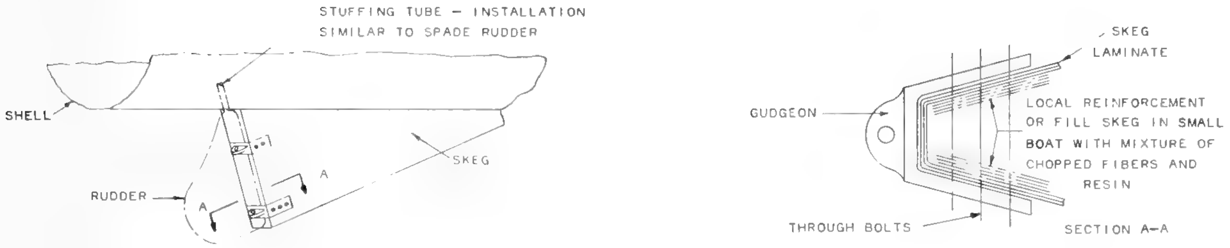


Fig. 3-43. Rudder Attachment for Large Cruising Sailboat

MECHANICAL FASTENERS

In designing connections utilizing mechanical fasteners, it is necessary to provide adequate strength to prevent failure of the fastener or the laminate retaining the fasteners. Through bolts and threaded fasteners, sometimes used with a bonding adhesive, are the most commonly used with reinforced plastics. The selection of the type of fastener to be used depends on the load, laminate strength and thickness, location in the boat hull, desired appearance of the finished hull, and ease of disassembly when necessary.

Bolted Connections

For bolted connections, several types of laminate failures may occur before the full strength of the bolt is attained. These failures are tearing from the bolt hole to the edge of the laminate, tearing the laminate along the line of the bolt holes and shearing a plug between the bolt hole and the edge of the laminate. Laminate failures may be avoided by using the proper spacing of bolts, both with respect to each other and with respect to the edge and side of the laminate. The dimensions used are defined in Fig. 3-44.

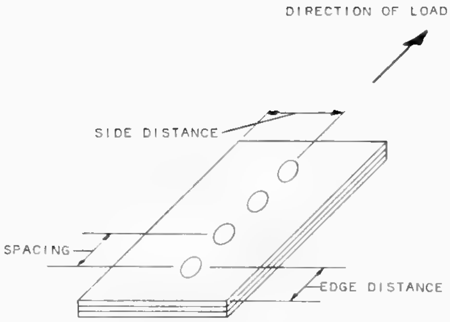


Fig. 3-44. Edge and Side Distances and Spacing for Bolt Type Fasteners

The required distances, in terms of the bolt diameter, are given in Table 3-1.

TABLE 3-1 - MINIMUM EDGE AND SIDE DISTANCES AND BOLT SPACING

Type of Reinforcement	Edge Distance	Side Distance	Spacing
Woven Roving & Cloth	2.5 diameters	2.5 diameters	3 diameters
Mat	2.0 diameters	2.0 diameters	3 diameters

If the above distances are used, failure of the connection will occur by local laminate crushing under the bolt or shearing of the bolt (1).

Table 3-2 gives crushing strengths in way of bolts as a function of ultimate tensile strength of the laminate for woven roving, cloth and mat reinforcement. To determine the maximum bearing stress at the bolt which the laminate will withstand without permanent deformation, or without complete breakdown, multiply the ultimate tensile strength of the laminate by the number given in the "No Permanent Deformation" or "Maximum Load" column respectively in Table 3-2. If several types of reinforcement are used in the laminate, the bearing stress value should be determined by appropriate tests. In the absence of specific test information, the bearing stress value may be determined for each type of reinforcement, and the lowest of these values applied to the whole laminate. This method of calculation will give conservative values. The values given have been extracted from test data for laminates 1/4 inch thick with 1/4 inch bolts. Thinner laminates especially in ranges below 1/8 inch, or larger bolt diameter to thickness ratios, will tend to reduce these values. The use of a bolt diameter to thickness ratio of 2 reduces these values by about 65 per cent for the proportional limit and 70 per cent for the maximum load. The information given here is based on test results reported in References (2) and (3).

TABLE 3-2 - LAMINATE BEARING STRENGTH

Type of Laminate	Laminate Thickness	Bolt Dia.	No Permanent Deformation	Maximum Load
Woven Roving or Cloth	1/4"	1/4"	.641*	.914*
Mat	1/4"	1/4"	1.87*	2.89*

*Bolt bearing stress divided by laminate ultimate tensile strength.

Threaded Fasteners

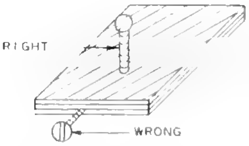


Fig. 3-45. Right and Wrong Direction for Threaded Type Fasteners

Whenever threaded type fasteners are used in fiberglass laminates, the fastener should always be perpendicular to the plies of reinforcement. Edge fastening should never be used, since this tends to delaminate the fiberglass laminate and has very little strength. Fig. 3-45 indicates the right and wrong directions for fasteners.

The strength of threaded fasteners in fiberglass laminates depends on a number of factors including the type of laminate, type of fastener, depth of penetration, diameter of fastener, size of pilot hole, and direction of loading. Tests (1) have been made on two basic directions of loading: axial, which tends to pull the fastener directly out of the laminate; and transverse, which pulls sideways on the fastener. Fig. 3-46 clarifies these loading directions.

a. AXIAL LOAD

b. TRANSVERSE LOAD

Fig. 3-46. Threaded Fastener Loading Directions

Also indicated in Fig. 3-46 is the "depth of penetration" as defined for both blind and through holes.

When used in fiberglass laminates, threaded fasteners should have edge and side distances equal to 2-1/2 times the fastener diameter, and a spacing of 3 times the fastener diameter. Distances are measured as indicated for bolted joints, Fig. 3-44.

Tables 3-3 and 3-4 give ultimate strengths for axial and transverse loading for three types of threaded fasteners. Table 3-3 gives strengths for fasteners in 10 ounce cloth-polyester resin laminates having the following range of physical properties:

Tensile Strength	30,000 to 45,000 PSI
Edge Compressive Strength	18,000 to 27,000 PSI
Shear Strength (Perpendicular)	14,000 to 17,000 PSI

Table 3-4 gives strengths for fasteners in mat-polyester resin laminates having the following physical properties:

Tensile Strength	6,000 to 25,000 PSI
Edge Compressive Strength	10,000 to 22,000 PSI
Shear Strength (Perpendicular)	10,000 to 13,000 PSI

Table 3-4 should also be used for woven roving laminates.

For laminates reinforced with various types of reinforcement, the table giving the lowest strength should be used. These tables give fastener type, size, recommended minimum penetration; below this amount strengths are erratic and unreliable; strengths for this minimum penetration, and maximum strength and penetration. Straight line interpolation may be used between these values. Penetrations greater than the given maximum do not increase the strength.

Fasteners given are standard steel machine screws, and self-tapping screws of two types, thread forming and thread cutting. Drilling and tapping of holes for machine screws should be in accordance with normal practice. The drilling of pilot holes for the self-tapping screws was investigated and it was found that, in general, the smallest hole which permits the screw to be driven without excessive difficulty gives the best results. The use of either larger or smaller holes results in decreased strengths.

The use of the tables is illustrated by Design Example 3-1. It must be noted that the strength values given are for load at failure and a reasonable factor of safety must therefore be applied as shown in the example.

DESIGN EXAMPLE 3-1 - USE OF TABLES FOR DETERMINING THREADED FASTENERS

A pad eye is to be fastened to a 1/2 inch thick mat laminate, and the pad eye holds a line with a breaking strength of 1500 pounds applied normal to the laminate. The pad eye is held to the laminate by 4 fasteners, which cannot penetrate the laminate. The problem is to determine the type and size of fastener to use.

If equal load distribution is assumed, each fastener must support 1/4 of the load, or 375 pounds. When the breaking strength of the load applying part is used a relatively small factor of safety may be used; assume 2 for this problem. The choice of factor of safety is discussed in Chapter 6. Each fastener must therefore be designed to support an ultimate load of 2 x 375 or 750 pounds.

As a first trial, take a number 4-40 thread cutting self-tapping screw, at a 3/8 inch maximum penetration from Table 3-4.

Axial holding force for minimum 2/16 inch penetration = 80 pounds

Axial holding force for maximum 7/16 inch penetration = 900 pounds

Axial holding force for 3/8 inch = 6/16 inch penetration =

$$80 + 4/5\ (900 - 80) = 736 \text{ pounds}$$

Since 736 pounds is less than the 750 pound ultimate load, this fastener is not satisfactory.

By repetition of the above calculation for different fasteners, the 6-32 self-tapping, thread cutting screw is found to be satisfactory. If the maximum allowable depth of penetration is increased to 7/16 inch the 4-40 fastener will be satisfactory.

Attachments to sandwich construction, decks or bulkheads, require special treatment, since lightweight core materials cannot retain threaded fasteners and may be crushed when

TABLE 3-3 - HOLDING FORCES OF FASTENERS IN 10 OUNCE CLOTH - POLYESTER LAMINATES (1)

	Axial Holding Force				Transverse Holding Force			
	Minimum		Maximum		Minimum		Maximum	
Fastener Size Thds.	Depth of Penetration 16th in.	Force lb	Depth of Penetration 16th in.	Force lb	Depth of Penetration 16th in.	Force lb	Depth of Penetration 16th in.	Force lb
MACHINE SCREW								
4 - 40	1	90	3	500	1	180	2	350
6 - 32	1	110	4	700	1	220	2	450
8 - 32	2	230	5	1000	1	280	3	880
10 - 32	2	260	6	1500	2	750	3	1100
1/4 - 20	2	320	8	2700	2	1000	4	1800
5/16 - 18	3	520	10	4000	2	1350	6	2000
3/8 - 16	3	620	11	4850	3	2600	7	3300
7/16 - 14	4	950	13	6800	3	3000	9	4500
1/2 - 13	4	1100	15	7720	4	4500	10	6000
9/16 - 12	5	1600	16	9000	5	6000	12	9000
5/8 - 11	5	1750	18	11600	5	6500	13	10000
3/4 - 10	6	2500	22	24000	6	8000	16	15000
SELF TAPPING - THREAD CUTTING SCREW								
4 - 40	2	140	6	1000	2	300	3	350
6 - 32	2	180	7	1300	3	500	4	650
8 - 32	4	420	12	2800	3	650	6	1500
10 - 32	4	460	12	3200	4	1000	8	2300
1/4 - 20	5	500	15	4200	6	2000	12	3400
SELF TAPPING - THREAD FORMING SCREW								
4 - 24	2	50	5	500	2	250	3	500
6 - 20	3	120	8	1200	2	260	4	530
8 - 18	3	170	11	2400	3	600	6	1000
10 - 16	4	290	13	3300	3	700	8	1800
14 - 14	4	400	15	4600	4	1300	11	3200
5/16 - 18	5	670	17	5700	5	2600	13	5100
3/8 - 12	6	1000	18	6400	6	4400	16	8400

Laminate Mechanical Properties

Tensile Strength	30000 to 45000 PSI
Edge Compressive Strength	18000 to 27000 PSI
Shear Strength (Perpendicular)	14000 to 17000 PSI

TABLE 3-4 - HOLDING FORCES OF FASTENERS IN MAT - POLYESTER LAMINATES (1)

	Axial Holding Force				Lateral Holding Force			
	Minimum		Maximum		Minimum		Maximum	
Fastener Size Thds.	Depth of Penetration 16th in.	Force lb	Depth of Penetration 16th in.	Force lb	Depth of Penetration 16th in.	Force lb	Depth of Penetration 16th in.	Force lb
				MACHINE SCREW				
4 - 40	2	40	5	450	1	150	2	290
6 - 32	2	60	6	600	1	180	2	380
8 - 32	2	100	7	1150	1	220	3	750
10 - 32	2	150	8	1500	2	560	4	1350
1/4 - 20	3	300	10	2300	3	1300	5	1900
5/16 - 18	3	400	12	3600	3	1600	7	2900
3/8 - 16	4	530	14	5000	4	2600	10	4000
7/16 - 14	4	580	16	6500	5	3800	12	5000
1/2 - 13	4	620	18	8300	6	5500	14	6000
9/16 - 12	4	650	20	10000	7	6500	15	8000
5/8 - 11	4	680	22	12000	7	6800	16	11000
3/4 - 10	4	700	24	13500	7	7000	17	17000
				SELF TAPPING - THREAD CUTTING SCREW				
4 - 40	2	80	7	900	2	250	3	410
6 - 32	2	100	7	1100	2	300	4	700
8 - 32	4	350	12	2300	3	580	6	1300
10 - 32	4	400	12	2500	3	720	7	1750
1/4 - 20	6	600	17	4100	4	1600	10	3200
				SELF TAPPING - THREAD FORMING SCREW				
4 - 24	2	50	6	500	2	220	3	500
6 - 20	3	110	10	850	2	250	4	600
8 - 18	4	180	13	1200	3	380	5	850
10 - 16	4	220	15	2100	4	600	8	1500
14 - 14	5	360	17	3200	4	900	11	2800
5/16 - 18	6	570	18	4500	5	1800	13	4400
3/8 - 12	6	700	18	5500	6	3600	16	6800

Laminate Mechanical Properties

Tensile Strength	6000 to 25000 PSI
Edge Compressive Strength	10000 to 22000 PSI
Shear Strength (Perpendicular)	10000 to 13000 PSI

nuts on bolts are pulled up too tightly. For these fasteners, an insert or build-up of solid fiberglass laminate should be used to replace the lightweight core material. Fig. 3-47 indicates this insert construction. Plywood, hard wood, filled resin, and metal inserts have been used, but are not recommended.

An alternate method for the attachment of fittings is the use of a through bolt with a special sleeve. This construction is shown in Fig. 3-48. The sleeve is used to increase the bearing area, and to provide a spacer so that the sandwich core cannot be crushed by indiscriminate tightening of the nut. Local reinforcement of the skins to increase bearing area may be necessary.

The attachment of heavily loaded fittings to sandwich construction can be accomplished by the use of through bolting, combined with solid fiberglass inserts or build-up between the skins. The solid fiberglass insert or build-up should be made as large as required to distribute the load over a greater area of the sandwich panels.

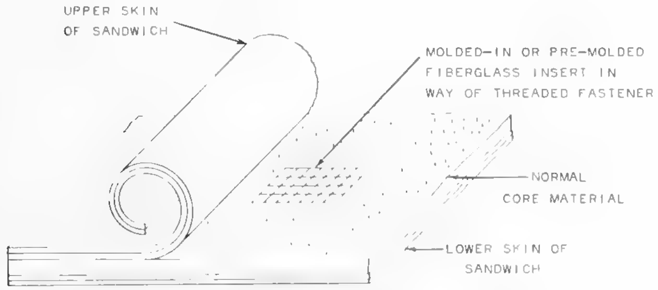


Fig. 3-47. Fiberglass Insert for Threaded or Bolted Fastener in Sandwich Construction

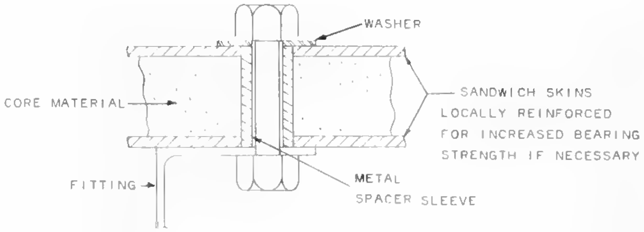
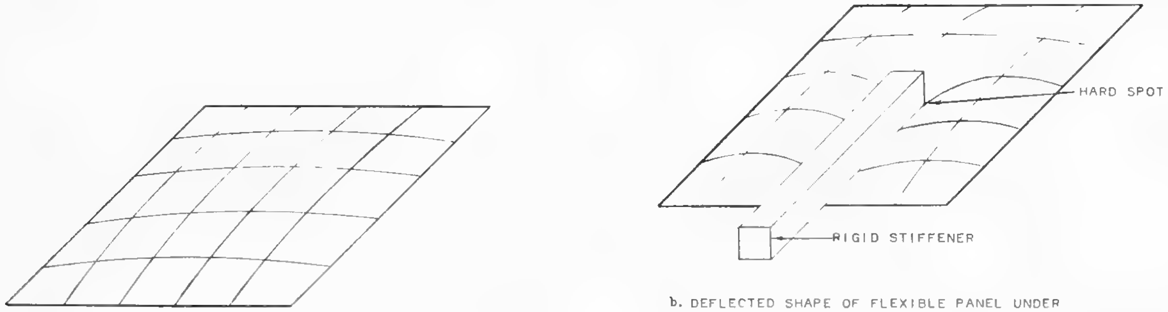


Fig. 3-48. Through Bolting in Sandwich Construction

TROUBLE CAUSING DETAILS

This Chapter has endeavored to show recommended construction details. The importance of good design details cannot be over-emphasized, since many of the difficulties experienced with fiberglass boats in the past can be traced directly to the use of improper details. Improper details can be easily corrected before construction but are very difficult to correct after the boat is built. No list of "things not to do" can cover all the possibilities, but a discussion of the principal classifications of trouble causing details should enable the designer to avoid major difficulty.



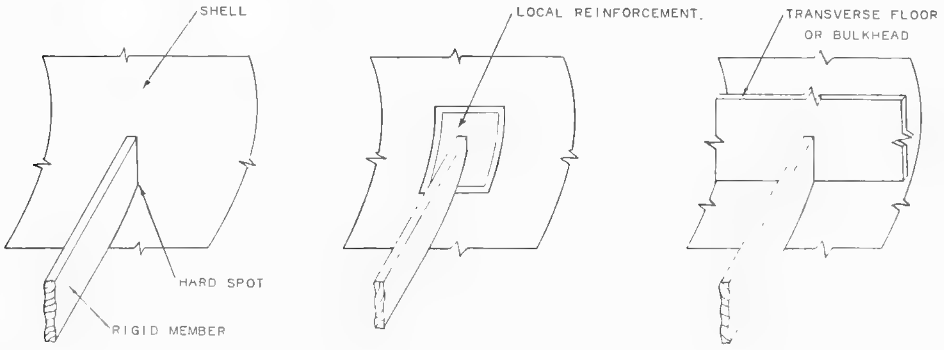
a. DEFLECTED SHAPE OF FLEXIBLE PANEL UNDER UNIFORMLY DISTRIBUTED TRANSVERSE LOAD NO STIFFENING — NO HARD SPOT

b. DEFLECTED SHAPE OF FLEXIBLE PANEL UNDER UNIFORMLY DISTRIBUTED TRANSVERSE LOAD WITH RIGID STIFFENER. NOTE ABRUPT CHANGE IN DEFLECTED SHAPE AT END OF STIFFENER WHICH CAUSES HIGH STRESS CONCENTRATION

Fig. 3-49. Hard Spot Due to Abrupt Ending of Stiffener on Shell

Hard Spots

Probably the major single trouble-maker in fiberglass construction is the so-called "hard spot." A hard spot is any isolated rigid point of support in a shell panel, and is caused when the shell panel attempts to flex under load but is prevented from doing so locally by a rigid support. This in turn causes an abrupt change in the deflected shape with very high local stresses, Fig. 3-49. These stresses can cause damage to the laminate and, in extreme cases, actual cracking of the shell will result. Examples of hard spots include abrupt endings of stiffeners in the middle of a shell panel and abrupt endings of partial bulkheads. The best cure for hard spots is to avoid them by continuing the offending member to another point of support, as extending a longitudinal to the next transverse member, Figs. 3-50 and 3-51. An alternate, of considerably less merit, is to taper the end of the member and to provide additional layers of reinforcement locally under the hard spot to reinforce the shell. This should be done at the junction of the shell with bulkheads and interior decks to prevent the formation of a hard line as indicated in Fig. 3-24. Location of bunks, seats, etc., against the shell should also be avoided to prevent hard spots, unless each connection is treated to minimize the abrupt change in panel deflection by local reinforcement.

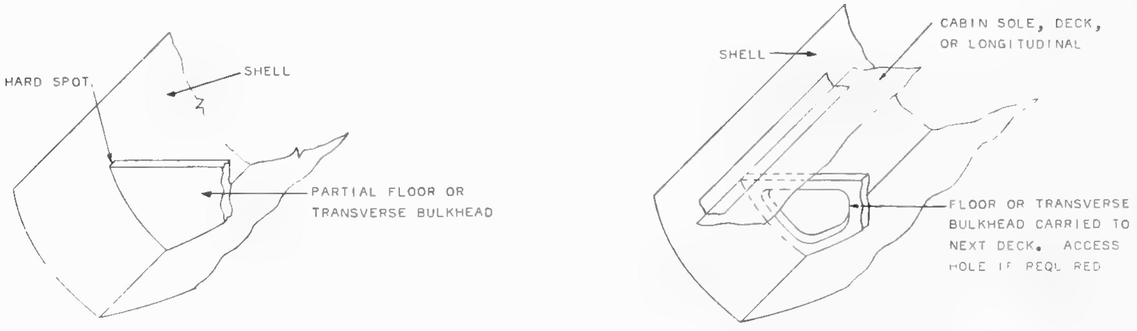


a. NOT ACCEPTABLE
FULL DEPTH LONGITUDINAL ENDING IN UNSUPPORTED PANEL

b. BETTER BUT TO BE AVOIDED
LONGITUDINAL TAPERED TO REDUCE RIGIDITY. LAMINATE REINFORCED LOCALLY AT HARD SPOT

c. BEST
LONGITUDINAL ENDS AT STRUCTURAL TRANSVERSE MEMBER

Fig. 3-50. Hard Spot - Longitudinal Endings

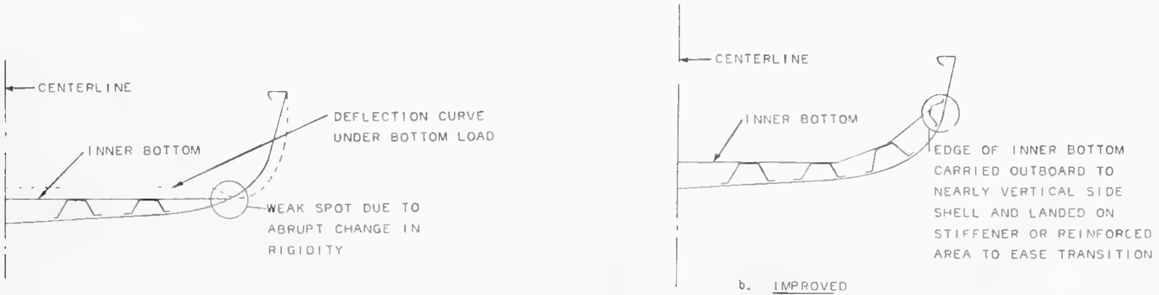


a. NOT ACCEPTABLE

b. ACCEPTABLE

Fig. 3-51. Hard Spot - Partial Floor or Transverse Bulkhead

A final type of hard spot is one which is not at first obvious, but which could easily cause failure in a high speed runabout. The condition, shown in Fig. 3-52a, occurs in double bottom construction, which is relatively very stiff and intended to reduce bottom deflection. The inner skin, usually a built-in flat, ends at the outer shell on the bottom of the hull instead of being carried over to the side shell. This, in effect, means that the stiff doubled portion of the bottom of the hull will deflect as a unit, and modify the deflection curve which would exist if the hull were single skin throughout. The junction of the two sections then becomes a hard spot liable to failure. The solution to the problem is to run the inner bottom to the side as shown in Fig. 3-52b, even at the cost of introducing a slight slope to the outboard portion of the inner skin.



a. POOR

b. IMPROVED

Fig. 3-52. Double Bottom Arrangement

Stress Concentrations

A major problem in all structural design is stress concentration. The usual design formulas give stresses based on the assumption that the member being considered is of uniform, or at worst gradually changing shape. When an abrupt change in shape occurs, such as a hole, sharp bend, or a lap joint in a tension member, stresses much higher than simple standard calculations indicate can occur. As explained in Chapter 5, this is particularly important in fiberglass design because of the material's lack of ductility.

The nature of a reinforced laminate is such that discontinuities causing stress concentrations are often introduced by the laminating process. For instance, a change in the number of plies of reinforcement, small laps between adjacent pieces of reinforcement, thick and thin spots in mat, voids and resin rich or poor areas are all examples of discontinuities in the material which should be avoided or compensated for. In the case of the change in the number of plies, the over-all thickness of the laminate determines the degree of severity of the discontinuity. A change from 8 to 9 plies is obviously less serious than a change from 8 to 4 plies. Abrupt changes in the number of plies such as 8 to 4 will create a high stress concentration which can be easily avoided by gradually reducing the plies with a generous distance between endings.

There exists a considerable amount of theoretical and experimental data and experience on stress concentrations in elastic, isotropic materials, to assist designers in determining their effect and to establish design rules. Unfortunately, similar technical information does not exist for fiberglass laminates. Some experimental work (4) has been done with laminates reinforced with 181 glass cloth only, and the number of samples tested for each configuration was limited. Therefore the effects of differences in reinforcements as well as variations in fabrication could not be evaluated. These effects must be considered when laminates reinforced with different types of reinforcement are used.

The major causes of stress concentrations in any material are holes, notches, and abrupt changes in the geometric property, such as, area or section modulus, which controls the stress in the cross section being considered. If holes must be cut, they should be kept as small as possible in relation to the size of the member. If a transition must be made in the depth of a shell longitudinal, it should be made gradually, preferably, at a 4 to 1 slope.

Re-entrant corners, generally called notches, should be avoided whenever possible, and if they must exist should have a generous radius. Fig. 3-53 indicates a re-entrant corner.

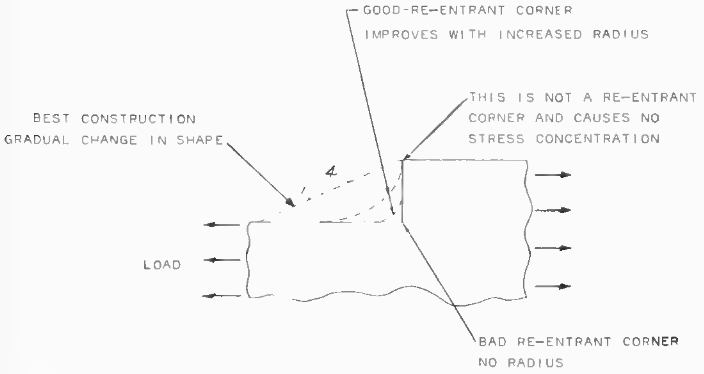
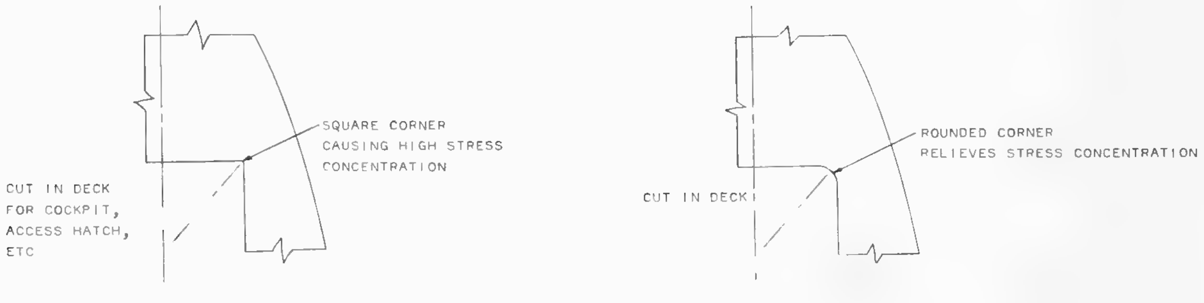


Fig. 3-53. Re-entrant Corner due to Change in Shape

A common source of difficulty in steel vessels is the high stress concentration at the corner of a rectangular or square hole. These corners are always given generous radii to reduce this stress concentration. The experimental work with glass cloth laminates (4) indicates, surprisingly, that for 181 cloth laminate a round cornered cut has slightly less strength than a cut of the same over-all size with square corners. No explanation is given for this seeming discrepancy, but it is presumed to be due to the orthotropic properties of the laminate. Since the reported difference between strength for square and round corners is small for orthotropic materials and since most boat laminates contain mat, which is essentially an isotropic material that should be much stronger with rounded corners, it is recommended that square or rectangular cuts in boat structure be provided with corner radii, as indicated in Fig. 3-54b.



a. NOT ACCEPTABLE

b. ACCEPTABLE

Fig. 3-54. Deck Cuts

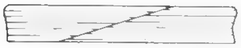
A common source of stress concentration due to structural discontinuity is the bonded joint. Table 3-5 obtained from (5) indicates, in broad categories, the stress concentration present in bonded joints between similar materials under three different types of loading. The loads indicated are tension (T), compression (C), and bending (M). Joints whose stress concentrations are listed as major for a particular type of loading should be avoided for major structural parts loaded in a similar way. When stress concentrations are listed as moderate, it is recommended that the joint be avoided unless the over-all stress level is kept low.

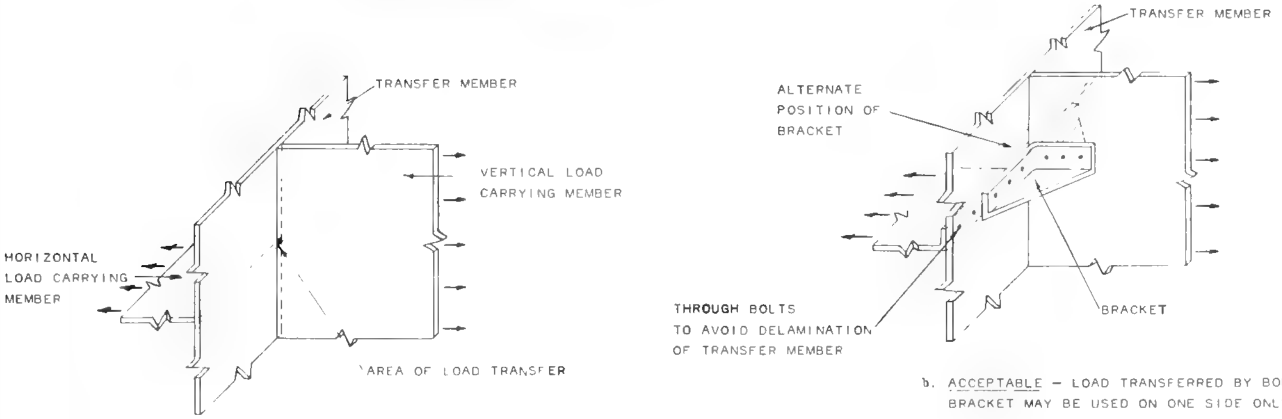
Notice the difference between the beveled joints and the unbeveled ones of the same type. This is an excellent illustration of the benefits of gradual changes in shape as opposed to abrupt changes.

Knife Edge Crossing

The knife edge crossing, illustrated in Fig. 3-55, is a problem which tends to occur often, and can be more serious in larger boats. As the figure indicates, the stress level in the load carrying members which meet at right angles to each other need not be high for this connection to be a trouble-maker, because the reduction in load carrying area is so great. The problem is magnified if the intervening member which must transmit the load is made of fiberglass laminate, because this intervening member is being loaded in the wrong direction, causing delamination, as was previously explained and indicated in Fig. 3-1. A bolted connection is used to avoid this delamination. Note how the introduction of small brackets increases the area of load transfer considerably.

TABLE 3-5 - STRESS CONCENTRATIONS IN BONDED JOINTS

JOINT	STRESS CONCENTRATION UNDER T	C	M
SCARF 	MINOR	MINOR	MAJOR
OFFSET LAP 	MAJOR	MAJOR	MAJOR
DOUBLE BUTT LAP 	MODERATE	MINOR	MAJOR
LAP 	MAJOR	MAJOR	MAJOR
DOUBLE BEVEL LAP 	MINOR	MINOR	MODERATE
INSET LAP 	MAJOR	MINOR	MAJOR
BEVELLED INSET LAP 	MODERATE	MINOR	MAJOR



a. NOT ACCEPTABLE – SMALL AREA OF LOAD TRANSFER

b. ACCEPTABLE – LOAD TRANSFERRED BY BOLTS. BRACKET MAY BE USED ON ONE SIDE ONLY AND MAY BE HORIZONTAL OR VERTICAL AS SHOWN.

Fig. 3-55. Knife Edge Crossing

REFERENCES

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(2) Werren, F. "Bolt Bearing Properties of Glass-Fabric-Base Plastic Laminate", U.S. Forest Products Laboratory Report 1824, June 1951

(3) Young, R.L. "Supplement to Bolt Bearing Properties of Glass-Fabric-Base Plastic Laminates", U.S. Forest Products Laboratory Report No. 1824-A, October 1955

(4) Strauss, Eric L. "Effects of Stress Concentration on the Strength of Reinforced Plastic Laminates", 14th Annual Technical and Management Conference, Reinforced Plastics Division, The Society of the Plastics Industry, Inc., February 1959

(5) Perry, H.A. "Adhesive Bonding of Reinforced Plastics" McGraw-Hill Book Company, Inc., 1959

4

Materials and Molding Methods

MATERIALS

Fiberglass laminates are essentially a combination of high strength glass fibers bonded together with relatively low strength resin. The glass fibers are distributed throughout the laminate and provide the strength to the combination. Although individual glass filaments can develop tensile strengths between 250, 000 and 400, 000 pounds per square inch, the mechanical distribution of the filaments in a laminate does not permit the combination to develop this strength.

Structural laminates usually contain 20 to 60 per cent by weight of fiberglass reinforcement. The strength of a laminate is primarily dependent upon the type and the amount of fiberglass reinforcement it contains. The amount or per cent of fiberglass reinforcement that can be placed in a laminate depends upon the molding process and type of reinforcement.

Other important factors affecting the strength of a laminate are the resin, chemical finish on the fiberglass filaments (1, 2) and the handling of these basic materials.

The selection of the type of reinforcement, resin and molding method should be made to meet the necessary requirements for a specific application. High unit strengths, comparable to other engineering materials such as wood, aluminim and steel, can be developed.

To obtain high stiffness weight ratio economically, molded-in stiffeners or sandwich construction are used. Sandwich panels are usually made by bonding fiberglass laminate facings to various low density core materials such as honeycomb, foam plastics, balsa wood and lightweight plastic spheres embedded in resin (3, 4).

Due to the rapid development and modifications of basic materials and molding methods, changes in the cost of materials, and variation of laminate construction will continuously occur in the future. Since such changes cannot be considered within the scope of this text, the following discussion is limited to presently available materials and molding methods.

To obtain maximum efficiency and economy, selection of basic materials and molding methods for specific applications should be in accordance with manufacturers' recommendations.

REINFORCEMENTS

The glass filament used in boat hull construction is a lime-alumina borosilicate E glass of low alkali content which has high chemical stability and moisture resistance. It is commonly known as E glass because of its initial development for electrical applications.

Usually, fiberglass filaments .00020 to .00100 inches in diameter, with most plastic reinforcement filaments averaging 0.00040 inches, are manufactured in parallel bundles known as strands. The strands usually consist of 204 fine glass filaments drawn together without twisting. The basic strands of glass filaments are used to make all of the different types of fiberglass reinforcements (1, 5). The types used in boat construction are roving, chopped strand mat, cut strands, cloth and woven roving. Table 4-1 presents current uses of the various types of reinforcements in boat hull construction.

Rovings

Rovings consist of straight bundles of continuous strands resembling a loose untwisted rope, Fig. 4-1. Rovings are one of the most economical forms of fiberglass reinforcements for boat construction.

Rovings are used as unidirectional reinforcement, woven into heavy coarse fabrics, chopped into short lengths for use in preforms and mats; or sprayed directly on the mold.

Unidirectional Roving: Consists of heavy uncrimped parallel bundles or rovings in the warp and a smaller number of thinner bundles in the fill which may be slightly crimped, Fig. 4-2. Nonwoven individual strands or rovings can also be laid parallel on the mold in alternate plies, at the same or predetermined angles, to obtain maximum efficiency in one or more directions.

Fig. 4-1. Fiberglass Roving of Continuous Filament Strands

Woven Roving: Consists of flattened bundles or rovings of fiberglass filaments 1/8 " to 1/4" wide, woven into a plain square pattern, Fig. 4-3. A number of different weave patterns are available ranging in weight from 14 to 27 ounces per square yard. Woven roving is not a cloth in the sense that the filaments are spun or twisted. The straight bundles of filaments are woven as strands. In general, the reinforcement in the warp direction is slightly greater than in the fill direction.

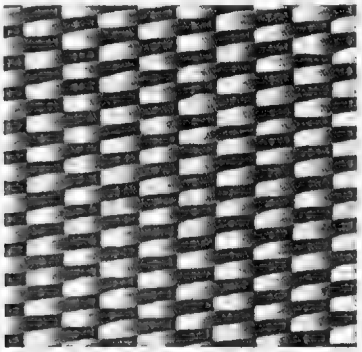

Fig. 4-2. Woven Roving Unidirectional Weave

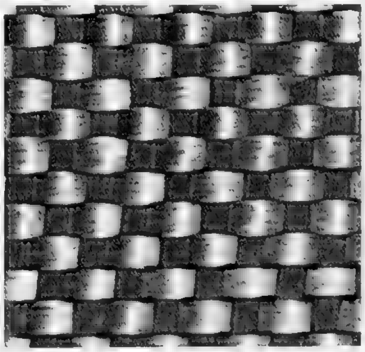

Fig. 4-3. Woven Roving Plain Weave

TABLE 4-1 - FIBERGLASS REINFORCEMENTS FOR BOAT HULLS

TYPE ( )( )	CONSTRUCTION	THICKNESS	WEIGHT	APPLICATION	MOLDING METHOD
Rovings					
Unidirectional	Greater number of strands in warp. Strands placed parallel to each other in one direction only.	As required		Additional strength in one direction. Usually placed locally, i. e. longitudinally at keel and deck to side connections. Stiffeners.	Contact Bag Autoclave Matched Die
Woven	Roving formed in heavy plain weave, slightly heavier in the warp direction.	.025-.043"	14-27 oz/sq. yd. 24-27 oz. most popular	Primary reinforcement for hull and deck.	Contact Bag
Chopped Fibers					
Mat	Random chopped fibers bonded together with resin binder or mechanically needled together.	.030-.080"	3/4 to 3 oz/sq. ft. 1-1/2 and 2 oz. most popular	Primary reinforcement for hull and deck. Reinforcement for bonded joints. Water barrier in cloth or woven roving laminates. High bulk for building thickness.	Contact Bag Autoclave Matched Die
Preforms	Random chopped fibers deposited over a preform screen and bonded together with resin binder.	As required		Primary reinforcement for hull and deck. Furnishings and hull components, i. e., seats, bunks, hatch covers, etc.	Autoclave Matched Die
Chopped Strands	Random chopped fiber mixed with resin. Fillers added as required for molding compounds.	As required		Primary reinforcement for hull and deck. High bulk for building thickness and filling small void spaces. Small parts, i. e., deck cleats, arm rests, trims, etc.	Fibers and resin deposited simultaneously on mold Contact Bag Matched Die
Cloth					
Weave	Plain square open weave with slightly greater number of strands in warp direction.	.008-.022"	7.5 to 19 oz/sq. yd. 10 oz. most popular	Primary reinforcement for hull and deck. Surface coat reinforcement. Local areas for additional strength in two directions.	Contact Bag
Unidirectional	Crowfoot satin weave with greater number of strands in warp.			Additional strength in one direction. Usually placed locally, i. e. longitudinally at keel and deck to side connections.	Contact Bag Autoclave Matched Die
Combinations					
Cloth and Mat	Fiberglass mat needled or mechanically stitched to cloth.		2 oz/sq. ft. mat with 10 oz/sq. yd. cloth most popular	Primary reinforcement for hull and deck.	Contact Bag
Rovings and Mat	Fiberglass mat needled to woven roving.		2 oz/sq. ft. mat with 24-27 oz/sq. yd. woven roving most popular	Primary reinforcement for hull and deck.	Contact Bag

References 1, 6 to 13 inclusive.

(*) All reinforcements to have a silane size or finish for maximum wet strength retention.

(**) Types of reinforcements presented in this table are currently being used in the molding methods discussed and are suggested for guidance only since types of reinforcement and molding methods are subject to change.

The physical characteristics of woven roving are not only different from those of mat but are also different from the properties of woven cloth.

Woven roving reinforcements cost more than mat, but are less expensive than cloth reinforcements.

The advantages of woven roving reinforcements are:

Good drapeability and handling characteristics in the contact or hand lay up molding method.

Provides a thicker build-up per ply of laminate than cloth.

Provides a high glass content per ply when molded by the contact molding method.

Has high directional physical strength and moduli for orientation in highly stressed areas.

Has extraordinary resistance to impact because of the greater number of untwisted strands in the individual bundles.

The disadvantages of woven roving reinforcements are:

The fine, tightly compacted filaments of glass strands in the woven roving are difficult to wet out or impregnate with resin. This can lead to insufficient bond between filaments within the individual bundles of rovings.

The coarse weave of woven roving can entrap air bubbles and form voids which tend to make the laminate porous and penetrable by water. This effect is especially noticeable in thinner laminates.

The coarse weave of woven roving can also cause resin rich areas between the individual bundles and layers of rovings. Resin rich areas are subject to brittle cracking, crazing, poor shear strength and poor interlaminar bond.

The high directional properties of woven roving are, for some considerations, a disadvantage. As the main directions of reinforcement in woven roving are in the warp and fill directions of the weave, the strengths at angles between these main directions are reduced as indicated in Chapters 5 and 6.

Spun Roving: Under development, but not included in the test program, is a new type of reinforcement designated "Spun Roving". Essentially this is one continuous filament strand entangled or looped around upon itself to give the equivalent weight of a standard parallel strand roving. Fabrics made from this spun roving resemble standard woven roving in appearance except that

Fig. 4-4. Fabric made from Spun Roving

they are somewhat more open in structure, Fig. 4-4. As a result, these fabrics are much easier to wet out. Strengths tend to be more isotropic than either woven roving or fiberglass cloths. Interlaminar shear strengths are improved. Limited test data indicates that these spun roving products are intermediate in their properties between standard chopped strand mats and woven rovings. Thickness per ply, using the contact or hand lay up molding method, are greater per unit of weight than woven roving, and are somewhat less than equivalent weight mat laminates.

Mat, Preforms and Chopped Strands

Mat: Consists of chopped strands of fiberglass, Fig. 4-5 randomly deposited, to form a sheet or layer. The layer of chopped strands is usually bonded or held together by a high solubility resin binder, compatible with molding resins, Fig. 4-6. Another type of mat does not use a binder, but is made from random strands of glass stitched together into a layer. During manufacture, needles are driven through the mat causing some of the glass strands to act as stitching.

Random fiberglass mat reinforcement is more economical than both woven roving and cloth reinforcements. Mats are available in weights of 3/4 ounce to 3 ounce per square foot. The 1-1/2 ounce and 2 ounce weights are the most suitable for boat hull construction since maximum economical build-up can be achieved with required conformity to hull forms and ease of material handling.

The advantages of mat reinforcement are:

Low cost per square foot and thickness.

Equal physical properties in all directions.

Good interlaminar bond due to interlocking action of fibers.

Can be molded or formed into moderate complex surfaces.

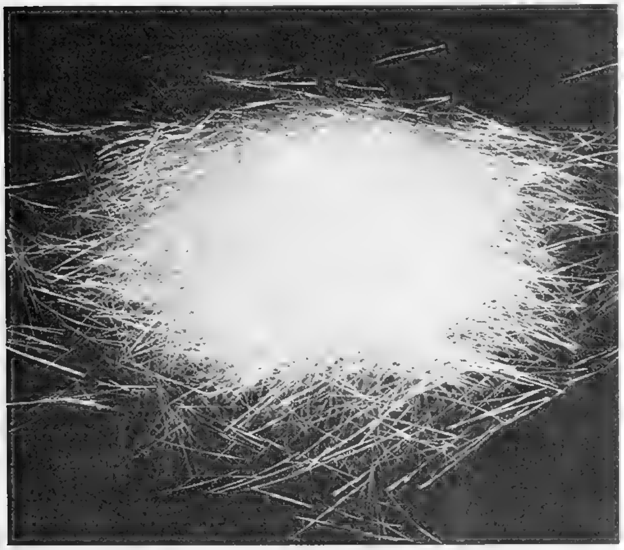

Fig. 4-5. Chopped Strands

Fig. 4-6. Mat - Resin Bonded

The disadvantages of mat reinforcement are:

Laminate thickness cannot be controlled accurately in contact molding.

Glass content, because of movement of the individual fibers during molding, becomes a variable and is somewhat difficult to control in contact molding.

In a polyester laminate, a typical mat fiber surface results because of polymerization shrinkage during cure of the resin, requiring surface finishing or a surface gel coat (1).

Contact molded mat laminates have a lower glass content than cloth or woven roving laminates which results in a lower modulus of elasticity for equal thicknesses. In order to overcome this deficiency, a thicker section is required.

In matched die molding uneven distribution of the chopped fibers and varying density can occur with deep draws and sharp corners.

Preforms: These are generally similar to mat except that they are slightly more expensive but are more practical for complex and deep draw matched die moldings. With preforms greater utilization of the reinforcement is obtained and the possibility of tearing, wrinkling and uneven glass distribution is reduced.

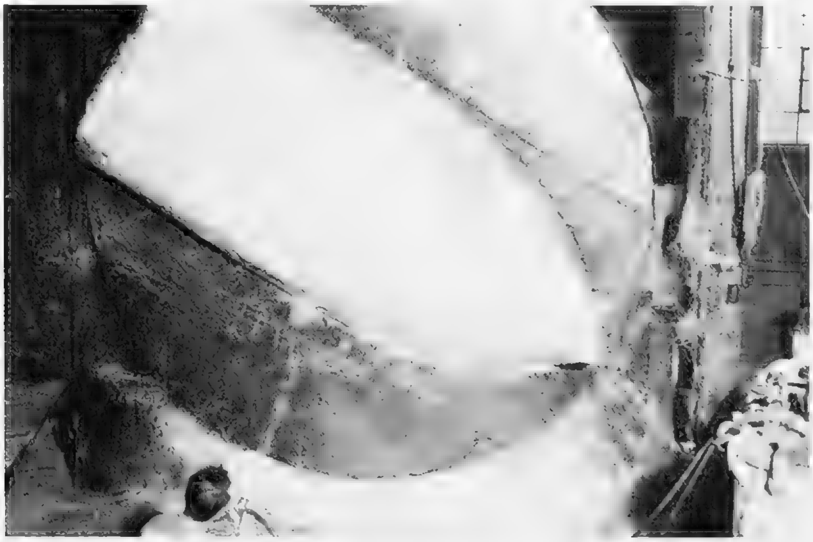

Fig. 4-7. Preform of 15' boat hull
(Courtesy Molded Fiberglass Boat Company)

Preforms are made by depositing chopped fibers of glass over a screen shaped in the form of the object to be molded (1, 14). Continuous rovings are cut into loose fibers which are randomly deposited on the screen by a stream of air drawn through it. Resin binder, compatible with the molding resin, is sprayed over the preform and cured to hold it together, Fig. 4-7. The preform is then removed from the screen and placed in the mold.

Chopped Strands: Some hulls and decks for small boats are presently being fabricated with chopped strands and resin simultaneously deposited on the mold from a spray gun.

Small inaccessible voids and areas requiring high bulk in small boats are usually filled with a pre-mix of chopped strands and resin.

Chopped strands mixed with mineral fillers and resins, form molding compounds readily adaptable to matched die moldings (1, 15). The resin, carrying the reinforcement, flows into place during the pressure molding process. These compounds can be used for molding small parts such as deck cleats, arm rests, trim, etc.

Cloth

Cloths and tapes are woven from twisted and plied strands of glass filaments. A wide range of weights and weaves are commercially available for special applications. Plain or square weaves, satin weaves and unidirectional weaves are among the available types. Good drape or shaping of some cloth reinforcements is possible but the material must be tailored to obtain proper location and orientation.

Plain Weave: Represents the simplest and commonest construction in woven cloth and is made in a number of styles. One cloth widely used in boat construction is a plain weave, weighing 10 ounces per square yard, and is commonly designated as boat cloth (6), Fig. 4-8.

Satin Weaves: Employ warp threads that pass over or under three or more fill threads giving high strength and directional properties, Fig. 4-9. Satin weave cloths are used primarily in the aircraft industry for obtaining very high strengths.

Fig. 4-8. Fiberglass Boat Cloth

Fig. 4-9. Satin Weave, 181 Cloth

Unidirectional Construction: Consists of a relatively large number of uncrimped and closely aligned heavy yarns in the warp, and a smaller number of light yarns in the fill, Fig. 4-10. This construction can be made in any style of weaves.

Fig. 4-10. Unidirectional Cloth

Cloth is presently one of the more expensive types of reinforcement but where consistency of high performance and structural efficiency in terms of strength to weight is required the cost can be justified.

The advantages of cloth reinforcements are:

> Cloth provides an effective surfacing material to cover woven roving and mat laminates to provide a better appearance and strength. One or several layers of cloth laid up over a rough surface laminate can improve the appearance of the finished hull.
>
> Cloth covered mat laminates can be fabricated by hand lay up, to work out excess resin and to obtain higher glass loadings.
>
> Cloth laminates and sections have the most consistent glass content, and have less deviation in physical properties and laminate thickness than any of the other types of fiberglass laminates.
>
> Cloth may also be used at high stress areas.

The disadvantages of cloth reinforcements are:

A resin rich bond may exist between heavier cloth plies which will cause weakness in interlaminar shear. As a result, a cloth laminate under edgewise compressive loading may fail by delamination.

Many layers of cloth are required for thick sections and, as a consequence, labor and time are increased.

Combinations

Fiberglass reinforcements are also manufactured in several combined forms. Two types of combined reinforcement are, mat stitched to cloth and mat stitched to woven roving.

The use of combined reinforcements has a number of advantages in boat hull construction. Mat stitched to cloth or woven roving improves the interlaminar bond of successive layers and reduces porosity. Combination reinforcements allow several plies to be laid up at one time.

Preimpregnated

Preimpregnated reinforcements, commonly called pre-preg materials, are reinforcements preloaded with resins. The resins are essentially the same as those used in normal operations where the resin is added to the reinforcement during molding (1).

The usual method for preloading is to pull the reinforcement through polyester or other molding resins and remove the excess resins by scrapper bars or squeeze rollers to control the glass to resin ratio. After resin impregnation, proper storage at low temperature is required to prevent the polyester resin from curing.

Depending on the application and cost, pre-pregs can be made by the fabricator or can be obtained to any desired specification from material suppliers.

The advantages of pre-pregs are:

Greater control of glass-resin ratios can be obtained.

Increased wetting of the glass fibers occurs.

Polyester resins of high viscosity can be used.

Resin wastage is reduced.

The disadvantages of pre-pregs are:

Additional equipment and storage facilities are required.

Storage life is reduced.

Tackiness may cause handling difficulties.

Sizes, Finishes and Binders

The terms size, finish and binder, due to the nature of their functions have been frequently confused by the end users of fiberglass. A size is a chemical treatment applied during manufacture to fiberglass filaments immediately after they are formed by drawing through the bushing orifices. A finish is a chemical treatment applied to a cloth after it is woven and cleaned. A binder is a bonding resin used to hold the chopped strands of fiberglass together in a mat or preform, during manufacturing, handling and molding.

Sizes and finishes are usually methacrylato chromic chloride types or unsaturated hydrolysis products of vinyl trichlorosilane (2, 7). These sizes and finishes are commonly known as "chrome" and "silane" types. Fiberglass filaments, used in the manufacture of mats, preforms and rovings, are usually sized with chrome or silane at the fiber forming machine.

The chief function of chrome and silane sizes and finishes is to improve the chemical bond between the molding resin and the glass filaments in the reinforcements. For the weaving of glass cloth, a different type of sizing is required to lubricate and hold the strand of filaments together during the weaving process. This sizing consists of oil, wetting agents and starch applied to the glass filaments during the forming operation. The lubricating action of this size assists in the weaving process and reduces the abrasion and the breaking of the glass filaments. Lubricating size for weaving is chemically non-compatible with the glass and resin and is detrimental to the bond between them. Therefore fiberglass cloth intended for high dry and wet strength laminates must be heat-treated or chemically washed to remove this size, and a chemically compatible finish be applied.

Silane sizes and finishes on fiberglass reinforcements are recommended in preference to chrome types for boat manufacture since greater laminate wet strength is obtained. Widely used silane finishes are Garan and A172.

The sizes, finishes and binders discussed are for use with polyester resins only. For epoxy resins, sizes and finishes should contain an aminosilane type similar to OCF-801 size and an A-1100 finish.

Several different binders are in common use (1). Highly soluble polyester resin binders are used on mat intended for boat construction by hand lay up.

RESINS

The resins most commonly used in the molding of fiberglass boats are thermosetting types. Thermosetting resins cannot be remolded once cured to the solid state. Thermosetting resins include polyesters, epoxies, phenolics and melamine.

With few exceptions, fiberglass boats are presently being made with polyester resins because of their cost advantage and versatility. Epoxy resins are being used in some boat hulls and will probably increase in usage (11).

Due to a wide variation in types of resins available, manufacturers maintain Research and Technical Service Departments for the assistance of fabricators of reinforced plastics. A large amount of technical data on resins is available from these sources. To obtain the highest quality laminates, manufacturer's recommendations for quantities and handling of resins, catalysts, accelerators and inhibitors should be followed. Deviation from the prescribed recommendations should only be made on the basis of extensive shop experience with the particular materials employed.

Polyesters

Polyester resins are formed by the reaction of polybasic acids and glycols. A wide variation in properties can be obtained by the use of various basic ingredients and proportions (5,7). The per cent elongation of the cured resin at rupture under tensile stress is used here as the basis for polyester classification.

Rigid Polyesters: These have higher physical strength properties than the more elastic types. Because of their flexural stiffness, rigid polyesters are used in applications such as smaller motorboat hulls having minimum framing where resistance to flexing under load is important. Rigid polyesters are more brittle and have less resistance to impact than the semi-flexible and flexible types. Cured non-reinforced rigid resins under tensile stress have an elongation at rupture between 0.5% to 3.0%.

Semi-Rigid Polyesters: These are compounded by the manufacturer to have greater resiliency and more resistance to impact and to retain much of the strength properties of the rigid type. A number of specialty polyesters, compounded for boat manufacture, fall into this classification. Semi-rigid polyesters are preferred for larger boat hulls exceeding 16 feet in length. In large boats the flexibility of the shell is controlled by spacing of the shell supports so that advantage may be taken of the improved impact resistance of semi-rigid polyesters. Semi-rigid, non-reinforced polyesters have an elongation at rupture of 3% to 10%. Polyesters with properties similar to semi-rigid types have been made by blending mixtures of rigid and flexible types. A blend of 90% rigid and 10% flexible polyesters has been commonly used in small boat construction. This mixture, which has been representative of good practice, is an arbitrary compromise between the strength and stiffness of the rigid type and the elastic flexible type (6).

Many fabricators prefer the single component, semi-rigid type for use in boat manufacture since it does not require mixing of the rigid and flexible components. Manufactured semi-rigid types have better resistance to aging than mechanical mixtures of rigid and flexible types.

Flexible Polyesters: These resins have an elongation exceeding 10 per cent at break and are both flexible and elastic. Due to their flexibility, they cannot be used alone in boat hull construction, but are often blended with rigid polyesters before molding.

Isophthalic Polyesters: These resins are a recent development of interest which exhibit faster curing time and somewhat better wet and dry properties than conventional polyesters (16). In general, isophthalic polyesters are better suited to pressure molding.

Self-extinguishing Polyesters: These resins are formulated to increase their resistance to fire (7, 17). They will not support combustion when the flame is removed.

Self-extinguishing polyesters are made from a number of compounds which are either additives to, or integral parts of the chemical structure of the resin. Included among these materials are chlorinated paraffins, tetrachloro phthalic anyhride, trichlorethyl phosphate, chlorendic "HET" acid, chloro maleic acid, organic phosphonates, and chlorinated styrenes (17). Antimony trioxide added to a polyester in small amounts, 1 to 5 per cent, is effective in increasing its fire resistance, particularly when used in connection with a chlorinated polyester. Some self-extinguishing polyesters have a high viscosity making them somewhat difficult to handle. Compounds added to increase fire resistance, that are not chemically bound in the resin, may reduce the physical properties and leech out upon exposure. The effect of these modifying agents on the strength and other properties of a laminate should be carefully investigated and calibrated prior to specific application.

One method of increasing the fire resistance of a laminate is to seal its surface with a self-extinguishing resin. The interior of the laminate is made with ordinary polyesters but its outermost plies are laid up with a self-extinguishing type.

Air Cured Polyesters: Some types of polyester resins cure in air with a tacky or sticky surface. Contact with air inhibits the curing reaction and leaves a sticky layer of uncured resin on the surface of the laminate. This layer of uncured resin can be an advantage where successive plies of reinforcement are laid up since it provides an effective bond for additional plies. The outer surface of a laminate made by the contact molding method should cure with a dry or tack free surface. Resin manufacturers produce special resins capable of curing tack free in contact with air (7).

Some of the standard rigid and semi-rigid resins produced for the reinforced plastics industry are air curing types and entire laminates can be made with them.

Epoxy

Epoxy resins are a more recent development which have found application as laminating resins, adhesives and coatings. Epoxy resins are syrup-like liquids which resemble polyesters in that they can be cured or polymerized into hard solids. Epoxy resins are chemically very different from polyesters, exhibit greater adhesion and have higher physical properties. Shrinkage during cure is also considerably lower than that of polyesters (18).

The limited use of epoxy resins in boat manufacture can be attributed to their higher cost and tendency of some of the curing agents used to cause skin irritation on contact. Recently developed curing agents greatly reduce this irritant effect. Also, improved molding techniques, where the resin and glass fibers are simultaneously deposited on the mold without appreciable contact by the operator, is increasing the usage of epoxy resin in boat manufacture (11, 13, 19).

Epoxy resins have a wide usage in fiberglass boat construction for bonding component parts together and in sealing and caulking. Superior coatings and paints with epoxide components have also been developed for marine use.

For the fabrication of structural laminates, epoxy resins can be molded by the same methods used for polyester resins.

Slightly higher mechanical properties can be obtained for structural laminates molded with epoxy resins as compared with polyester laminates. This is particularly essential where weight and thickness criteria are of utmost importance (18).

Catalysts

Catalysts, in the form of pastes or liquids, are added to polyesters to start polymerization or the curing reaction (7, 20, 21). Approximately 1 to 2 per cent by weight of a catalyst is used in the resin. Benzoyl peroxide dispersed in dibutyl phthalate, and methyl ethyl ketone peroxide are several of many organic peroxides used for this purpose. If a batch of resin is catalyzed, it must be used and not returned to storage. The type and concentration of catalyst used affects the rate and conditions of a curing reaction.

Accelerators

Accelerators are usually added to polyester resins to initiate a cure at room temperature (7,21). These compounds are added to a resin in combination with catalysts to start a rapid curing reaction without the application of heat. Cobalt naphthenate and dimethyl aniline are two commonly used accelerators. Accelerators and catalysts will only work together in certain combinations or pairs.

Resins used for contact molding of boats often contain an accelerator added by the manufacturer, and these resins require only the addition of a suitable catalyst to cure at room temperature. A knowledge of the pot life of a particular resin mix is necessary to provide adequate time for impregnation of the reinforcement between the completion of resin mixing and the beginning of resin hardening.

Stabilizers

Stabilizers or inhibitors are compounds added to polyesters by the manufacturer to prolong storage life (7,21). Since polyesters are active chemicals which will slowly set or gel over a long period of time, depending on storage conditions, overage polyester should not be used. If tertiary butyl catechol or hydroquinone is added in small amounts to inhibit the gelling reaction, the catalyst quantity must be modified.

The effective storage life of a polyester is largely determined by its inhibitor level and the temperature at which it is stored. High ambient temperatures will result in shorter storage life.

FILLERS AND PIGMENTS

Fillers and pigments are added to the molding resins to reduce shrinkage, minimize crazing, lower material costs, impart color or opacity and to improve surface finishes (1). Addition of excessive amounts of fillers can also increase resin viscosity to a point where it could be difficult to work with. Laminates containing fillers may be opaque and may not be readily inspected for internal flaws. Filled resins are often used as surfacing materials for laminates. Commonly used fillers include diatomaceous earths, calcium carbonate and aluminum silicate (22).

The addition of approximately 3% of silica dioxide filler by weight to a polyester resin will make it resemble grease in consistency. When these modified resins are applied to vertical surfaces, they will not drain or run off. Filled resins of this type are called thixotropic resins, and are available pre-compounded from various manufacturers (6, 7, 22).

STIFFENER AND SANDWICH CORES

When necessary to economically provide greater strength and rigidity to a hull, deck or bulkhead, stiffeners or sandwich type construction may be used depending on the degree of strength and rigidity desired (3, 4). In concept, the construction of a core stiffener and a sandwich panel is identical except that the stiffener is proportioned to have a limited width of flange and the sandwich panel is proportioned to have continuous facings throughout the entire panel. The flanges of the stiffener and the facings of the sandwich panel are usually thin high strength fiberglass laminates and the cores are thicker low density materials.

Commonly used materials for stiffener and sandwich panel cores in boat hull construction are wood, foamed plastics, honeycomb, and lightweight plastic spheres embedded in resin, Fig. 4-11.

For stiffeners, in addition to the full core materials, cores of hollow rectangular aluminum tubing and half round paper tubing, cut to fit the hull form, are also being used (6, 7).

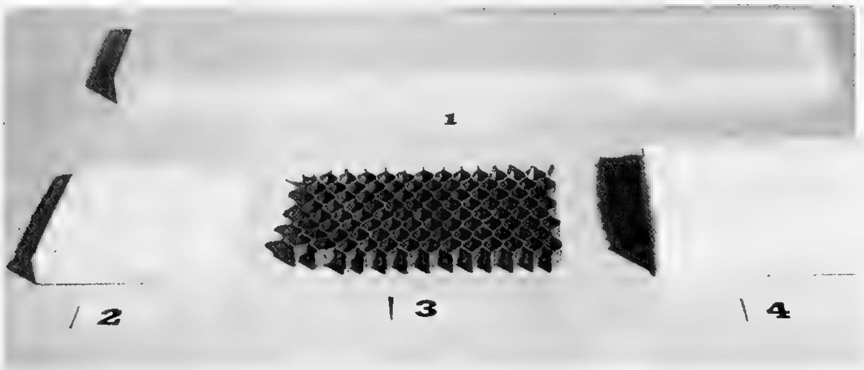

Fig. 4-11. Low Density Core Materials - 1. Balsa Wood, 2. Polyurethane, 3. Honeycomb, 4. Polystyrene

Wood

Various types of wood such as hard woods, plywood and balsa have been used as core materials. Experience has indicated that solid hard wood cores, encased in the laminate, have a tendency to swell and thereby crack the laminates covering them, causing water penetration. Both waterproof plywood and balsa wood cores have proven satisfactory, balsa wood being used more frequently (23).

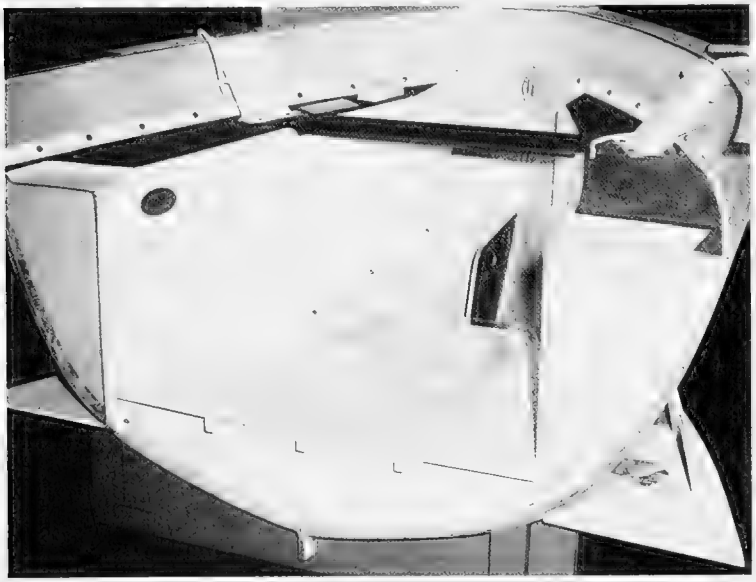

Fig. 4-12. Lifeboat with foam for buoyancy
(Courtesy W. Chance Associates)

Foamed Plastics

Rigid unicellular prefoamed or foamed in place plastics (5) are primarily used in fiberglass boat construction to provide buoyancy by filling hollow spaces under boat seats and other locations, Fig. 4-12. Unlike cork, kapok and other materials, foam plastics will not decay or become water-logged. Prefoamed polystyrene and foamed in place polyurethane plastics are generally used as buoyancy materials. Polystyrene foam, unless properly coated to prevent contact, will be attacked by resins containing liquid styrene.

Although relatively expensive, unicellular plastic foams, in addition to providing buoyancy have the following important advantages to warrant their use as core materials:

Lightweight.

Resistance to water, fungi and decay.

Can be foamed in place - polyurethane or expandable polystyrene beads (24, 25).

Are available in prefoamed logs, boards or rods and can be easily cut, shaped and bonded - cellular cellulose acetate and polystyrene (26, 27). Unlike the lower cost prefoamed polystyrene, cellular cellulose acetate does not dissolve in resins. Fig. 4-13 illustrates the use of foam plastics as a core material.

Fig. 4-13. Polyurethane foamed in place cores for main longitudinals of 36' LCVP test section *(Courtesy Budd Company)*

Honeycomb

Honeycomb cores of aluminum, fiberglass laminates, cotton duck and waterproof paper are available in various sizes and weights (27, 28). Waterproof paper honeycomb core sandwich construction, Fig. 4-14, is the most commonly used in boats for interior bulkheads, decks, seats, etc.

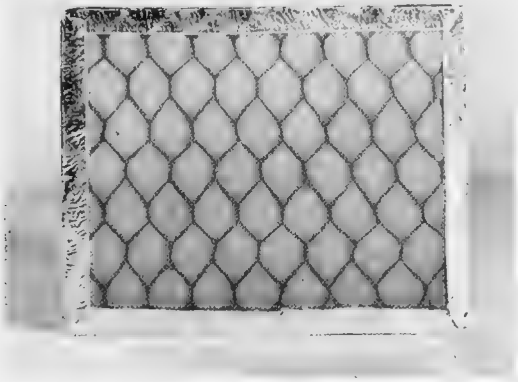

Fig. 4-14. Sandwich Panel with Waterproof Paper Honeycomb Core

Lightweight Plastic Spheres Embedded in Resin or Syntactic Foams

Lightweight gas filled phenolic spheres embedded in either polyester or epoxy resin forms a denser troweled in place type of core material, Fig. 4-15, presently being used in certain areas of some boat hulls (26).

Polystyrene beads expanded to approximately 1/8" diameter spheres and embedded in epoxy resin are a new type of troweled in place core material that is presently being investigated (25).

The advantage of these troweled in place core materials is apparent due to the simplicity of application, particularly in small restricted areas.

Fig. 4-15. Syntactic foam being troweled in place *(Courtesy Union Carbide Corporation)*

MOLDING METHODS

Nearly every type of molding method developed for reinforced plastics has been used to make fiberglass boats (1). Many methods are in current use and all have distinct advantages and disadvantages. The selection of a proper molding method for a particular boat construction is dependent primarily on the size of the boat, production rate, total number to be produced, and cost of both molding equipment and molded boat hull. The familiarity of the molder with a given process and the availability of related tooling and equipment may well be the most important considerations. The molding process most widely used in boat hull construction is the contact method (6). This discussion indicates available methods and is not intended to specify any specific molding process for any particular boat.

Heat Cure

Fiberglass reinforcement and properly catalyzed resin can be cured to a hard structural laminate by the application of heat to initiate the reaction (21). Steam or electrically heated molds are used to develop heat cured laminates with superior physical properties at rapid production cycles. Open molds can be heated by a bank of infra-red heat lamps or resistance heaters. Heat cure during molding, or subsequent heat cure, can produce superior laminates.

Room Temperature Cure

Room temperature cure does not require a heated mold. The addition of an accelerator and catalyst to the resin will cause the necessary reaction which produces sufficient heat to cure the laminate without the application of external heat (7, 21). Room temperature cure is extremely useful for producing very large lay ups as boat hulls because they allow extended cure time and are difficult to heat. This slow cure cycle limits the rate of production for any individual mold.

Contact Molding

The contact molding method, as illustrated in Figs. 4-16 and 4-17, is simply the laying up of plies of resin impregnated fiberglass reinforcement to the required thickness on an open female or male mold of the desired hull form and allowing the laminate to cure at room or elevated temperature (14). After the cure is completed, the boat hull is removed from the mold and the process is repeated. For extremely large size hulls, the molds may be made in two halves for ease in lay up and removal of the molded hull. It is easier to lay up the plies of reinforcement over a male mold although an uneven outer surface results. Additional finishing operations are usually required to obtain a smooth outer surface and good appearance. Since a smooth outer surface is desirable in boat hulls, the female mold is generally preferred.

Fig. 4-16. Molding of hull of sailboat in female mold. Resin mix being sprayed on reinforcement *(Courtesy American Carbide Corporation)*

Fig. 4-17. Fiberglass hull of a 40' ketch molded on a male form *(Courtesy Jean Filloux)*

Bag Molding

This molding method uses a flexible membrane or bag to apply vacuum or positive pressure to a laminate during the molding operation.

Vacuum bag molding applies pressure against a laminate by drawing a vacuum under the bag. This molding operation is limited to a pressure slightly less than atmospheric, 14.7 PSI. Vacuum bag molding of boat hulls is currently not being used to any appreciable extent except in the autoclave molding method discussed below. Fig. 4-18 illustrates the flexible rubber blanket in position covering the lay up in the mold prior to placing the entire mold assembly into the autoclave. Pressure bag molding, Fig. 4-19, uses compressed air or steam to force the bag down against the laminate during the molding operation. Pressure bag molding can ordinarily operate at pressures up to 40 PSI. Bag molding operations can readily use heated mold surfaces to produce superior laminates under rapid cure cycles (9).

Autoclave Molding

Autoclave molding uses steam to apply a uniform pressure, up to 100 PSI, and heat to the lay up (14). Usually a vacuum is pulled between a bag and the lay up to remove air and excess resin prior to applying positive pressure. Fig. 4-20 illustrates a mold assembly inside a large autoclave.

The hull size that can be made by this molding method is only limited by the size and initial cost of the necessary equipment.

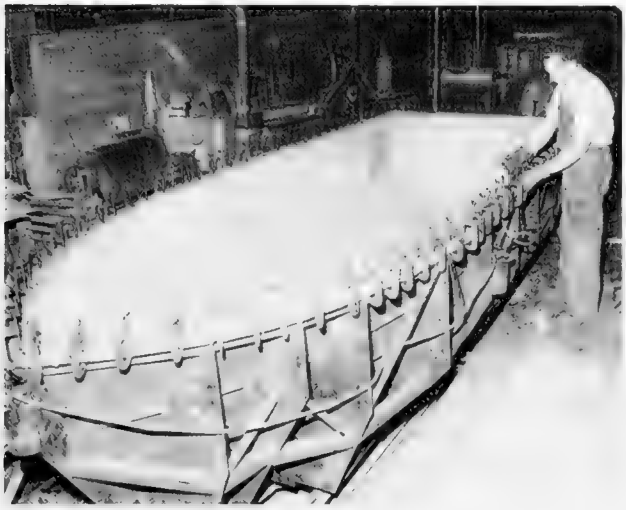

Fig. 4-18. Rubber blanket in position over fiberglass lay up *(Courtesy Universal Molded Products Corporation)*

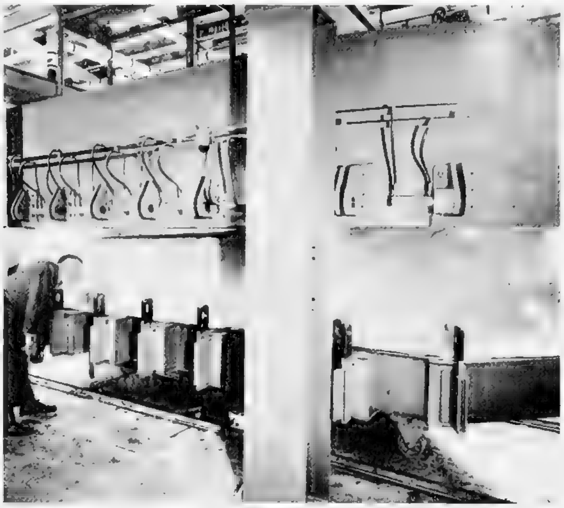

Fig. 4-19. Molding of 15' hull by pressure bag method *(Courtesy Winner Manufacturing Company)*

Matched Die Molding

Matched die molding using both a male and female die combined as shown in Fig. 4-21, applies both pressure up to 170 PSI (8) and heat to the laminate. In most operations, mechanical stops are used to control the applied pressure and laminate thickness.

It has been demonstrated that the use of heated, matched metal dies produces fiberglass boats on a rapid molding cycle (8, 12). At present, matched die molds have been limited in use to hulls of approximately 17 feet in length due to the high cost of the initial equipment requiring quantity production for amortization.

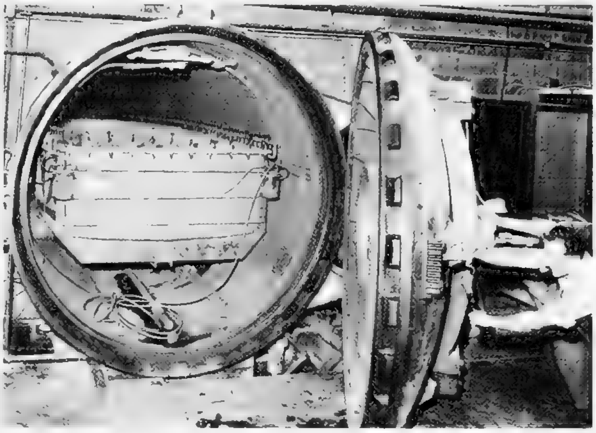

Fig. 4-20. Mold assembly inside of autoclave *(Courtesy Universal Molded Products Corporation)*

Sprayed Reinforcement and Resin

A recently developed production tool, that has caused interest in the boat industry and could possibly be used in all molding methods to increase production, is a special spray gun,

Fig. 4-22, capable of simultaneously depositing chopped strand fiberglass and catalyzed resin on the mold (11, 13, 19).

In contact molding, fiberglass hulls can be rapidly built up over hull forms by use of this spray gun. This process is presently being used in the production of some boat hulls, Fig. 4-23.

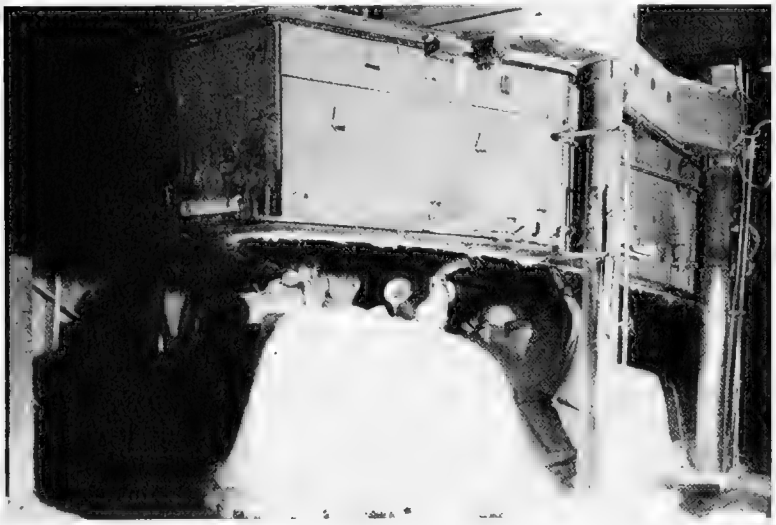

Fig. 4-21. Molding of 15' hull by matched die molding
(Courtesy Molded Fiberglass Boat Company)

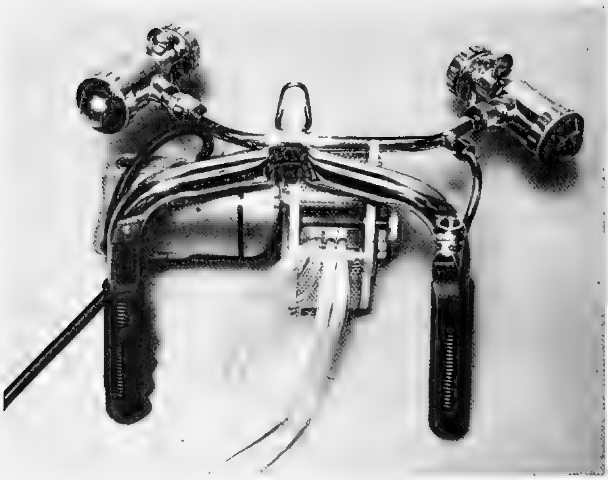

Fig. 4-22. Spray gun
(Courtesy Rand Development Company)

Fig. 4-23. Spray gun depositing chopped fibers and resin on hull mold *(Courtesy Larsen Boat Company)*

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5

Engineering Properties of Laminates

Basic engineering properties of reinforced laminates, such as, specific gravity, strength, moduli, Poisson's ratio, resistance to impact, etc. are primarily dependent upon the type and direction of the reinforcement, the resin, the molding method and fabrication technique used (1). These properties can be affected after fabrication by extended exposures to unfavorable environmental conditions and long term loading.

Production methods with good quality controls can consistently produce high quality laminates. Thoughtful design with the judicious selection of basic materials and molding methods can minimize the adverse effects of environment and long term loading.

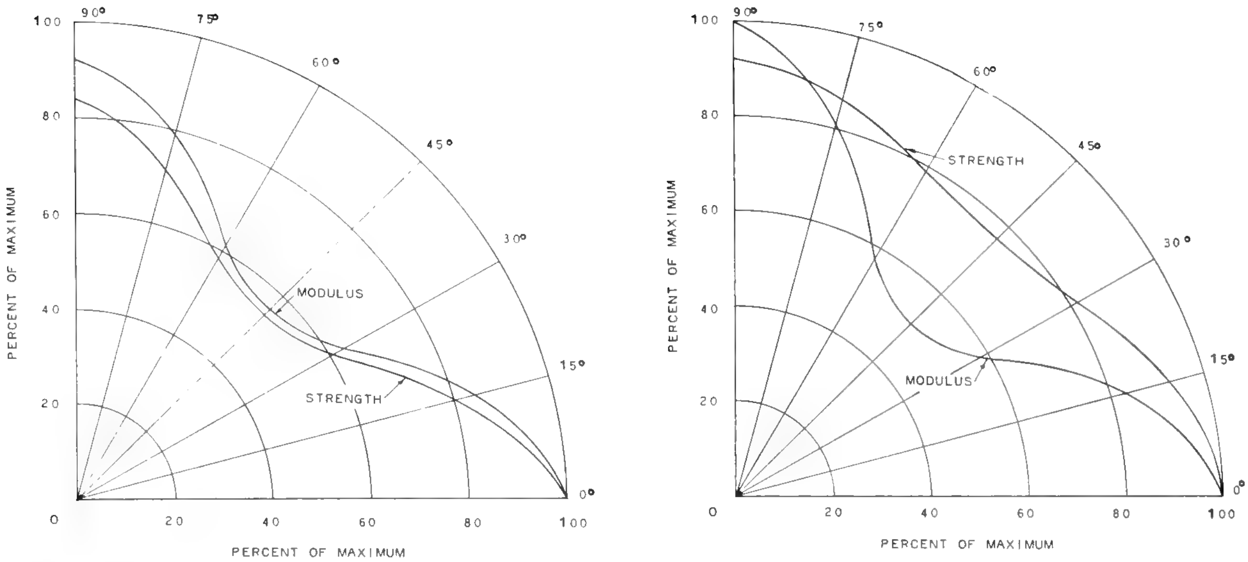
DIRECTIONAL PROPERTIES

One of the important characteristics of glass cloth and woven roving laminates is the variation of their physical properties with direction (1). This variation of properties is analogous to the difference in the physical properties of wood measured with and across the grain. Materials which exhibit this characteristic are referred to as orthotropic as opposed to isotropic materials, such as, steel and aluminum, whose properties are essentially the same in all directions.

Fiberglass laminates with chopped strands reinforced throughout are isotropic. Fiberglass laminates with mat reinforcement throughout are also considered as isotropic when the laminates are thin and the applied stresses are in the plane of the laminate. This assumption neglects the difference in properties in the direction perpendicular to the plane of the laminate. When the laminates are thick and when the applied stresses are not in the plane of the laminates, these differences must be considered.

Figs. 5-1 and 5-2 illustrate the variation in physical properties of glass fabric laminates with direction. Directions referred to are all in the plane of the laminate. Fig. 5-1 shows the difference in tensile and compressive strengths and moduli for a 10 ounce cloth polyester laminate with changing direction. Fig. 5-2 gives the same information for a 25-27 ounce woven roving polyester resin laminate. The figures show only one quadrant, the others being similar. The figures indicate the perpendicular axes of major strength, 0 degrees and 90 degrees, which are aligned respectively with the warp and fill directions of the fabric. The direction of minimum properties is at 45 degrees.

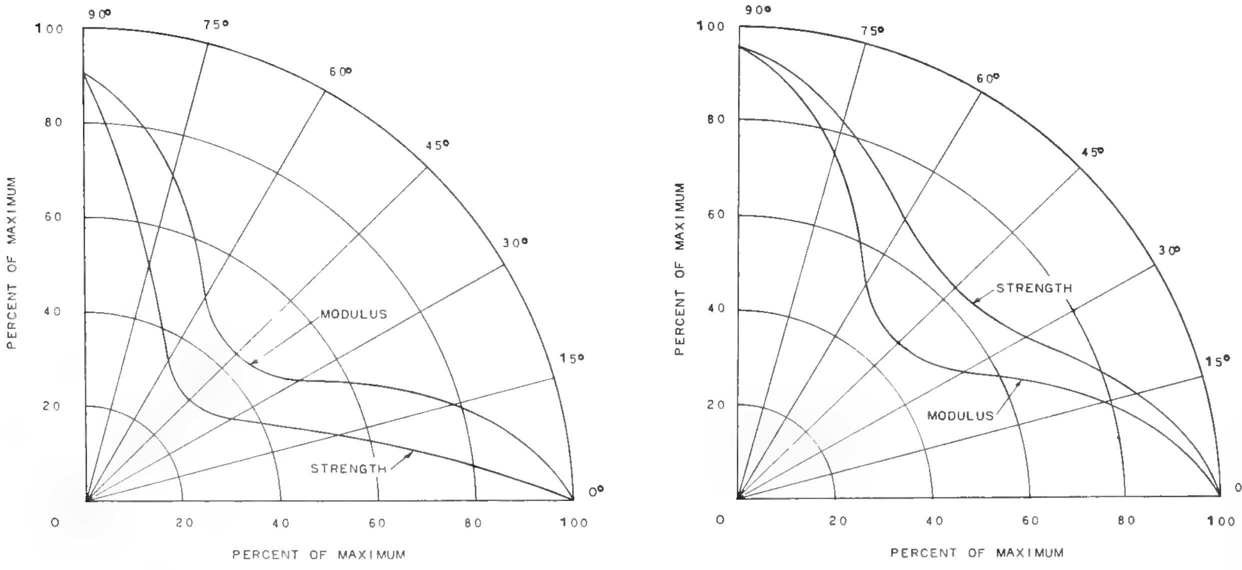
This orthotropic characteristic of glass cloth and woven roving laminates has great significance in the orientation of the plies of reinforcement in a laminate and in the stress analysis of these materials (2). A detailed discussion of a directional stress analysis problem is given in Chapter 6.



a. TENSION

b. COMPRESSION

Fig. 5-1. Directional Properties of Parallel-Laminated 10 Ounce Cloth and Polyester Resin, Contact Molded - Wet Condition



a. TENSION

b. COMPRESSION

Fig. 5-2. Directional Properties of Parallel-Laminated 25-27 Ounce Woven Roving and Polyester Resin, Contact Molded - Wet Condition

RELATIONSHIPS BETWEEN REINFORCEMENTS, MOLDING METHODS AND PROPERTIES

There exists definite relationships between reinforcements, molding methods and engineering properties (1, 3, 4). In general, increased molding pressure decreases laminate thickness and increases glass percentage. Strength properties are improved in proportion to increases in the glass content, Fig. 5-3.

The different types of fiberglass reinforcements vary widely in thickness and weight per ply in a finished laminate, when molded by the same method. Differences in shop practices or molding techniques also produce variations in laminate thickness, weight and strength properties for any particular type of reinforcement. This variation due to shop practices can be materially reduced by quality control. Fabricators experienced in working with a specific type of reinforcement, resin system and molding method can consistently produce high quality laminates.

Table 5-1 presents the relationship between reinforcements, molding methods, physical and mechanical properties. The values given in Table 5-1 are over-all averages presented for comparison only and should not be used for design unless verified by qualification tests. Fabricators should investigate the effects of the important variables to establish the most efficient and economical relationship for each specific application. There are a number of other minor causes of variability in laminate properties, such as, humidity, temperature and improper storage and handling of basic materials which should be considered in the production of fiberglass laminates.

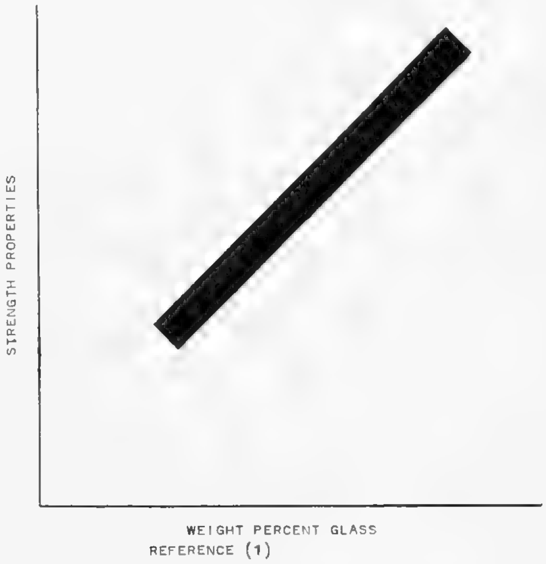


Fig. 5-3. Strength Properties Improve with Increased Glass Content

TEST PROGRAM TO OBTAIN PROPERTIES - CONTACT MOLDED

Purpose

Due to practical limitations of the pressure molding methods, the greatest percentage of fiberglass boats are presently being produced by the contact molding method. All of the larger sizes of fiberglass boats are being made by the contact molding method. Unless new molding methods are developed, the contact molding method is the most suitable for construction of the larger fiberglass boats to be built in the near future. With further improvement of the basic materials and techniques for contact molding, an increase in the construction of these larger sizes of boat hulls is expected (5).

Since the contact molding method is the most widely used for boat construction, this extensive test program (6) was conducted to obtain necessary properties data for fiberglass mat, woven roving and cloth reinforced polyester laminates molded by this method. Also, since marine applications were of primary consideration, all mechanical properties were obtained from tests of laminates in the "wet" condition or immersed in water at room temperature for 30 days.

TABLE 5-1. FIBERGLASS POLYESTER LAMINATES - RELATIONSHIPS BETWEEN REINFORCEMENTS, MOLDING METHODS, PHYSICAL AND MECHANICAL PROPERTIES

OVER-ALL AVERAGE VALUES* FOR COMPARISON ONLY

Molding Method & Reinforcement	Molding Pressure PSI	Nominal Weight Per Cent Glass	Specific Gravity	Thickness per Ply Inches	Tensile		Flexural		Compressive		Shear Strength		
					Strength PSI x 10^3	Modulus PSI x 10^6	Strength PSI x 10^3	Modulus PSI x 10^6	Strength PSI x 10^3	Modulus PSI x 10^6	Perpendicular PSI x 10^3	Parallel PSI x 10^3	Interlaminar PSI x 10^3
Contact													
2 oz. mat	0-1	23	1.31	.060	11.6	0.91	20.5	0.85	16.9	0.93	9.9	10.1	2.78
25-27 oz. W.R.¶¶		51	1.64	.037	33.0	2.06	27.1	1.81	17.0	2.45	13.3	9.6	2.60
10 oz. cloth ¶		46	1.63	.016	24.1	1.95	31.1	1.96	18.9	2.46	12.1	10.6	2.57
Vacuum Bag													
2 oz. mat	12	38	1.50	.038	18.6	1.17	27.1	1.24	22.4	1.16	12.8	-	3.02
10 oz. cloth ¶		50	1.67	.015	24.2	1.94	35.3	1.97	21.7	1.55	12.1	-	2.65
Pressure Bag **													
2 oz. mat	15-40	41	1.53	.035	19.5	1.21	29.2	1.29	22.8	1.22	13.1	-	3.27
Autoclave													
2 oz. mat	25-100	48	1.61	.028	21.4	1.23	31.2	1.38	23.1	1.24	13.6	-	3.42
Matched Metal Die **													
2 oz. mat	50-170	50	1.63	.026	22.3	1.28	32.5	1.44	24.1	1.29	14.2	-	3.45

Mechanical properties are for short term loading tests on samples immersed in water at room temperature for 30 days.

Tentative values based on limited test data.

¶ Cloth and woven roving tested in direction of warp.

¶¶ W.R. designates woven roving.

This test program was limited to those basic properties considered to be of immediate need to designers and fabricators. Additional spare panels were fabricated and are being retained for future testing on fatigue, creep and stress rupture properties.

Materials and Method of Fabrication

To properly evaluate the properties, 236 20 inch x 20 inch test panels were fabricated by the contact molding method. Tests were made on 6500 specimens cut from these panels, and the results were statistically analyzed. The following is a list of reinforcements, resin system and the molding method used to fabricate these panels.

Mat: Chopped strand mat conforming to Military Specification MIL-M-15617-A, 2 ounces per square foot in weight and having a high solubility polyester binder.

Woven Roving: Style HG 56 or BS 6055 with approximately equal strength in both directions and weighing approximately 25-27 oz. per yard, or equivalent.

Cloth: Style 1000-150 conforming to Military Specification MIL-Y-1140-C, plain weave construction weighing 9.66 ounces per square yard, or equivalent. For simplicity this material is designated as 10 ounce cloth.

All of the fiberglass reinforcement had a high wet strength Silane, Garan or 136 type finish.

Cloth and woven roving laminates were parallel laminated; warp direction of all plies were laid up in the same direction.

A blend of approximately 90 per cent rigid and 10 per cent flexible polyester resins or a suitable modified polyester resin with equal properties was used. The difficult task of selecting resin systems, without appearing to be arbitrary, leads to this widely used formulation compromise which has been representative of good practice. All rigid resin used conformed to Military Specification MIL-R-7575-A.

The catalyst system used and methods of lay up conformed to the resin manufacturer's recommendations.

The laminates represent the result of good shop practice with close adherence to the resin manufacturer's process specifications for producing boat hulls and other large structures using the contact or hand lay up method. No special post cure by heat or other procedure was used to produce improved panels.

Types of Laminates:

M1 = Mat - 2 ounces per square foot

M2 = Woven roving - 25-27 ounces per square yard

M3 = Cloth - 10 ounces per square yard

M4 = Mat with 1 ply of 10 ounce cloth on each face

M5 = Woven roving with 1 ply of 10 ounce cloth on each face

Test Procedures

Property	Procedure	
	ASTM	LP-406b
Tensile strength	D-638	1011
Flexural strength	D-790	1031.1
Compressive strength	D-695	1021.1
Shear strength perpendicular	D-732	1041
Shear strength parallel	*	
Tensile modulus	D-638	1011
Flexural modulus	D-790	1031.1
Compressive modulus	D-695	1021.1
Specific gravity	5011	
Per cent glass by volume	USAF 4.3.2.1.2	
Per cent glass by weight	USAF 4.3.2.1.2	
Tensile Poisson's Ratio	*	
Compressive Poisson's Ratio	*	

Mechanical properties specimens were wet-conditioned or immersed in water at room temperature for 30 days.

* developed specifically for this program, see Appendix A.

All of the above properties were tested on specimens cut at 0 degrees, 45 degrees and 90 degrees from the warp direction of the test panel.

Statistical Analysis of Test Data

The test program was developed primarily to study the following four main variables which were considered of primary importance:

1. Fabricators - effects of variations in good shop practice.
2. Laboratories - effects of variations in testing techniques and equipment.
3. Materials - effects of different types of reinforcement.
4. Laminate thickness - effects of number of reinforcement plies.

To keep the number of test samples to a minimum and still obtain the necessary data for statistical confidence in the results, a balanced fourth of a full set of $(4)^4$ factorial design plus additions was used. One material was added and all thicknesses were studied for one of the materials.

It was necessary to omit a very small portion of the test data because the pattern of its scatter showed these points to deviate for different reasons, than those determining the normal scatter. Because the data for different fabricators frequently clustered around different averages, it was necessary to establish a high and low range of values. In order to establish reasonable lower limits, few unrealistic test results were excluded in the computation of the data.

For each range an average value and a lower limit was established. It can be stated, with 95 per cent confidence, that not more than 5 per cent of the panels made under similar conditions will give values below the lower limit.

5. A detail discussion of the statistical procedure is given in Appendix B.

Results of Investigation of Main Variables

1. Fabricators - effects of variations in good shop practice.

This variable has considerable effect on some of the properties. The differences are consistent in the sense that they are the same for all laminate thicknesses and for angles from the warp.

2. Laboratories - effects of variations in testing techniques and equipment.

Consistent differences among test laboratories were found in some small areas of the test data. The measurement error between duplicate coupons was not found to be controlling for any property. In most cases, the measurement error was negligible compared to the average random variability of a single fabricator making similar laminates.

3. Materials - effects of different types of reinforcement.

As expected, the different types of reinforcement and glass percentage show marked differences in physical and mechanical properties.

For most properties, and particularly for the thicker laminates, little apparent difference exists between laminates faced with single ply 10 ounce cloth and laminates of equal construction without facings. For these laminates, with and without cloth facings, some differences do exist in glass content and tensile strength within both mat and woven roving reinforcements and in tensile and flexural moduli for mat reinforcement only.

Laminates of mat reinforcement are generally isotropic or nondirectional for all properties. Laminates of cloth and woven roving reinforcement are orthotropic or directional for most strength and modulus properties, but are isotropic for shear strength properties. Laminates of cloth and woven roving are particularly directional for tensile strength, values at 45 degrees to the warp being much lower than values at 0 degrees and 90 degrees to the warp.

4. Laminate Thickness - effects of number of reinforcement plies.

The thickness of the test laminates is a minor factor in the data for some of the reinforcements and properties. There seems to be little consistency in this effect. It is detected in the moduli values for some of the reinforcements and for the strength values for other reinforcements. Thickness effect is particularly apparent in all strengths and moduli for woven roving reinforcement.

The flexural strength data for woven roving showed an important difference with laminate thickness. Flexural strength data for laminates with other reinforcements, 2 ounce mat and 10 ounce cloth did not vary with thickness. Thickness effect for woven roving and mat laminates faced with 10 ounce cloth was the same for equivalent laminates without the facings.

The flexural modulus values were affected by laminate thickness for all reinforcements and angles to the warp.

Compressive strength was found to vary with each thickness for all reinforcements except 10 ounce cloth.

For shear strength perpendicular to warp, 10 ounce cloth and woven roving laminates showed some differences with thickness while mat laminates did not.

For shear strength parallel to warp, laminates with all types of reinforcements showed small differences with thickness.

Discussion of Tables

The data are presented in a manner considered important, from a statistical viewpoint, to clearly indicate the effect of different shop practices on the properties of laminates molded by the contact or hand lay up method. For most properties, the tables contain high and low values as established by the statistical analysis. An average value and a lower limit value established at a 95 per cent confidence level is given for each range. It is important to emphasize that both the high and low range of values were determined from test panels made by good fabrication practice as individually established by the participating fabricators. The high range of values in the tables may be taken as high standards for good fabrication practice and experience with the particular type of reinforcement.

The data in the tables would present a much simpler appearance if single property values were given for each material. Due to the wide differences in the properties of the laminates produced by the participating fabricators, the use of a single property value would not be valid and could lead to serious misunderstanding. If the average property values of the laminates in the lowest range were reported alone, the tables would give no indication of what can be accomplished by good shop practice. If the average value from the high range of properties was used as a single value, designers would be misled into thinking that all fabricators could produce laminates of equally high quality. If an over-all average of the high and low test results were reported alone, it would differ considerably from the true values of any fabricator. Any attempt to rectify this situation by establishing some kind of a range of variation around an over-all average would introduce more confusion, since this range does not represent the variability of the material of any one fabricator. Rather, it would be a mixture of the intrinsic and random variability of the material for any one fabricator with the systematic differences in level due to systematic differences in shop practices.

There appears to be no valid substitute then for indicating the variation among fabricators, particularly when this variation is large. Therefore this variation is indicated by giving two separate average values. One value is for those fabricators who maintained a definitely higher average level; another value is for those fabricators who produce material at a lower average level.

Below each average value, a lower limit, LL, is also given. It can be taken as assured that 95 per cent of the panels from a single fabricator who can maintain the average given, will have values of the property above this lower limit.

Entry into a table's high or low range should be made on the basis of qualification tests. Basic testing of samples from several large panels for tensile, flexural and compressive strengths and moduli, and per cent glass would enable a fabricator to determine his laminate quality. Application of the tables could be made on the basis of a few such fixed points. A fabricator producing laminates with high tensile and flexural strengths and moduli would design from the high range values of the table. Conversely, a fabricator obtaining values in the low ranges would necessarily design to that range. Fabricators with improved shop practices and rigid quality control can undoubtedly produce the higher strength laminates consistently.

PHYSICAL PROPERTIES

Thickness and Weight

The importance of laminate thickness and its effect on physical properties has been previously discussed and should be carefully controlled during the molding process. This is particularly true for contact molding where variation in thickness can occur more readily than with pressure molding. Table 5-2 presents the relationship between the number of plies and laminate thickness, and Table 5-3 presents the relationship between the number of plies and laminate weight. Since the variation in laminate thickness and weight for all fabricators was not as significant as the variation in strength properties, over-all averages were considered sufficiently reliable. In addition to the average values, the ranges of average variability in thickness and weight are also given.

Glass Content and Specific Gravity

Glass content is controlled by the type of reinforcement and molding method used to make the laminate. The specific gravity of a laminate is dependent upon the glass content and, to a lesser degree, upon the voids that may be present in the laminates. Table 5-4 presents per cent glass by weight and volume, and specific gravity for the laminates evaluated.

Void Content

Fiberglass laminates often have small voids or bubbles which detract from their strength properties (7). Voids are formed chiefly by entrapment of air during lay up of the resin and reinforcement and by release of volatile components from the resin during cure.

Laminates made by the contact molding method tend to have a higher void content than laminates molded under pressure. Sufficient pressure on a laminate during molding can force out a large portion of the air bubbles. Although voids cannot be eliminated entirely from laminates made by the contact method, careful fabrication techniques can be used to keep them at a minimum. Laminates that are essentially void free can be made with light cloth reinforcement by the contact method.

Air bubbles can be worked out of a lay up to a considerable degree by use of rollers and other implements. Inclusion of air bubbles in the resin during mixing or stirring operations should be avoided. Resin cure temperatures should be kept below the point

TABLE 5-2. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED PLIES VERSUS LAMINATE THICKNESS IN INCHES

	NUMBER OF PLIES																
Laminate	2	3	4	5	6	7	8	9	10	11	12	13	14	15	20	25	30	35
M1 2 Oz Mat	.137 **.116** .095	.213 **.175** .137	.280 **.237** .194	.347 **.299** .251	.414 **.361** .308	.481 **.423** .365	.547 **.485** .423	.614 **.546** .478	.681 **.609** .537	.748 **.671** .594	.815 **.733** .651	.882 **.795** .708	.949 **.857** .765	1.016¶¶ **.919**¶ .822¶¶				
M2 25-27 Oz. W. R.	.076 **.071** .062	.115 **.109** .104	.156 **.147** .139	.197 **.185** .173	.239 **.223** .208	.280 **.262** .243	.321 **.300** .278	.363 **.338** .313	.404 **.376** .348	.445 **.414** .383	.487 **.452** .418	.528 **.490** .453	.569 **.528** .488	.610 **.566** .523				
M3 10 Oz Cloth	.036 **.032** .028	.054 **.048** .042	.071 **.064** .057	.087 **.080** .073	.102 **.095** .087	.119 **.111** .103	.133 **.127** .119	.151 **.143** .135	.167 **.159** .152	.184 **.176** .168	.200 **.192** .184	.216 **.208** .200	.232 **.224** .216	.248 **.241** .232	.329 **.322** .313	.411 **.402** .394	.492 **.484** .475	.573 **.564** .556
M4 10 Oz. Cloth * 2 Oz. Mat ** 10 Oz. Cloth *	.176 **.149** .128	.229 **.205** .180	.288 **.261** .234	.346 **.371** .288	.406 **.374** .341	.464 **.430** .395	.523 **.486** .449	.581 **.542** .503	.640 **.598** .556	.699 **.654** .610	.757 **.711** .664	.816 **.767** .717	.875 **.823** .770	.934 **.879** .823				
M5 10 Oz. Cloth * 25-27 Oz. W. R. ** 10 Oz. Cloth *	.118 **.104** .096	.153 **.138** .123	.190 **.172** .153	.228 **.206** .184	.265 **.240** .214	.303 **.274** .245	.340 **.308** .275	.377 **.342** .306	.415 **.376** .337	.452 **.410** .367	.489 **.444** .398	.527 **.478** .428	.564 **.512** .459	.602 **.546** .490				

* Face ply constant at one ply each face and included in weight.

** Core ply as indicated.

¶ Average values.

¶¶ Average values plus or minus the average deviation.

TABLE 5-3. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED PLIES VERSUS LAMINATE WEIGHT - POUNDS PER SQUARE FOOT

Laminate	NUMBER OF PLIES 2	3	4	5	6	7	8	9	10	11	12	13	14	15	20	25	30	35
M1 2 Oz. Mat	.108 **.910** .801	1.55 **1.32** 1.09	2.02 **1.76** 1.50	2.49 **2.20** 1.88	2.96 **2.64** 2.32	3.42 **3.08** 2.73	3.89 **3.52** 3.14	4.36 **3.96** 3.55	4.83 **4.40** 3.96	5.30 **4.84** 4.38	5.77 **5.28** 4.79	6.24 **5.72** 5.20	6.71 **6.16** 5.60	7.18¶¶ **6.60¶** 6.00¶¶				
M2 25-27 Oz. W.R.	.640 **.620** .604	1.00 **.960** .918	1.35 **1.28** 1.22	1.69 **1.61** 1.53	2.04 **1.94** 1.83	2.38 **2.26** 2.14	2.73 **2.59** 2.44	3.07 **2.91** 2.75	3.42 **3.24** 3.06	3.77 **3.56** 3.36	4.11 **3.89** 3.67	4.46 **4.21** 3.97	4.08 **5.54** 4.28	5.22 **4.86** 4.51				
M3 10 Oz. Cloth	.320 **.270** .220	.450 **.400** .350	.590 **.540** .490	.725 **.675** .625	.882 **.832** .782	1.020 **.970** .920	1.16 **1.11** 1.06	1.29 **1.24** 1.19	1.43 **1.38** 1.33	1.57 **1.52** 1.47	1.71 **1.66** 1.61	1.84 **1.79** 1.74	1.98 **1.93** 1.88	2.12 **2.07** 2.02	2.81 **2.76** 2.71	3.19 **3.44** 3.39	4.18 **4.13** 4.08	4.87 **4.82** 4.77
M4 10 Oz. Cloth * 2 Oz. Mat ** 10 Oz. Cloth *	1.33 **1.16** 1.04	1.73 **1.57** 1.42	2.15 **1.99** 1.82	2.58 **2.40** 2.12	3.00 **2.81** 2.61	3.42 **3.22** 3.01	3.85 **3.63** 3.38	4.27 **4.04** 3.81	4.70 **4.45** 4.21	5.13 **4.86** 4.61	5.56 **5.27** 5.01	5.99 **5.68** 5.41	6.42 **6.09** 5.81	6.45 **6.50** 6.21				
M5 10 Oz. Cloth * 25-27 Oz.W.R. ** 10 Oz. Cloth *	1.00 **.926** .850	1.32 **1.22** 1.15	1.64 **1.52** 1.40	1.96 **1.82** 1.68	2.29 **2.12** 1.96	2.61 **2.43** 2.25	2.93 **2.73** 2.53	3.25 **3.03** 2.81	3.57 **3.33** 3.10	3.89 **3.63** 3.38	4.21 **3.94** 3.66	4.53 **4.24** 3.94	4.85 **4.55** 4.23	5.17 **4.85** 4.51				

* Face ply constant at one ply each face and included in weight.

Core ply as indicated

¶ Average values

¶¶ Average values plus or minus the average deviation.

TABLE 5-4. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED GLASS CONTENT AND SPECIFIC GRAVITY

LAMINATE	RANGE		% GLASS BY WEIGHT	% GLASS BY VOLUME	SPECIFIC GRAVITY
M1 2 Oz. Mat	HIGH (1) *	AVG.	30.7 **	17.6 **	1.45 **
		L. L.	25.0	13.4	1.38
	LOW (3)	AVG.	22.4	12.2	1.40
		L. L.	16.7	8.0	1.33
M2 25-27 Oz. W.R.	HIGH (1)	AVG.	55.7	41.8	1.79
		L. L.	48.9	35.3	1.69
	LOW (3)	AVG.	50.4	32.0	1.64
		L. L.	43.6	25.5	1.54
M3 10 Oz. Cloth	HIGH (1)	AVG.	47.8	30.8	1.63
		L. L.	45.8	27.6	1.51
	LOW (3)	AVG.	45.7	29.2	1.56
		L. L.	43.7	26.0	1.44
M4 10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth	HIGH (1)	AVG.	34.4	20.2	1.50
		L. L.	28.7	16.0	1.43
	LOW (3)	AVG.	28.3	16.1	1.41
		L. L.	22.6	11.9	1.34
M5 10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth	HIGH (1)	AVG.	63.0	41.8	1.79
		L. L.	56.2	35.3	1.69
	LOW (3)	AVG.	50.4	32.0	1.64
		L. L.	43.6	25.5	1.54

* Number of Fabricators

L.L. = Lower Limit

** Values the same for all thicknesses

where volatiles would form gas bubbles. Careful placement of the plies in a lay up will eliminate wrinkles which can result in large voids between the plies.

The following method (8) can be used to calculate the per cent voids in a laminate:

$$\text{Per cent voids} = 100 - 100\,a \left[\frac{d}{c} + \frac{e}{b} + \frac{f}{g}\right]$$

a = specific gravity of the laminate from Table 5-4

b = specific gravity of fiberglass = 2.55

c = specific gravity of cured resin = 1.18 to 1.24 as obtained from manufacturers.

d = resin content, by weight.

e = glass content, by weight.

f = filler content

g = specific gravity of filler

Table 5-5 contains average values of per cent voids for the test laminates calculated by this method. Since fillers were not included in the test laminates, filler content and corresponding specific gravity were omitted.

TABLE 5-5. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED

VOID CONTENT

Laminate	Average Per Cent Voids in Laminate Volume
M1 - 2 Oz. Mat	2.51
M2 - 25-27 Oz. Woven Roving	1.82
M3 - 10 Oz. Cloth	1.12
M4 - 10 Oz. Cloth - 2 Oz. Mat - 10 Oz. Cloth *	2.31
M5 - 10 Oz. Cloth - 25-27 Oz. Woven Roving - 10 Oz. Cloth **	2.44

* 2 Oz. mat faced on each side with a single layer of 10 Oz. cloth.

** Woven roving faced on each side with a single layer of 10 Oz. cloth.

MECHANICAL PROPERTIES

Tensile, Flexure, Compression and Shear

Tables 5-6 to 5-14 present tensile, flexural, compressive and shear strengths with corresponding moduli for the laminates tested. Also included are values for Poisson's ratio for tension and compression. An over-all average value is given for perpendicular shear modulus since there was insufficient data to determine any level of variability for this property.

The effects of the different types of reinforcements on these properties have been previously discussed in the section; Results of Investigation of Main Variables.

Impact Strength

Non-laminated plastics and similar homogeneous materials are often tested for impact strength by an Izod test in which a small notched or unnotched sample about 1/2 inch x 1/2 inch square is clamped as a vertical cantilever beam and struck by a swinging pendulum. The test is run on a series of samples under standard conditions and the impact necessary to break the test sample is determined.

The Izod impact test is less applicable to laminate materials than to homogeneous materials except when used as a rough screening method. The Izod impact method gives the energy absorbed at failure and not a partial failure as usually occurs in laminated materials (1).

Large areas of fiberglass laminates when struck perpendicular to the direction of lamination tend to distribute the impact force due to the arrangement of the reinforcement and due to their relatively low moduli. Therefore, under impact they deflect readily and are capable of absorbing heavy blows. Failure of a laminate under heavy impact involves complex shearing and delamination effects.

To determine the relative impact resistance of laminates with various reinforcements, a test simulating actual service conditions as nearly as possible was developed. This test consists of dropping a cylindrical impacter through a smooth steel tube to strike the simply supported test panels. The impact testing machine consists of a 4 inch inside diameter, seamless steel tube, 20 feet long, mounted vertically with a cylindrical impact striker having a hemispherical head 3 inches in diameter, Fig. 5-4. The striker could be varied in weight from 7 to 150 pounds by the addition or subtraction of cylindrical increments. This test provides a realistic, comparative test of large panels of fiberglass laminates for resistance to impact or heavy blows.

Laminated fiberglass panels fail under impact by delamination, puncturing, tearing and crushing. These complex effects are difficult to evaluate. Under standardized conditions the following method is considered a reasonable and practical approach to the problem. After receiving a single blow from the dropped impacter, the panels are tested for leakage under a 2 foot head of water. For comparison, panels which are damaged to approximately one-half their thickness and which leak more than 3 but less than 6 gallons per hour under the 2 foot head of water are judged to be in a critical condition. The impact force necessary to produce a critical condition of leakage is expressed as the weight of the impacter in pounds multiplied by the height of drop in feet. A series of panels were tested for each of the types of laminates, M1, M2, M3, M4 and M5 previously discussed. Comparative evaluation of the

a. Impacter at Top of 20 Ft. Long Seamless Steel Tube

b. Panel Under Test on Supporting Frame

Fig. 5-4. Impact Test Equipment *(Courtesy Budd Company)*

laminates tested was made on the basis of panel thickness and weight versus impact strength values for the critical condition only, and are given in Figs. 5-5 and 5-6. The order of relative impact resistance for these laminates was found to be:

M2 and M5 - Woven roving and woven roving faced on each side with cloth.
M3 - Cloth
M1 and M5 - Mat and mat faced on each side with cloth.

The addition of the cloth facings to the woven roving and mat laminates has little effect on the impact strength.

Figs. 5-5 and 5-6 can only give a relative indication of the effect of impact loading. No test data is available which gives information on combined stresses due to impact plus other loadings. Until such time as more data is available the designer will have to rely on experience and judgment for determining laminate configurations where these combined loads may occur.

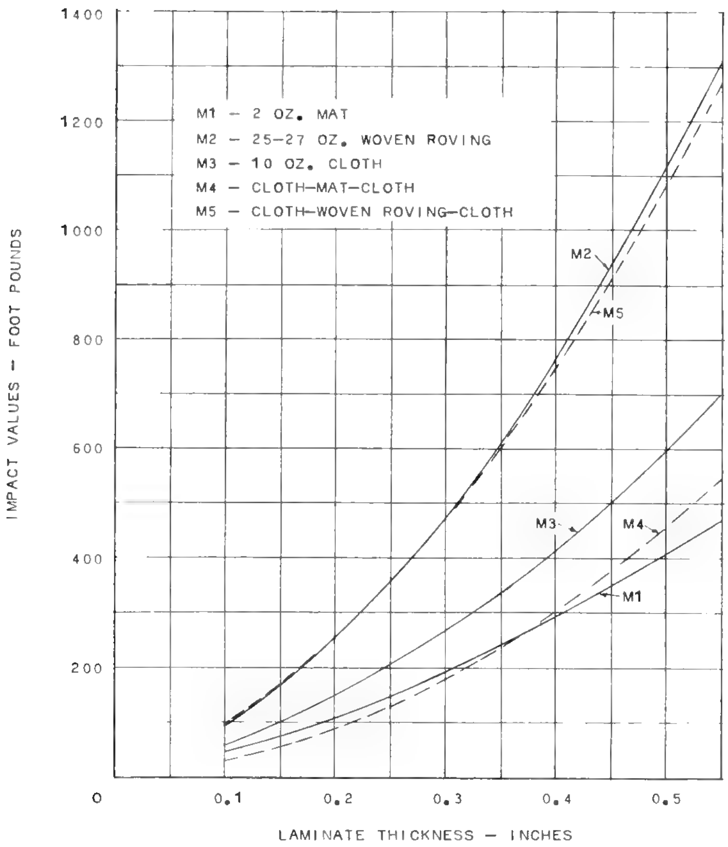


Fig. 5-5. Impact Values of Fiberglass Polyester Laminates in the Critical Condition - Based on Laminate Thickness

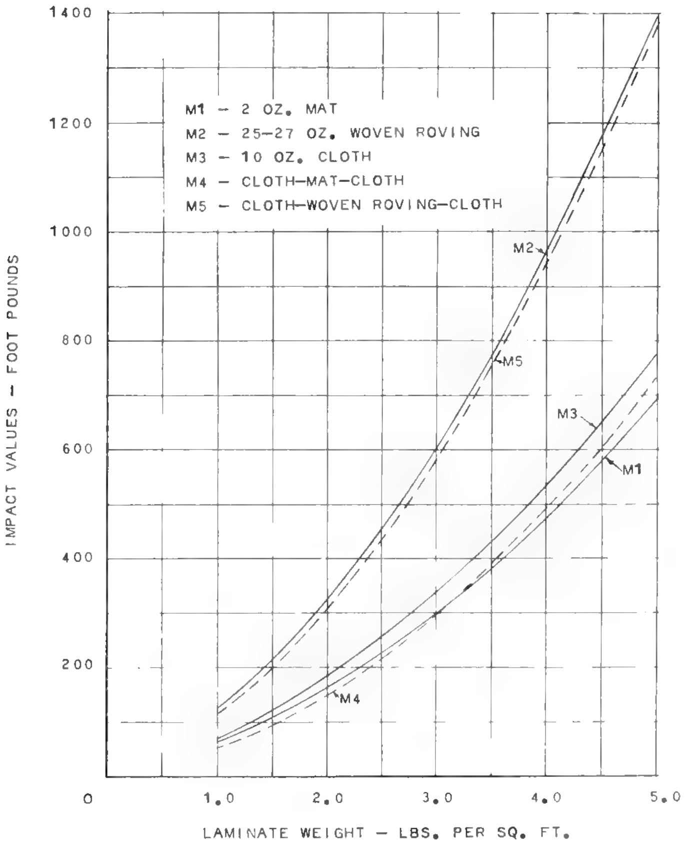


Fig. 5-6. Impact Values of Fiberglass Polyester Laminates in the Critical Condition - Based on Laminate Weight

TABLE 5-6. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED TENSILE STRENGTH *

Units in 10^3 psi

LAMINATE	RANGE		0°				45°				90°			
M1	HIGH (1) **	AVG.	14.6 ¶				15.1 ¶				15.9 ¶			
2 Oz. Mat		L. L.	10.2				10.7				11.5			
	LOW (3)	AVG.	11.0				11.5				12.3			
L. T. R. = 4.4		L. L.	6.6				7.1				7.9			
M2			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	HIGH (1)	AVG.	37.8	40.6	42.8	41.8	7.4	9.8	11.5	11.8	35.8	37.6	39.0	37.8
25-27 Oz. W.R.		L. L	31.5	34.3	36.5	35.5	5.4	7.8	9.5	9.8	29.5	31.3	32.7	31.5
			t1	t2	t3	t4					t1	t2	t3	t4
L. T. R. = 6.3 for 0° & 90° = 2.0 for 45°	LOW (3)	AVG.	30.1	32.9	35.1	34.1	¶¶				28.1	29.9	31.3	30.1
		L. L.	23.8	26.6	28.8	27.8					21.8	23.6	25.0	23.8
M3							t1	t2	t3	t4				
	SINGLE RANGE (4)	AVG.	24.1				12.0	12.2	14.0	14.2	20.2			
10 Oz. Cloth		L. L.	17.9				8.4	8.6	10.4	10.6	14.0			
L. T. R. = 6.2 for 0° & 90° = 3.6 for 45°			¶¶				¶¶				¶¶			
M4 10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth	HIGH (1)	AVG.	17.5				15.8				15.8			
		L. L.	13.1				11.4				11.4			
	LOW (3)	AVG.	13.9				12.2				12.2			
L. T. R. = 4.4		L. L	9.5				7.8				7.8			
M5			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth	HIGH (1)	AVG.	31.3	39.8	41.3	42.3	7.4	9.8	11.5	11.8	28.0	34.3	37.0	37.3
		L. L.	25.0	33.5	35.0	36.0	5.4	7.8	9.5	9.8	21.7	28.0	30.7	31.0
			t1	t2	t3	t4					t1	t2	t3	t4
L. T. R. = 6.3 for 0° & 90° = 2.0 for 45°	LOW (3)	AVG.	23.6	32.1	33.6	34.6	¶¶				20.3	26.6	29.3	29.6
		L. L.	17.3	25.8	27.3	28.3					14.0	20.3	23.0	23.3

* Short Term Loading, Wet Condition	L. L. = Lower Limit
** Number of Fabricators	L. T. R. = Lower Tolerance Range
¶ Values same for all thicknesses	Nominal Thickness Range t1 = 1/8", t2 = 1/4" t3 = 3/8", t4 = 1/2"
¶¶ Single Range Only	

TABLE 5-7. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED TENSILE MODULUS *

Units in 10^6 psi

LAMINATE	RANGE		0°				45°				90°			
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
M1	HIGH (1) **	AVG.	.90	1.10	1.37	1.40	.90	1.10	1.37	1.40	.90	1.10	1.37	1.40
2 Oz. Mat		L. L.	.70	.90	1.17	1.20	.70	.90	1.17	1.20	.70	.90	1.17	1.20
	LOW (3)	AVG.	.82	.90	1.01	.91	.82	.90	1.01	.91	.82	.90	1.01	.91
L. T. R. = .20		L. L.	.62	.70	.81	.71	.62	.70	.81	.71	.62	.70	.81	.71
M2	HIGH (1)	AVG.	2.26	2.48	2.57	2.61	1.02	1.24	1.33	1.37	2.06	2.28	2.37	2.41
25-27 Oz. W.R.		L. L.	1.76	1.98	2.07	2.11	.52	.74	.83	.87	1.56	1.78	1.87	1.91
	LOW (1)	AVG.	1.84	2.06	2.15	2.19	.60	.82	.91	.95	1.64	1.86	1.95	1.99
L. T. R. = .50		L. L.	1.34	1.56	1.65	1.69	.10	.32	.41	.45	1.14	1.36	1.45	1.49
M3	SINGLE RANGE (4)	AVG.	1.95¶				1.09¶				1.80¶			
10 Oz. Cloth		L. L.	1.40				.54				1.25			
L. T. R. = .55			¶¶				¶¶				¶¶			
M4 10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth	HIGH (1)	AVG.	1.13	1.20	1.27	1.30	1.13	1.20	1.27	1.30	1.13	1.20	1.27	1.30
		L. L.	.93	1.00	1.07	1.10	.93	1.00	1.07	1.10	.93	1.00	1.07	1.10
	LOW (3)	AVG.	.93	.97	1.14	1.01	.93	.97	1.14	1.01	.93	.97	1.14	1.01
L. T. R. = .20		L. L.	.73	.77	.94	.81	.73	.77	.94	.81	.73	.77	.94	.81
M5 10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth	HIGH (1)	AVG.	2.26	2.48	2.57	2.61	1.02	1.24	1.33	1.37	2.06	2.28	2.37	2.41
		L. L.	1.76	1.98	2.07	2.11	.52	.74	.83	.87	1.56	1.78	1.87	1.91
	LOW (1)	AVG.	1.84	2.06	2.15	2.19	.60	.82	.91	.95	1.64	1.86	1.95	1.99
L. T. R. = .50		L. L.	1.34	1.56	1.65	1.69	.10	.32	.41	.45	1.14	1.36	1.45	1.49

* Short Term Loading, Wet Condition

** Number of Fabricators

¶ Values same for all thicknesses

¶¶ Single Range Only

L.L. = Lower Limit

L.T.R. = Lower Tolerance Range

Nominal Thickness Range t1 = 1/8", t2 = 1/4"
t3 = 3/8", t4 = 1/2"

TABLE 5-8. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED TENSILE POISSON'S RATIO *

LAMINATE	RANGE		0°	45°	90°
M1 2 Oz. Mat	SINGLE RANGE (4) **	AVG.	.32¶	.32 ¶	.32¶
		L. L.	.19	.19	.19
L. T. F. = .60			¶¶	¶¶	¶¶
M2 25-27 Oz. W. R.	SINGLE RANGE (4)	AVG.	.14	.65	.11
		L. L.	.06	.30	.05
L. T. F. = .46			¶¶	¶¶	¶¶
M3 10 Oz. Cloth	SINGLE RANGE (4)	AVG.	.17	.54	.17
		L. L.	.07	.22	.07
L. T. F. = .42			¶¶	¶¶	¶¶
M4 10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth	SINGLE RANGE (4)	AVG.	.32	.32	.32
		L. L.	.19	.19	.19
L. T. F. = .60			¶¶	¶¶	¶¶
M5 10 Oz. Cloth 25-27 Oz. W. R. 10 Oz. Cloth	SINGLE RANGE (4)	AVG.	.14	.65	.11
		L. L.	.06	.30	.05
L. T. F. = .46			¶¶	¶¶	¶¶

* Short Term Loading, Wet Condition

** Number of Fabricators

¶ Values same for all thicknesses

¶¶ Single Range Only

L. L. = Lower Limit

L. T. F. = Lower Tolerance Factor

TABLE 5-9. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED FLEXURAL STRENGTH *

Units in 10^3 psi

LAMINATE	RANGE		0°				45°				90°			
M1 2 Oz. Mat	HIGH (1)	AVG.	27.6 ¶				27.6 ¶				27.6 ¶			
		L. L.	21.0				21.0				21.0			
	LOW (3)	AVG.	20.5				20.5				20.5			
L. T. R. = 6.6		L. L.	13.9				13.9				13.9			
M2 25-27 Oz. W.R.	HIGH (3)		t1	t2	t3	t4	¶¶				t1	t2	t3	t4
		AVG.	27.7	31.2	32.9	32.6					27.7	31.2	32.9	32.6
		L. L.	21.8	25.3	27.0	26.7					21.8	25.3	27.0	26.7
	LOW (1)		t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
		AVG.	23.7	27.2	28.9	28.6	19.1	20.0	18.5	19.8	23.7	27.2	28.9	28.6
L. T. R. = 5.9		L. L.	17.8	21.3	23.0	22.7	13.2	14.1	12.6	13.9	17.8	21.3	23.0	22.7
M3 10 Oz. Cloth			¶¶				¶¶				¶¶			
	SINGLE RANGE (4)	AVG.	31.1				24.7				31.1			
L. T. R. = 4.6		L. L.	26.5				20.1				26.5			
M4 10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth	HIGH (1)	AVG.	27.6				27.6				27.6			
		L. L.	21.0				21.0				21.0			
	LOW (3)	AVG.	20.5				20.5				20.5			
L. T. R. = 6.6		L. L.	13.9				13.9				13.9			
M5 10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth	HIGH (3)		t1	t2	t3	t4	¶¶				t1	t2	t3	t4
		AVG.	27.7	31.2	32.9	32.6					27.7	31.2	32.9	32.6
		L. L.	21.8	25.3	27.0	26.7					21.8	25.3	27.0	26.7
	LOW (1)		t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
		AVG.	23.7	27.2	28.9	28.6	19.1	20.0	18.5	19.8	23.7	27.2	28.9	28.6
L. T. R. = 5.9		L. L.	17.8	21.3	23.0	22.7	13.2	14.1	12.6	13.9	17.8	21.3	23.0	22.7

Short Term Loading, Wet Condition

* Number of Fabricators

¶ Values same for all thicknesses

¶¶ Single Range Only

L.L. = Lower Limit

L.T.R. = Lower Tolerance Range

Nominal Thickness Range t1 = 1/8", t2 = 1/4"
t3 = 3/8", t4 = 1/2"

TABLE 5-10. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED FLEXURAL MODULUS *

Units in 10^6 psi

LAMINATE	RANGE		0°				45°				90°			
M1			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	HIGH (1)	AVG.	.82	1.00	1.23	1.50	.92	1.12	1.22	1.48	1.08	1.12	1.24	1.46
2 Oz. Mat		L. L.	.52	.70	.93	1.20	.62	.82	.92	1.18	.78	.82	.94	1.16
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	LOW (1)	AVG.	.41	1.26	.90	.78	.46	1.08	.94	.85	.45	1.11	.95	.96
L. T. R. = .30		L. L.	.11	.96	.60	.48	.16	.78	.64	.55	.15	.81	.65	.66
M2			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	HIGH (1)	AVG.	2.25	2.80	2.56	2.67	1.02	1.19	1.08	1.19	2.08	3.08	2.44	2.42
25-27 Oz. W.R.		L. L.	1.65	2.20	1.96	2.07	.42	.59	.48	.59	1.48	2.48	1.84	1.82
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	LOW (1)	AVG.	1.66	2.07	1.91	1.61	.76	.91	.86	1.00	1.41	1.46	1.65	1.62
L. T. R. = .60		L. L.	1.06	1.47	1.31	1.01	.16	.31	.26	.40	.81	.86	1.05	1.02
M3			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	HIGH (1)	AVG.	1.73	2.04	2.10	2.68	.96	1.16	1.19	1.49	2.17	1.90	1.95	2.66
10 Oz. Cloth		L. L.	1.30	1.61	1.67	2.25	.53	.73	.76	1.06	1.74	1.47	1.52	2.23
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	LOW (1)	AVG.	1.60	2.00	2.08	2.16	.75	1.14	1.04	.97	1.52	1.76	1.75	1.78
L. T. R. = .43		L. L.	1.17	1.57	1.65	1.73	.32	.71	.61	.54	1.09	1.33	1.32	1.35
M4			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth	HIGH (1)	AVG.	1.66	1.39	1.54	1.48	1.16	1.04	1.22	1.26	1.43	1.43	1.36	1.30
		L. L.	1.36	1.09	1.24	1.18	.86	.74	.92	.96	1.13	1.13	1.06	1.00
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	LOW (1)	AVG.	1.24	1.26	1.08	1.20	.69	.82	1.00	.98	1.06	1.14	1.04	1.10
L. T. R. = .30		L. L.	.94	.96	.78	.90	.39	.52	.70	.68	.76	.84	.74	.80
M5			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth	HIGH (1)	AVG.	2.25	2.80	2.56	2.67	1.02	1.19	1.08	1.19	2.08	3.08	2.44	2.42
		L. L.	1.65	2.20	1.96	2.07	.42	.59	.48	.59	1.48	2.48	1.84	1.82
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	LOW (1)	AVG.	1.66	2.07	1.91	1.61	.76	.91	.86	1.00	1.41	1.46	1.65	1.62
L. T. R. = .60		L. L.	1.06	1.47	1.31	1.01	.16	.31	.26	.40	.81	.86	1.05	1.02

* Short Term Loading, Wet Condition

** Number of Fabricators

L.L. = Lower Limit

L.T.R. = Lower Tolerance Range

Nominal Thickness Range t1 = 1/8", t2 = 1/4"
t3 = 3/8", t4 = 1/2"

TABLE 5-11. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED COMPRESSIVE STRENGTH *

Units in 10^3 psi

LAMINATE	RANGE		0°				45°				90°			
M1			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	HIGH (3) **	AVG.	21.0	20.0	22.8	24.3	21.0	20.0	22.8	24.3	21.0	20.0	22.8	24.3
2 Oz. Mat		L.L.	12.9	11.9	14.7	16.2	12.9	11.9	14.7	16.2	12.9	11.9	14.7	16.2
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	LOW (1)	AVG.	15.9	14.9	17.7	19.2	15.9	14.9	17.7	19.2	15.9	14.9	17.7	19.2
L.T.R. = 8.1		L.L.	7.8	6.8	9.6	11.1	7.8	6.8	9.6	11.1	7.8	6.8	9.6	11.1
M2			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	SINGLE RANGE (4)	AVG.	13.9	15.8	19.2	19.2	10.6	9.5	11.2	11.8	13.9	15.8	19.2	19.2
25-27 Oz. W.R.		L.L.	4.3	6.2	9.6	9.6	5.3	4.2	5.9	6.5	4.3	6.2	9.6	9.6
L.T.R. = 9.6 for 0° & 90° = 5.3 for 45°			¶¶				¶¶				¶¶			
M3	SINGLE RANGE (4)	AVG.	21.1 ¶				16.1 ¶				19.4 ¶			
10 Oz. Cloth		L.L.	13.0				10.0				13.0			
L.T.R. = 5.9			¶¶				¶¶				¶¶			
M4			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
10 Oz. Cloth 2 Oz. Mat	HIGH (3)	AVG.	21.0	20.0	22.8	24.3	21.0	20.0	22.8	24.3	21.0	20.0	22.8	24.3
10 Oz. Cloth		L.L.	12.9	11.9	14.7	16.2	12.9	11.9	14.7	16.2	12.9	11.9	14.7	16.2
			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
	LOW (1)	AVG.	15.9	14.9	17.7	19.2	15.9	14.9	17.7	19.2	15.9	14.9	17.7	19.2
L.T.R. = 8.1		L.L.	7.8	6.8	9.6	11.1	7.8	6.8	9.6	11.1	7.8	6.8	9.6	11.1
M5			t1	t2	t3	t4	t1	t2	t3	t4	t1	t2	t3	t4
10 Oz. Cloth 25-27 Oz. W.R.	SINGLE RANGE (4)	AVG.	13.9	15.8	19.2	19.2	10.6	9.5	11.2	11.8	13.9	15.8	19.2	19.2
10 Oz. Cloth		L.L.	4.3	6.2	9.6	9.6	5.3	4.2	5.9	6.5	4.3	6.2	9.6	9.6
L.T.R. = 9.6 for 0° & 90° = 5.3 for 45°			¶¶				¶¶				¶¶			

* Short Term Loading, Wet Condition

** Number of Fabricators

¶ Values same for all thicknesses

¶¶ Single Range Only

L.L. = Lower Limit

L.T.R. = Lower Tolerance Range

Nominal Thickness Range t1 = 1/8", t2 = 1/4"
t3 = 3/8", t4 = 1/2"

TABLE 5-12. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED COMPRESSIVE MODULUS *

Units in 10^6 psi

LAMINATE	RANGE		0°			45°			90°		
M1	HIGH (1) **	AVG.	1.35 ¶			1.35 ¶			1.35 ¶		
2 Oz. Mat		L. L.	.74			.74			.74		
	LOW (1)	AVG.	.93			.93			.93		
L. T. F. = .55		L. L.	.51			.51			.51		
M2			t2	t3	t4	t2	t3	t4	t2	t3	t4
	SINGLE RANGE (4)	AVG.	1.90	2.69	2.75	.98	1.17	1.23	1.82	2.57	2.63
25-27 Oz. W.R.		L. L.	1.02	1.44	1.48	.52	.63	.66	.98	1.38	1.41
L. T. F. = .54			¶¶			¶¶			¶¶		
M3	SINGLE RANGE (4)	AVG.	2.46			1.26			2.51		
10 Oz. Cloth		L. L.	1.82			.93			1.86		
L. T. F. = .74			¶¶			¶¶			¶¶		
M4 10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth	HIGH (1)	AVG.	1.35			1.35			1.35		
		L. L.	.74			.74			.74		
	LOW (1)	AVG.	.93			.93			.93		
L. T. F. = .55		L. L.	.51			.51			.51		
M5			t2	t3	t4	t2	t3	t4	t2	t3	t4
10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth	SINGLE RANGE (4)	AVG.	1.90	2.69	2.75	.98	1.17	1.23	1.82	2.57	2.63
		L. L.	1.02	1.44	1.48	.52	.63	.66	.98	1.38	1.41
L. T. F. = .54			¶¶			¶¶			¶¶		

* Short Term Loading, Wet Condition

** Number of Fabricators

¶ Values same for all thicknesses

¶¶ Single Range Only

L.L. = Lower Limit

L.T.F. = Lower Tolerance Factor

Nominal Thickness Range t2 = 1/4", t3 = 3/8"
t4 = 1/2"

TABLE 5-13. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED COMPRESSIVE POISSON'S RATIO *

LAMINATE	RANGE		0°	45°	90°
M1	SINGLE RANGE (4) **	AVG.	.42¶	.42¶	.42¶
2 Oz. Mat		L. L.	.22	.22	.22
L. T. F. = .52			¶¶	¶¶	¶¶
M2	SINGLE RANGE (4)	AVG.	.25	DATA INADEQUATE FOR ANALYSIS	.25
25-27 Oz. W.R.		L. L.	.07		.07
L. T. F. = .30			¶¶	¶¶	¶¶
M3	SINGLE RANGE (4)	AVG.	.23	.61	.23
10 Oz. Cloth		L. L.	.06	.37	.06
L. T. F. = .25 for 0° & 90° = .60 for 45°			¶¶	¶¶	¶¶
M4	SINGLE RANGE (4)	AVG.	.42	.42	.42
10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth		L. L.	.22	.22	.22
L. T. F. = .52			¶¶	¶¶	¶¶
M5	SINGLE RANGE (4)	AVG.	.25	DATA INADEQUATE FOR ANALYSIS	.25
10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth		L. L.	.07		.07
L. T. F. = .30			¶¶	¶¶	¶¶

* Short Term Loading, Wet Condition

** Number of Fabricators

¶ Values same for all thicknesses

¶¶ Single Range Only

L.L. = Lower Limit

L.T.F. = Lower Tolerance Factor

TABLE 5-14. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED SHEAR STRENGTH AND MODULUS *

LAMINATE	RANGE	PERPENDICULAR							PARALLEL				
			STRENGTH - 10^3 psi				MODULUS - 10^6 psi		RANGE		STRENGTH - 10^3 psi		
			t1	t2	t3	t4		RANGE		t1	t2	t3	t4
M1	HIGH (1) **	AVG.	13.1¶				0.40 §	HIGH (1) **	AVG.	10.5	12.7	12.3	14.3
2 Oz. Mat		L. L.	11.2						L. L.	8.5	10.7	10.3	12.3
	LOW (1)	AVG.	9.9					LOW (1)	AVG.	8.5	9.8	10.7	11.3
L. T. R. = 1.9		L. L.	8.0						L. L.	6.5	7.8	8.7	9.3
M2	HIGH (2)	AVG.	15.1	15.9	16.5	16.3	0.45		¶¶				
25-27 Oz. W.R.		L. L.	13.2	14.0	14.6	14.4							
	LOW (2)	AVG.	11.9	13.6	14.1	13.8		SINGLE RANGE (4)	AVG.	7.5	9.3	10.4	11.1
L. T. R. = 1.9		L. L.	10.0	11.7	12.2	11.9			L. L.	5.5	7.3	8.4	9.1
M3	HIGH (1)	AVG.	12.7	12.7	14.7	15.0	0.52		¶¶				
10 Oz. Cloth		L. L.	10.5	10.5	12.5	12.8							
	LOW (1)	AVG.	10.7	12.7	12.7	12.3		SINGLE RANGE (4)	AVG.	9.0	10.5	11.2	11.6
L. T. R. = 2.2		L. L.	8.5	10.5	10.5	10.1			L. L.	6.4	7.9	8.6	9.0
M4	HIGH (1)	AVG	13.1				0.49	HIGH (1)	AVG.	10.5	12.7	12.3	14.3
10 Oz. Cloth 2 Oz. Mat 10 Oz. Cloth		L. L.	11.2						L. L.	8.5	10.7	10.3	12.3
	LOW (1)	AVG.	9.9					LOW (1)	AVG.	8.5	9.8	10.7	11.3
L. T. R. = 1.9		L. L.	8.0						L. L.	6.5	7.8	8.7	9.3
M5	HIGH (2)	AVG.	15.1	15.9	16.5	16.3	0.52		¶¶				
10 Oz. Cloth 25-27 Oz. W.R. 10 Oz. Cloth		L. L.	13.2	14.0	14.6	14.4							
	LOW (2)	AVG.	11.9	13.6	14.1	13.8		SINGLE RANGE (4)	AVG.	7.5	9.3	10.4	11.1
L. T. R. = 1.9		L. L.	10.0	11.7	12.2	11.9			L. L.	5.5	7.3	8.4	9.1

* Short Term Loading, Wet Condition

** Number of Fabricators

¶ Values same for all thicknesses

¶¶ Single Range Only

§ Over-all Average

L.L. = Lower Limit

L.T.R. = Lower Tolerance Range

Nominal Thickness Range t1 = 1/8", t2 = 1/4"
t3 = 3/8", t4 = 1/2"

Fatigue

When certain materials are subject to cyclic or repeated loads, fatigue failure can occur at stresses below the ultimate static strength. Fatigue failure can be due to the reversal of a tensile, flexural or torsional stress in a member. Reversal of stress can occur with or without an initial or "mean" stress. If a mean stress is present in a system that undergoes stress reversals, the stress at failure is further reduced. In other words, when a member is preloaded and then subjected to stress reversals, the fatigue strength of the member is less than the strength of the same member without preload. Fatigue failures are usually propagated by cracks in high tensile areas and can be accelerated by initial cracks, flaws, discontinuities, holes, notches, etc.

Fiberglass laminates are subject to fatigue failures. However, because of the nature of their composition, it is difficult to pinpoint what type of failure actually predominates, that is, tensile, shear or delamination.

Figs. 5-7 and 5-8 present SN curves or fatigue strengths as per cent of ultimate strengths for mat-polyester and 181-136 cloth-polyester laminates in the dry condition, tested parallel to warp and at 73 degrees F and 50 per cent relative humidity. Similar data for 10 ounce cloth and woven roving is presently unavailable. These curves indicated that both tensile and flexural fatigue strengths of fiberglass polyester laminates tend to level off at approximately 20 to 30 per cent of their ultimate strengths at 10 million cycles (9-16). This stress level defines the fatigue limit or the value at which the material can undergo stress reversals for an indefinite period.

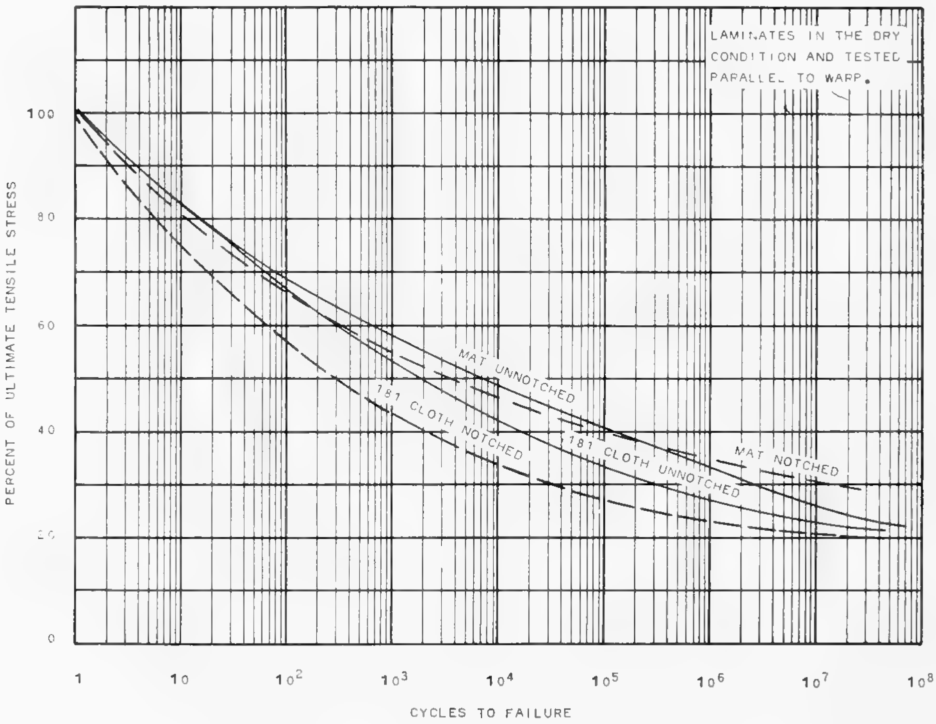


Fig. 5-7. Tensile Fatigue Strength of Fiberglass Polyester Laminates

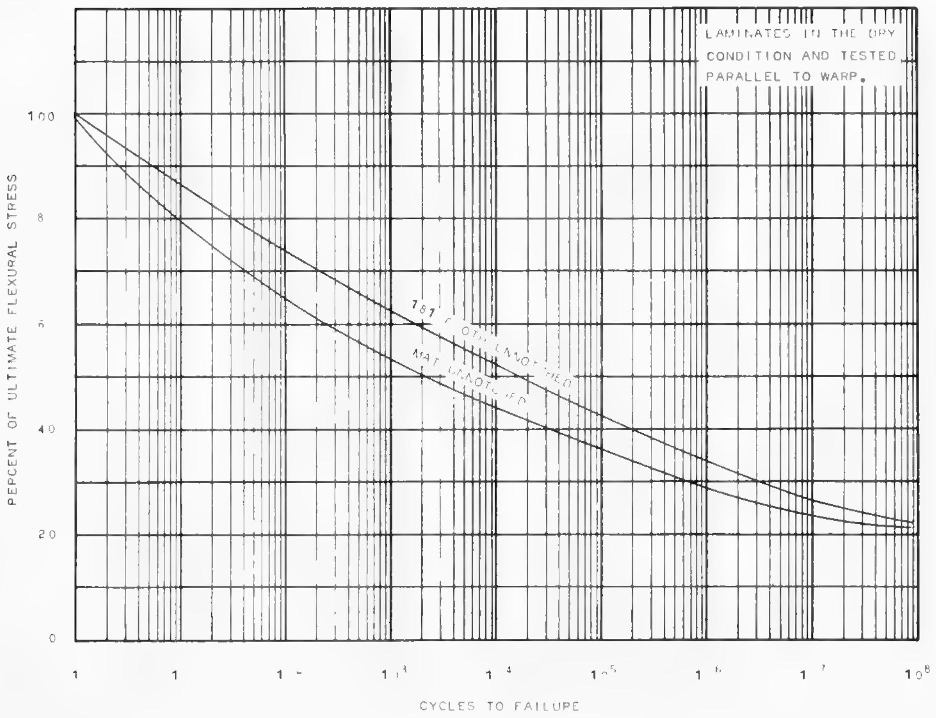


Fig. 5-8. Flexural Fatigue Strength of Fiberglass Polyester Laminates

Laminates exposed to elevated temperatures and extreme weathering conditions or immersed in water will have reduced fatigue strengths. In most cases, notched laminates fail at lower stress levels, for a given number of cycles, than unnotched laminates.

Further investigation is required to ascertain whether the effect of fatigue on the strengths of mat, 10 ounce cloth and woven roving laminates for boat hull construction will be of greater or lesser magnitudes due to their lower moduli.

For design purposes, when fatigue strength data for a specific application is not available, a low enough stress should be selected to insure that the laminate will withstand the applied loads for the required number of cycles to be expected in the normal life span of the structure.

Creep

Creep or deformation of fiberglass reinforced laminates under constant stress is dependent on time and temperature. Laminates made of different fiberglass reinforcements and resins will exhibit different creep characteristics (17, 18).

Figs. 5-9 to 5-14 illustrate tensile and flexural creep relationships of mat, woven roving and cloth polyester laminates at various percentages of the short term ultimate strengths. These curves are for laminates in the wet condition tested at 73 degrees F in water except for the tensile tests on the mat laminates which were in the dry condition and taken at 73 degrees F and 50 per cent relative humidity. Figs. 5-9 to 5-14 indicate that creep increases at high percentages of ultimate stress and with duration of continuous loading. Cloth laminates have lower creep characteristics than either mat or woven roving laminates.

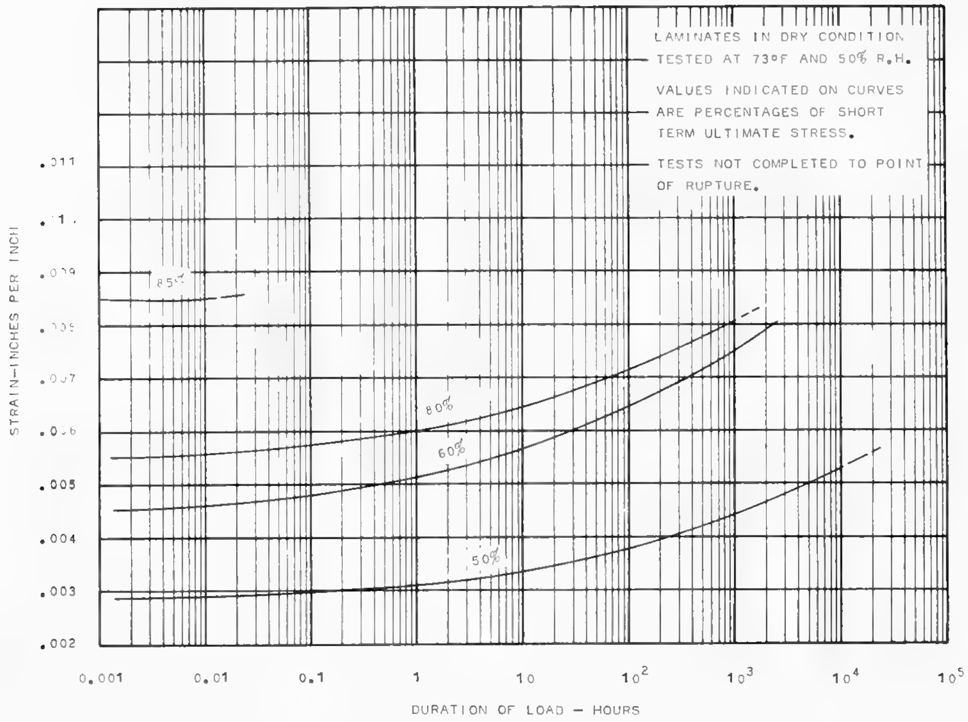


Fig. 5-9. Tensile Creep for Continuously Loaded Mat-Polyester Laminates

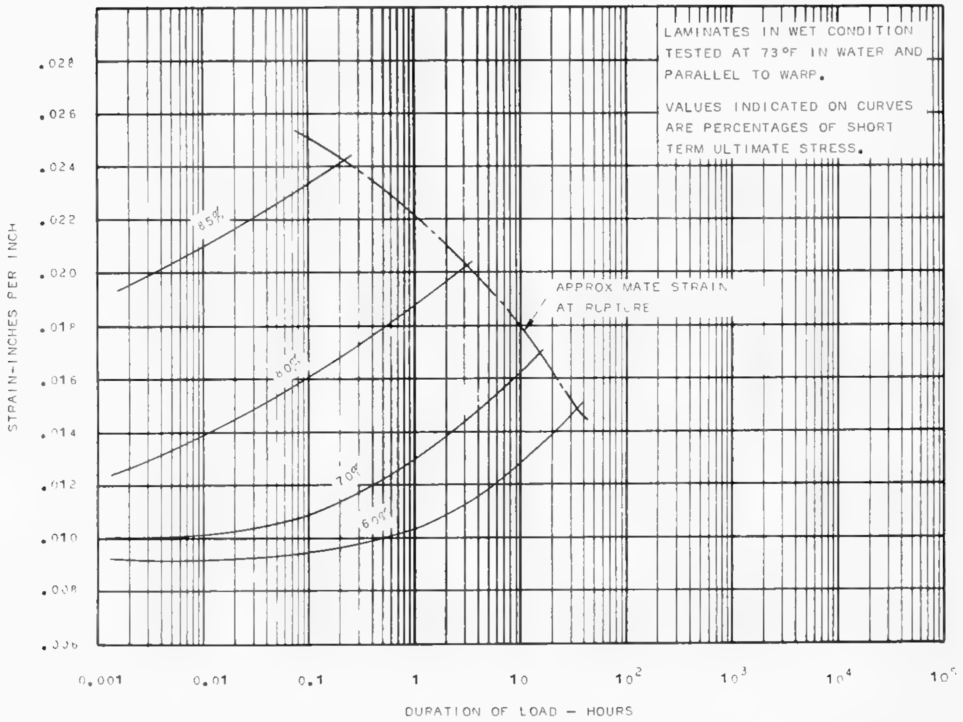


Fig. 5-10. Tensile Creep for Continuously Loaded 25-27 Ounce Woven Roving-Polyester Laminates

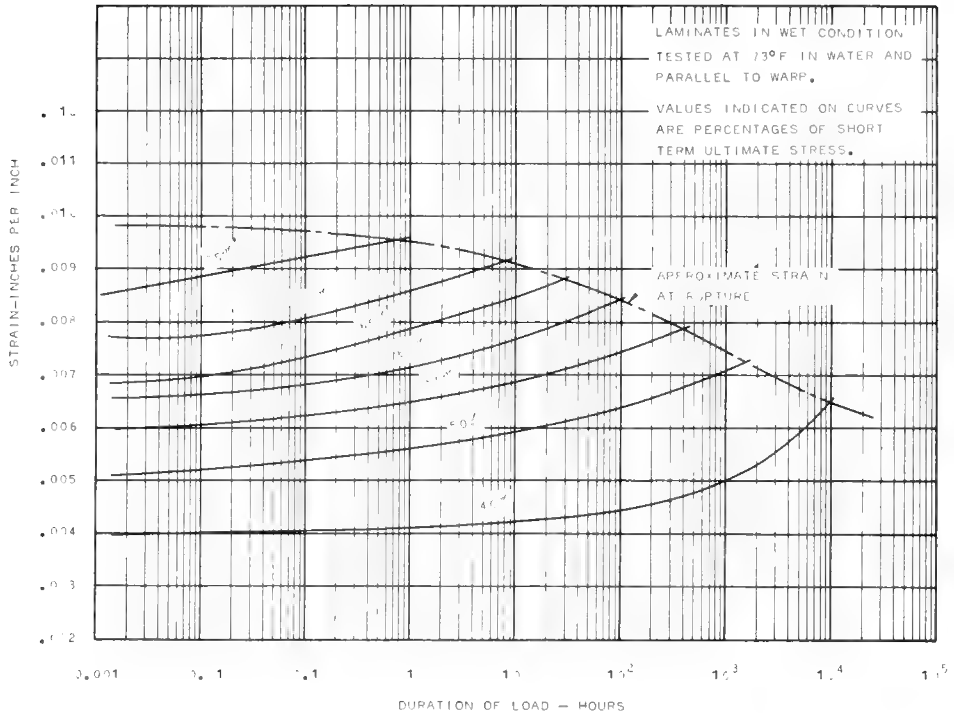


Fig. 5-11. Tensile Creep for Continuously Loaded 10 Ounce Cloth-Polyester Laminates

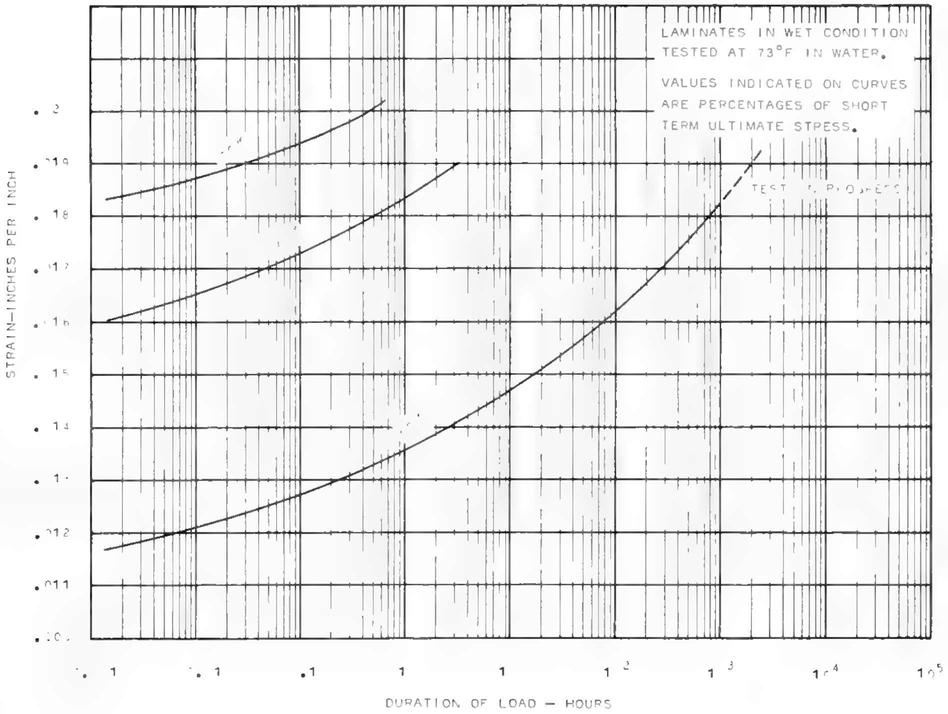
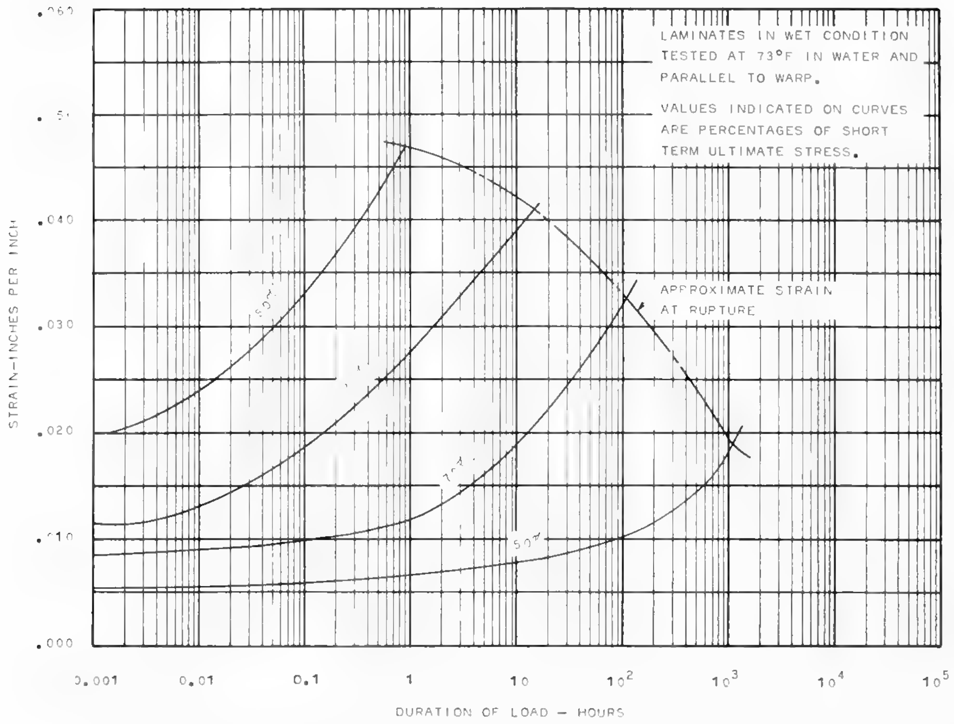


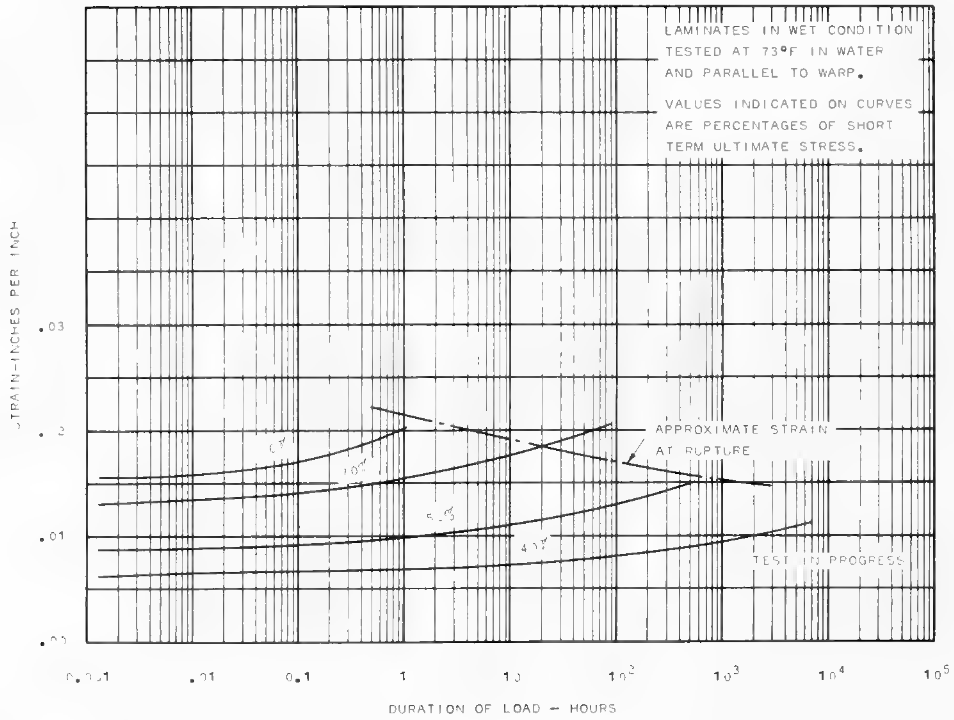
Fig. 5-12. Flexural Creep for Continuously Loaded Mat-Polyester Laminates



LAMINATES IN WET CONDITION TESTED AT 73°F IN WATER AND PARALLEL TO WARP.

VALUES INDICATED ON CURVES ARE PERCENTAGES OF SHORT TERM ULTIMATE STRESS.

Fig. 5-13. Flexural Creep for Continuously Loaded 25-27 Ounce Woven Roving-Polyester Laminates



LAMINATES IN WET CONDITION TESTED AT 73°F IN WATER AND PARALLEL TO WARP.

VALUES INDICATED ON CURVES ARE PERCENTAGES OF SHORT TERM ULTIMATE STRESS.

Fig. 5-14. Flexural Creep for Continuously Loaded 10 Ounce Cloth-Polyester Laminates

Since the initial strains and total strains indicated in the Figures are relatively small for the lower stress percentages at room temperatures, it appears that creep in fiberglass laminates may be negligible when the load percentages are further reduced to normal design stress levels of 20 to 30 per cent of ultimate stress. When fiberglass laminates are exposed to higher temperatures, creep may be of considerable importance.

Further investigation of the creep characteristics of commonly used boat hull laminates is required for normal design stress levels and slightly higher temperatures.

Rigidity

The flexural rigidity of a material is dependent on the moment of inertia of the section and the modulus of elasticity of the material. With a constant moment of inertia, the flexural rigidity increases with increased modulus of elasticity. Although the modulus of elasticity of fiberglass alone is 10.0×10^6, present fiberglass reinforced plastics can only attain moduli of elasticity between 0.5×10^6 to 5.0×10^6. The range of values is dependent on the type of reinforcement, resin and the molding method used. Lack of stiffness when compared to steel and aluminum can be of considerable importance when maximum rigidity is required. But low stiffness can be advantageous where flexibility is desired for impact. Lightweight sandwich construction with fiberglass laminate facings can be utilized where maximum rigidity is necessary.

SUPPLEMENTARY TEST PROGRAM TO OBTAIN PROPERTIES

Purpose

The types of laminate constructions evaluated by the basic test program do not include all of the many new types recently developed for boat hull construction. This supplementary test program was conducted to determine engineering properties of some of these new types of laminate constructions considered to be the most typical of those employed in the boat industry. Table 5-15 has been developed from the results of this test program. For ease of comparison both physical and mechanical properties are included.

The values given in Table 5-15 are intended for guidance only and each fabricator should conduct the necessary tests to establish similar properties representative of the laminates made in his plant.

Materials and Method of Fabrication

The materials and method of fabrication used were essentially the same as those used in the basic program except for the weights of the mats which were 3/4 and 1-1/2 ounces instead of 2 ounces. The laminates were made by the contact or hand lay up method with a polyester resin and cured at room temperature. The resin was formulated specifically for the contact molding of boat hulls and to provide some elasticity in the cured laminate. The catalyst system used was methyl ethyl ketone peroxide. No special post cure by heat was used to produce improved panels.

Types of Laminates

M6 = 1 ply 10 ounce cloth, 1 ply 1-1/2 ounce mat, 1 ply 25-27 ounce woven roving.

M7 = 1 ply 3/4 ounce mat, 1 ply 10 ounce cloth, 1 ply 25-27 ounce woven roving.

TABLE 5-15. FIBERGLASS POLYESTER LAMINATES - CONTACT MOLDED PHYSICAL AND MECHANICAL PROPERTIES OF TYPICAL BOAT HULL CONSTRUCTIONS

OVER-ALL AVERAGE VALUES* FOR GUIDANCE ONLY

Laminate Construction	Thickness Inches	Per Cent Glass		Specific Gravity	Tensile **						Flexural **						Compression **						Shear Strength ¶ Perpendicular PSI x 10^3		
		Volume	Weight		Strength PSI x 10^3			Modulus PSI x 10^6			Strength PSI x 10^3			Modulus PSI x 10^6			Strength PSI x 10^3			Modulus PSI x 10^6					
					0°	45°	90°	0°	45°	90°	0°	45°	90°	0°	45°	90°	0°	45°	90°	0°	45°	90°	0°	45°	90°
M6 1 ply 10 oz. cloth 1 ply 1-1/2 oz. mat 1 ply 25-27 oz. W.R. ¶¶	0.115	23.1	40.9	1.44	31.7	7.9	16.9	1.38	0.33	0.84	25.8	21.4	23.3	1.04	.86	.98	12.6	12.5	12.2	1.14	0.67	1.09	11.9	11.4	11.6
M7 1 ply 3/4 oz. mat 1 ply 10 oz. cloth 1 ply 25-27 oz. W.R.	0.094	26.5	45.5	1.48	26.6	6.6	15.8	1.28	0.26	0.92	27.9	21.7	25.2	.70	.60	.59	8.9	9.7	9.5	1.24	0.63	1.12	11.1	11.6	11.8
M8 1 ply 1-1/2 oz. mat 2 plies 25-27 oz. W.R.	0.128	27.3	46.7	1.49	26.9	6.8	20.4	1.51	0.26	0.99	34.4	20.6	26.3	1.04	.76	.84	12.1	11.3	12.5	1.29	0.74	1.21	13.0	12.7	12.8
M9 1 ply 1-1/2 oz. mat 1 ply 25-27 oz. W.R. 1 ply 3/4 oz. mat 1 ply 25-27 oz. W.R.	0.155	25.9	44.3	1.49	25.5	9.9	20.4	1.39	0.36	1.06	38.4	20.7	32.8	1.24	1.43	1.01	14.2	13.6	13.7	1.28	0.75	1.19	14.1	13.4	13.0
M10 1 ply 25-27 oz. W.R. 1 ply 3/4 oz. mat 1 ply 25-27 oz. W.R. 1 ply 3/4 oz. mat 1 ply 25-27 oz. W.R.	0.158	32.0	52.9	1.56	31.5	8.8	21.4	1.44	0.28	1.14	26.7	14.5	24.0	1.56	.63	1.25	13.4	12.1	13.2	1.33	0.72	1.20	14.5	13.6	12.5

* Mechanical properties from short term loading tests.

** Wet condition, 30 day immersion in water.

¶ Dry condition, 72 degrees F and 50 per cent relative humidity.

¶¶ W.R. designates woven roving.

M8 = 1 ply 1-1/2 ounce mat, 2 plies 25-27 ounce woven roving.

M9 = 1 ply 1-1/2 ounce mat, 1 ply 25-27 ounce woven roving, 1 ply 3/4 ounce mat, 1 ply 25-27 ounce woven roving.

M10 = 1 ply 25-27 ounce woven roving, 1 ply 3/4 ounce mat, 1 ply 25-27 ounce woven roving, 1 ply 3/4 ounce mat, 1 ply 25-27 ounce woven roving.

Test Procedures

The test procedures, conditioning and cutting of specimens were the same as those used for the basic test program with the following exceptions:

> All samples were conditioned for 48 hours at 72 degrees F and 50 per cent relative humidity before being immersed in distilled water for 30 days. The shear test samples were not immersed in water.
>
> The shear test samples were tested dry at 72 degrees F and 50 per cent relative humidity.
>
> Per cent glass by volume and weight are determined by an Owens Corning Fiberglas test procedure instead of by the USAF method used in the basic test program.
>
> All flexural test specimens were cut 1 inch wide instead of the 1/2 inch width specified in LP-406-b, 1031.1.

Evaluation of Test Data

Since the purpose of this supplementary program was to evaluate various types of laminate constructions within a limited time, it was necessary to restrict the scope of this program to a minimum number of test panels and specimens which would provide maximum data. All of the panels were fabricated and tested by a single laboratory. These panels were made with one polyester resin and only one panel was made for each type of laminate construction.

The effects of differences in fabricators, laboratories and thicknesses could therefore not be evaluated in this program and only the effect of variations in laminate reinforcements was obtained.

Simple average values without confidence limits were determined from 5 tests per property, per specimen, per direction except for moduli values which were taken on two specimens.

FACTORS AFFECTING ENGINEERING PROPERTIES

In addition to the type of reinforcement and molding method used, shop practice, environmental conditions and duration of loading are other primary factors affecting the engineering properties of fiberglass reinforced laminates.

Careless production methods which lack proper handling and storage of basic materials and adequate quality control will produce laminates with defects that will reduce the engineering properties of the laminates. All fabricators should investigate their facilities and molding operations to improve their production methods and quality of their products.

When exposed to unfavorable environmental conditions fiberglass laminates can be adversely affected. To minimize these effects, fiberglass laminates should be properly selected and adequately protected with a suitable gel coat.

Fiberglass laminates under long term continuous loading will exhibit a reduction in strength properties. This is a characteristic of the material that must be considered in design and proper stress levels must be selected to assure satisfactory long term service.

Shop Practice

The physical and mechanical properties of a laminate can be considerably reduced by fabrication defects such as voids, wrinkles, delamination, washing, resin dryness or richness, crazing and foreign inclusions (7). Also shrinkage of the resin and temperature changes that occur during curing cause residual stresses in fiberglass laminates affecting their mechanical properties. These effects can be minimized with properly controlled curing cycles.

Voids: The causes and effects of voids in laminates have been previously discussed in this Chapter. Excessive void content can be eliminated by careful lay up and handling technique, particularly in contact or hand lay up molding.

Wrinkles: Wrinkles in a laminate are caused by the careless handling of the plies of reinforcement during the lay up and molding process. A wrinkle between the plies of a laminate causes a weak area in the interlaminar bond and reduces the mechanical strength properties of the laminate. A wrinkle in the reinforcement causes a change in direction of an applied stress which is detrimental to the over-all strength of the laminate.

Delaminations: Lack of proper contact between adjacent plies in a laminate during cure results in interlaminar separation. The area of separation can be a void space or can be filled with excess resin. Either of these conditions results in a weak spot in the laminate. This type of defect does not readily occur in laminates cured under pressure but can result from careless lay up in the contact method.

Washing: The equal distribution of fiberglass mat, preform or chopped strand reinforcement can be disturbed by the relative movement of matched mold surfaces. This will cause weak spots in the laminate due to the separation and uneven distribution of the reinforcement. The effect of washing can be largely eliminated by careful mold design and handling of reinforcements during the molding process.

Resin Dryness: Laminates are resin dry when made with insufficient or unequally distributed resin. Resin dryness results in inadequate bonding of the fiberglass reinforcement causing excessive voids or porosity in the laminate resulting in low wet strength retention.

Resin Richness: Excessive amounts or uneven distribution of resin in a laminate can cause resin rich areas. These resin rich areas are subject to cracking and reduce the physical properties in a laminate due to the lack of adequate reinforcement in these areas.

Crazing: Crazing is the formation of tiny cracks through the body of a resin due to rapid or excessively hot curing conditions. Resin rich areas or heavy unreinforced gel coats of a laminate are subject to crazing. Gradual deterioration in crazed areas of a laminate can occur when subjected to weather and moisture. Laminates made with rigid polyester resins have a greater tendency to craze than laminates made with semi-rigid resins.

Foreign Inclusions in Laminates: Boat hulls are usually large and careless handling during the lay up can cause the inclusion of scraps of wood, pieces of string, paper, dirt, etc. These foreign inclusions can cause separation and wrinkles in a laminate and reduce its mechanical properties.

Good shop practice requires that a molding plant be kept as clean as possible to prevent contamination of the laminates.

Curing Shrinkage: During the curing process, the thermosetting resins used in reinforced plastics shrink in volume due to molecular crosslinking when passing from the liquid to the solid state. This reduction in volume or polymerization shrinkage is more marked in the case of polyester than epoxy resins. The resin forms a bond with the glass during the curing process. Since the glass does not undergo any appreciable change in volume during cure, shrinkage of the resin sets up compressive stresses in the glass and residual tensile stresses in the resin. In addition, the interfacial bond between the glass and resin may be subject to shearing stresses during the curing and bonding processes.

Another type of internal stress occurring during cure is due to thermal shrinkage. The curing process develops a considerable amount of heat in a laminate due to exothermic chemical reaction. Resins have a considerably higher coefficient of thermal expansion than glass. A differential thermal shrinkage between the glass and resin occurs when a laminate cools after curing. The effect of thermal shrinkage is additive to that of polymerization shrinkage in causing residual stresses in the glass and resin of the cured laminate.

The residual stresses in the complex structure of a fiberglass laminate can affect its short term or long term loading strength, fatigue strength and resistance to crazing and weathering.

Since these stresses and defects result from the curing process, they can be minimized by selection of optimum curing methods. Excessively rapid cures or exotherms higher than those required for proper cure should be avoided since they can cause damage to a laminate during cure. Thick laminate sections are particularly subject to uneven cure and thermal stresses.

The assistance of resin and catalyst manufacturers should be obtained in order to determine the optimum curing cycle for a molding process unless the fabricator has established methods from the results of extensive shop practice.

Environment

Fiberglass reinforced plastics can be adversely affected by unfavorable environmental conditions. Extended periods of water immersion and exposure to extreme weathering conditions can cause some reduction in strength properties and these effects must be considered when selecting a laminate for a specific application.

Water Immersion: The immersion of a fiberglass polyester laminate in water for a considerable length of time will result in some reduction in mechanical properties (18). The degree of reduction is influenced by the types of finish on the fiberglass and the percentage of voids in the laminate. High void content laminates have low wet strength retention. As previously discussed, high void content or porosity can occur in laminates with fiberglass contents exceeding the average fabrication range.

Figs. 5-15 and 5-16 give the relationships between fiberglass content, per cent voids and wet strength retention for 10 ounce cloth and 25-27 ounce woven roving with silane finishes. The graphs in these Figures, developed from limited data (19), indicate that laminates with fiberglass contents within the average fabrication ranges have wet strength retentions of approximately 80 to 95 per cent with the exception of compressive strength which has approximately 50 to 80 per cent retention. Laminates with lower fiberglass contents than the average fabrication range have higher percentages of wet strength retention even though they have lower initial strengths.

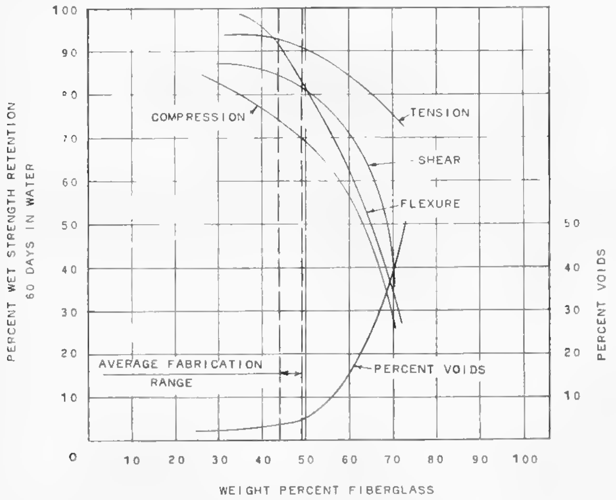


Fig. 5-15. Fiberglass Polyester Laminates - Contact Molded 10 Oz. Cloth with Silane Finish. Relationships Between Fiberglass Content, Per Cent Voids and Wet Strength Retention

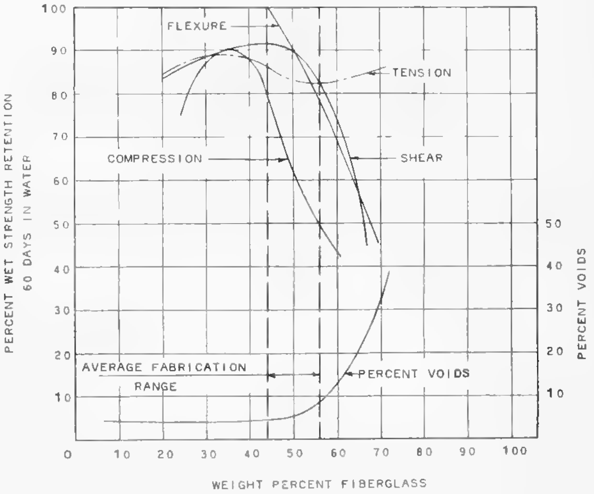


Fig. 5-16. Fiberglass Polyester Laminates - Contact Molded 25-27 Oz. Woven Roving with Silane Finish. Relationships Between Fiberglass Content, Per Cent Voids and Wet Strength Retention

Equivalent data for fiberglass mat laminates relating fiberglass content, per cent voids and wet strength retention are presently not available. Limited data indicates that fiberglass mat laminates with silane finish on the reinforcement and fiberglass content within the average fabrication range, have wet strength retentions of approximately 80 to 95 per cent for most of the mechanical properties.

Recent tests on fiberglass polyester laminates immersed in water for one year have been conducted (18) and the results are given in Table 5-16.

In most instances, laminates subjected to extended periods of continuous water immersion will have reduced percentages of wet strength retention. When properly coated with an effective paint or the more commonly used pigmented gel coat, fiberglass polyester laminates used in boat hull construction will satisfactorily resist the adverse affects of exposure to normal environmental conditions.

Weathering: Clear or translucent fiberglass polyester laminates exposed to direct sunlight and weather over a period of years will tend to yellow and show some reduction in mechanical properties. Fire-retardant resins containing chlorine in their molecular structure will deteriorate at a faster rate (20). Ultra-violet rays contained in the sunlight are considered to be the chief cause of weather deterioration.

TABLE 5-16. FIBERGLASS POLYESTER LAMINATES
PER CENT WET STRENGTH FOR EXTENDED PERIOD OF IMMERSION *

Laminate	Test Period Days	Tensile Strength	Tensile Modulus	Flexural Strength	Flexural Modulus
1-1/2 Oz. Mat	60	97.0	79.8	85.5	79.6
	365	NA **	NA	NA	NA
10 Oz. Cloth	60	82.4	97.8	83.5	94.5
	365	83.0	87.5	78.8	94.3
25-27 Oz. W.R.	60	89.7	79.7	77.0	94.7
	365	80.4	NA **	62.0	77.6

Ref. (18)

* Wet strength retention expressed as a percentage of short term dry strength. Dry strength tests at 73° F and 50% Relative Humidity. Wet strength tests at 73° F after immersion in water. All test samples cut parallel to warp direction.

** Not available.

When exposed to the normal range of weathering temperatures, fiberglass polyester laminates do not exhibit any appreciable change in mechanical properties. In general, mechanical properties are adversely affected by increasing temperature (21).

Most laminates, particularly those used in boat hulls, are covered by paints, finishes or pigmented gel coats for appearances. These coatings protect the laminate by screening out the ultra violet rays and minimizing moisture absorption. Severe weathering exposure tests of 3 years duration have proven the efficiency of these and other protective coatings in preventing the deterioration of fiberglass polyester laminates.

While extended weather exposures do cause some limited reduction in the strength properties of fiberglass polyester laminates, these materials are considered superior to wood under long term exposure. Wood under long term weather exposure is subject to swelling, cracking, dry rot, warping and fungus attack. Ferrous and some other metals not protected by coatings, are also subject to severe deterioration under extended weather exposure.

Chemical Resistance: Fiberglass polyester laminates, when properly cured, are resistant to most acids, oils and solvents. They are affected by strong alkalis, acids and chlorinated solvents (4, 22). At normal outdoor exposure temperatures, fresh and salt water, gasoline and fuel oils can be stored in fiberglass polyester tanks without any deteriorating effect on the laminate.

Both fuel and potable water tanks can be constructed as integral parts of a fiberglass hull structure to utilize the tank sides as stiffening for the shell. This results in a weight saving and reduced cost. Maintenance costs for special linings and painting are not required for fiberglass tanks.

Long Term Loading

As is the case with other structural materials, fiberglass reinforced laminates will fail under long term continuous loading at stresses below the ultimate stress for short term loading (18). Figs. 5-17, 5-18 and 5-19 give tensile, flexural and shear long term loading characteristics for mat, woven roving and cloth reinforced polyester laminates in the wet condition. These graphs show the per cent of short term ultimate stress at which the laminates will fail in a given time. For example; a 10 ounce cloth polyester laminate, M3, when continuously loaded at 40 per cent of the short term ultimate tensile stress will sustain this stress for 10,000 hours, Fig. 5-17.

As indicated by these graphs, mat polyester laminates have higher tensile and flexural strength retention than both cloth and woven roving laminates under long term continuous loading.

The effect of periodic or non-continuous loading has not been investigated. It is felt that periodic loading will not be cumulative and therefore will not have the same effect as continuous loading if the working stress level selected is approximately 20 to 30 per cent of the ultimate stress.

When selecting fiberglass laminates, designers must carefully consider the loading time intervals as well as the direction and magnitude of the applied loads. The judicious selection of working stress levels to allow for extended periods of loading is necessary to provide an adequate structure.

The nature and time interval of boat hull loads is such that the effect of long term continuous loading will be negligible in most cases. When extended periods of storage are contemplated for a boat hull, careful distribution of its weight on the supporting structure is necessary to minimize the effect of long term loading. Maximum design loads usually occur only momentarily or for short durations in the life span of a boat. Assuming a straight line extrapolation of these curves, it is believed that for normal design loads which may be periodic, the factors of safety suggested in Chapters 2 and 6 for fiberglass construction will allow working stress levels that will not have a long term loading effect on the laminate or reduce the maximum useful life expectancy of practically all boats.

PROPERTIES OF LOW DENSITY CORE MATERIALS

As previously discussed in Chapter 4, numerous types of core materials for use in closed frames and sandwich panels are available. The selection of a core material for boat hull construction depends on its physical and mechanical properties, its location in the hull and its specific function. Different core materials can be used satisfactorily in similar applications with minor variations in performance. In many applications the final selection is based on ease in handling and costs.

Table 5-17 gives physical and mechanical properties data for the most commonly used low density core materials (23-29). Additional research and development should result in improvement of these core materials.

Fig. 5-20 present SN or fatigue shear strengths as percentages of ultimate shear strengths, for the various commonly used core materials (30).

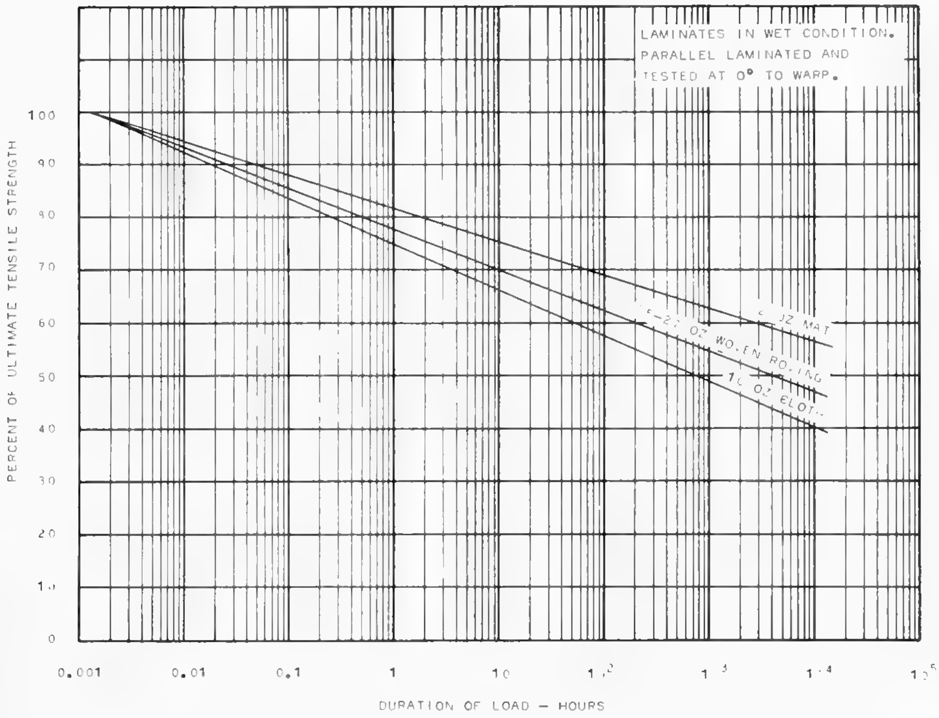


Fig. 5-17. Tensile Strength Retention of Continuously Loaded Polyester Fiberglass Laminates

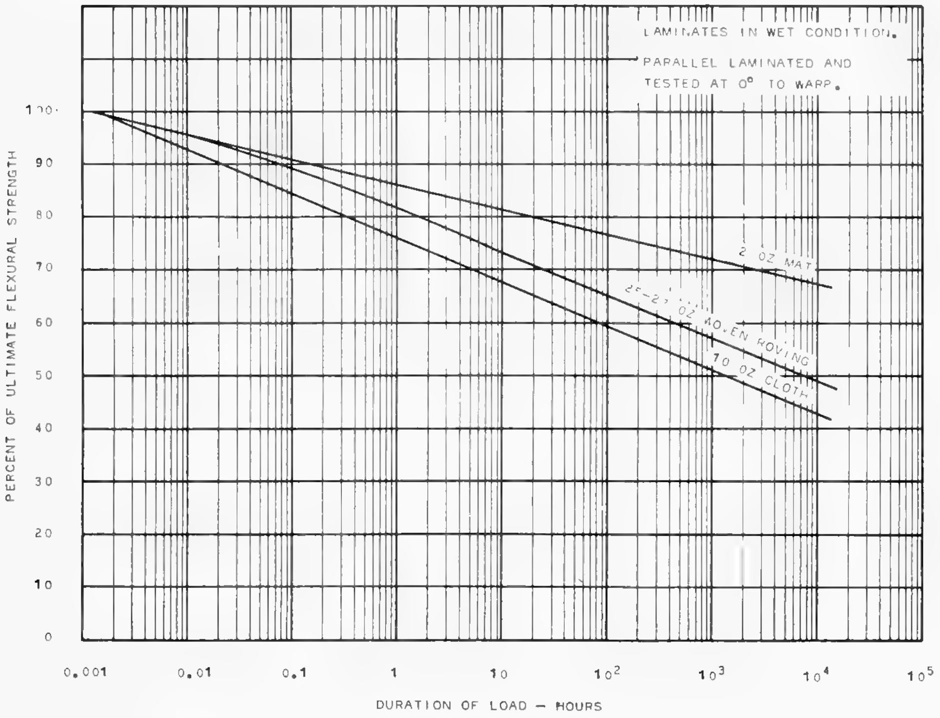


Fig. 5-18. Flexural Strength Retention of Continuously Loaded Polyester Fiberglass Laminates

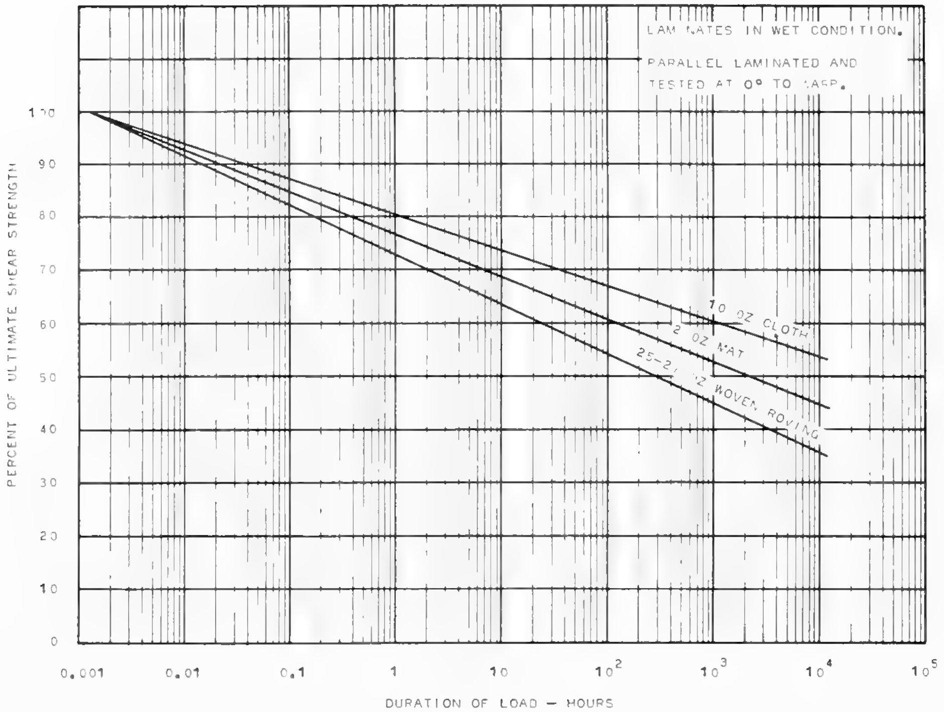


Fig. 5-19. Shear Strength Retention of Continuously Loaded Polyester Fiberglass Laminates

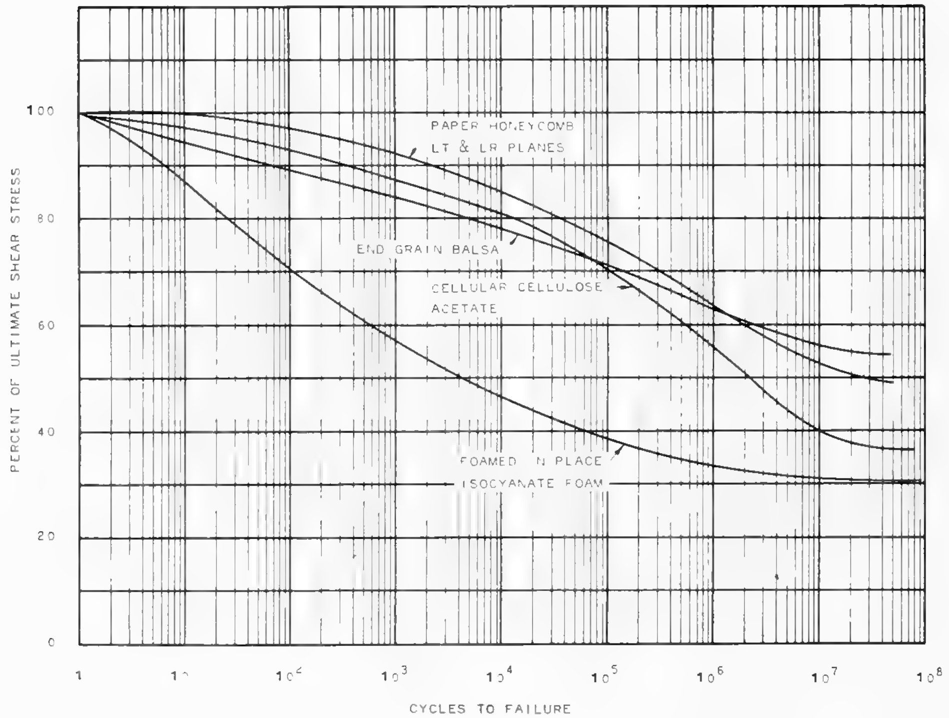


Fig. 5-20. Shear Fatigue Strength of Low Density Core Materials - Dry Condition

TABLE 5-17. PROPERTIES OF LOW DENSITY CORE MATERIALS *

CORE MATERIAL	COMPOSITION	DENSITY lb/ft^3	SHEAR STRENGTH psi	SHEAR MODULUS $x\ 10^3$ psi		COMPRESSIVE STRENGTH psi		COMPRESSION MODULUS $x\ 10^3$ psi	
Polystyrene Foam	Homogeneous Foam Expanded Polystyrene	1.3 - 1.7	22.0 - 30.0	.400 - .850		10.0 - 22.0			
		1.6 - 2.0	27.0 - 36.0	.700 - 1.60		16.0 - 32.0			
		1.7 - 2.3	30.0 - 40.0	1.00 - 1.30		16.0 - 38.0			
				Perpendicular to Grain	Parallel to Grain			Perpendicular to Grain	Parallel to Grain
Isoyanate Foam	Plastic Foam Available in Blocks and Sheets and can be foamed in place.	6.0	110.0	2.7	3.1	150.0		3.5	5.0
		8.0	150.0	3.8	4.4	230.0		6.0	8.0
		10.0	210.0	5.1	5.8	310.0		9.0	11.0
		12.0	260.0	6.5	7.5	420.0		12.0	15.0
		16.0	385.0	9.6	11.1	670.0		21.0	23.0
CCA Foam Cellular Cellulose Acetate	Plastic Foam Available in Blocks, Sheets and Strips	6.0 - 7.0	140.0	1.25 - 2.00		125.0			
		7.0 - 8.0	185.0	2.00 - 4.00		200.0			
Balsa Wood	Natural Wood Available in Blocks, Sheets and Strips	5.1 - 8.3	311.3 End Grain						
		5.0	130.0 - 145.0	-		550.	40. - 70	210.	
		9.0	245.0 - 290.0	-		1440.	80. - 115	580.	
		14.0	385.0 - 475.0	-		2600.	130. - 180	1000.	
			Flat Grain			Ultimate Strength End Grain	At Proportional Limit-Flat Grain	End Grain Compression	
Paper Honeycomb 7/16 Cell 60 Lb. Kraft 20% Phenolic Resin	Resin Impregnated Hexagonal Cell Structure of Kraft Paper Strips	1.76	Compressive Loading Parallel to core flutes and perpendicular to core ribbons 1.0 inch thick core 37.0 Parallel to core flutes and parallel to core ribbons 67.0	Compressive Loading Parallel to core flutes and perpendicular to core ribbons 0.5 inch thick core 3.70 Parallel to core flutes and parallel to core ribbons 0.5 inch core 9.6		110.0		50.2	
7/16 Cell 125 Lb. Kraft 35% Phenolic Resin		3.96	Compressive Loading Parallel to core flutes and perpendicular to core ribbons 144.0 Parallel to core flutes and parallel to core ribbons 247.0	Compressive Loading Parallel to core flutes and perpendicular to core ribbons 0.5 inch thick core 8.7 Parallel to core flutes and parallel to core ribbons 0.5 inch core 23.9		460.0		60.0	
Micro-Balloons Phenolic Resin Spheres	Gas Filled Spheres Embedded in Resin Base	10.0 - 40.0	-	-		1500. - 2700. Polyester Bound 800. - 1500. Epoxy Bound		-	

* Core Materials Tested in Dry Condition

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6

Design of Laminates

The efficient and economical utilization of construction materials and the selection of the appropriate material for specific applications can only be accomplished by knowledge of the behavior of available materials and associated design theories. This Chapter presents fundamental structural principles and theories as guidance for designing with fiberglass reinforced plastics. The utilization of these materials does not require any new principles of design but certain principles assume greater importance and require more extended consideration when designing for fiberglass reinforced plastics. Changes in the design procedures and theories presented will probably occur with increased design experience and when complete technical data as to the behavior of these materials becomes available.

Some of the design data developed, particularly tables and graphs associated with compressive strengths, plates, stiffener and plate combinations and sandwich construction, although considered theoretically sound, have not been completely verified by detail laboratory tests, but have proven satisfactory in some limited applications. Therefore careful interpretation of these data should be made.

Factors affecting the strength of fiberglass reinforced plastics as discussed in Chapter 5 are not considered in the design procedures presented here since they are not functions of the basic design principles and theories. These factors however should not be ignored and proper allowances should be provided when necessary. They should be separately considered for each application and adequately allowed for in the selection of the factors of safety.

The physical properties values for the various types of reinforcements used in the design examples are values given in Tables 5-6 to 5-14. These values have been selected at random to demonstrate the suggested methods of analyses. The higher values in the tables should only be used when justified with necessary strength tests of the actual production laminate to be used.

BEHAVIOR OF LAMINATES

Fiberglass laminates are composed mainly of two materials, fiberglass reinforcement and resin. A laminate is similar to reinforced concrete with the exception that the fibers are distributed throughout the entire laminate and occupy a greater volume than does the steel in reinforced concrete. In the fiberglass laminate the glass and resin are assumed to act as a unit for all combinations of stresses, whereas in reinforced concrete the steel acts principally to resist tension while the concrete resists compression. This implies that for any loading condition, both the resin and the fiberglass reinforcement are firmly bonded together and undergo equal deformations.

In the elastic design of steel, the assumption is made that the material is never stressed beyond the proportional limit. Within this range, the material obeys Hooke's Law of Proportionality, i.e. the unit stress is directly proportional to the unit strain. Fiberglass laminates are complex structurally and do not always behave according to Hooke's Law, but in the majority of cases this assumption can be made without appreciable error in the results.

Therefore in the design procedures and theories for laminates or structures composed of fiberglass and resin combinations, the following basic assumptions are considered valid:

> The fiberglass and resin act as a single unit and have equal strains under all loading conditions.
>
> The material is considered elastic and obeys Hooke's Law. This assumes that the stress is directly proportional to the strain and that the material will return to its original shape when the load is removed.

Most fiberglass reinforced laminates, because of their layered construction, are not homogeneous. Laminates are built up of a number of layers of the same or different type of reinforcement and each layer may have different physical properties in different directions. The physical properties and structural behavior of a laminate are primarily dependent upon the type and orientation of the reinforcement, the resin and the molding method used to fabricate the laminate.

Since many types of reinforcements and resins are available, there can be many satisfactory types of fiberglass laminates. Further variations in laminates are due to fillers, glass and resin content and laminate thickness. These variable factors can be controlled in some cases by the designer or fabricator.

The factors under control of the designer include the choice of fiberglass reinforcements, resins, dimensions, form and molding method. This gives the designer considerable latitude in designing boat hulls or other structures. In addition, there are a number of factors that cannot be controlled to any extent by the designer.

The factors beyond the control of the designer include variability of resins and other materials from one lot to another and variations in workmanship and technique. The degree of variability due to these factors may be established by testing methods and allowed for by the designer. The development of quality control methods by resin manufacturers and the use of better fabrication techniques are gradually reducing the effect of these variables.

The strength of fiberglass reinforced plastics is basically dependent upon the adhesion and the greater frictional resistance between the resin and glass fiber (1). The greater the adhesion and frictional resistance the greater the strength. The maximum theoretical strength that can be developed occurs when the adhesion strength plus the frictional resistance between the resin and glass fiber equals the cohesion strength of the resin. To assist in developing this maximum strength, sizes and finishes are applied to the glass fibers which react chemically with the glass when applied, and later react with the resin during molding. The frictional resistance is developed by the shrinkage of the resin during curing.

Stress-Strain Relationship

The mechanical behavior of a material under load can generally be predicted from observations of its stress-strain curve (2, 3). The stress-strain curve is obtained by gradually loading a test specimen to rupture, usually in tension, measuring the strain at various stress levels and plotting the results. The two most important characteristics obtained from the tensile test are strength and ductility. Speed of testing, preloading, form and cross-section shape will considerably affect the properties of a material.

Figs. 6-1, 6-2 and 6-3 are typical stress-strain curves for metals, wood and fiberglass laminates. The curves have several points of inflection and each point is indicative of a specific change in the behavior of the material. From these points of inflection, properties such as proportional limit, yield point, initial and secondary moduli of elasticity and point of rupture or ultimate stress can be determined.

Fig. 6-1 indicates the variation in the stress-strain behavior for some commonly used structural metals. The first part of the curves in Figs. 6-1a, 6-1b and 6-1c are substantially a straight line to point P, the proportional limit. This indicates a constant ratio between the stress and strain, and within this range the material behaves elastically conforming to Hooke's Law of Proportionality. The numerical value of the ratio is the modulus of elasticity, E, and is determined by dividing the unit stress by the unit strain.

$$E = \frac{f_t}{\varepsilon} \qquad (6.1)$$

Where E = Modulus of Elasticity - psi

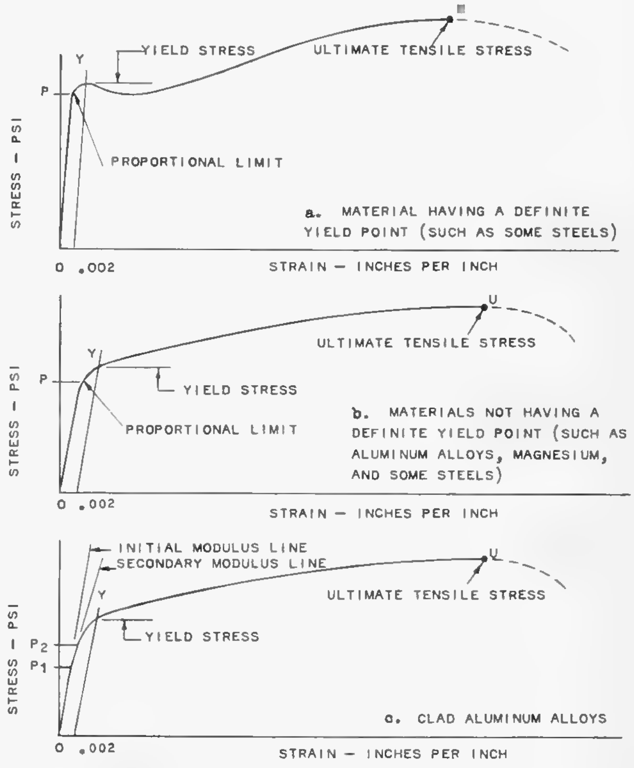
f_t = Unit stress - psi

ε = Unit strain - inches per in.

Beyond the proportional limit, the ratio of the stress to strain, designated as the tangent modulus, varies with the slope of the stress-strain curve and is usually different at each stress value.

The curve in Fig. 6-1c shows two separate proportional limits and moduli of elasticity; initial and secondary. This curve indicates the behavior of clad aluminum alloys where the initial modulus holds up to the proportional limit of the relatively soft covering and the secondary modulus holds up to the proportional limit of the stronger core material.

Beyond the proportional limit, the strain increases at a faster rate with increased stress, and slightly above this limit the material begins to retain a permanent set upon removal of the stress. For some steels, a sharp break in the curve occurs at a stress considerably below the ultimate tensile stress, Fig. 6-1a. At this stress, referred to as the yield point on the curve, the material breaks down rapidly and a sudden large increase in deformation occurs with little or no increase in stress. Nonferrous metals and some steels do not have this sharp break or yield point but yield gradually after passing the proportional limit, Figs. 6-1b and 6-1c.



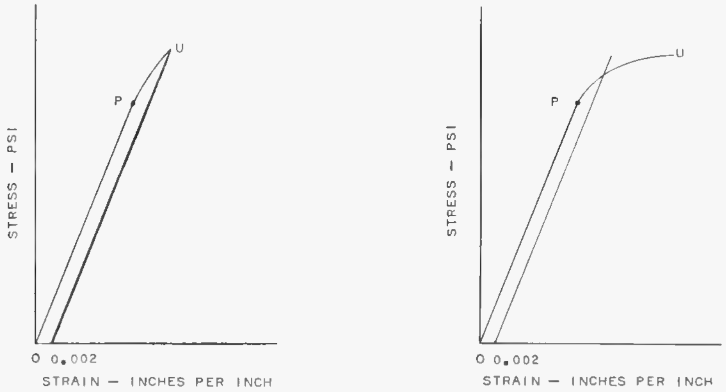
REFERENCE 4

Fig. 6-1. Typical Tensile Stress-Strain Curves for Metals

Based on practical limitations of permissible deformation in a structure, an arbitrary strain of 0.2 per cent has been established for most metals and the corresponding stress at this strain is referred to as the yield stress. This yield stress, point Y on the curves, is taken at the intersection of the stress-strain curve with a line drawn parallel to the straight or elastic portion of the curve, OP, through 0.002 strain at zero stress. For metals, factors of safety are usually based on this yield stress.

The ultimate tensile stress indicated as point U on the curves in Figs. 6-1a, 6-1b and 6-1c, is simply the stress at the maximum load based on the original cross-sectional area. It is interesting to note that most metals including steel and aluminum have yield strengths considerably lower than their ultimate strengths and have comparatively large deformations between their proportional limits and ultimate strengths.

The stress-strain curves for plywood, Fig. 6-2a and wood, Fig. 6-2b, similar to the nonferrous metals curve, Fig. 6-1b, do not have yield points but yield gradually after passing the proportional limit. The deformations between the proportional limits and the ultimate strengths, particularly for plywood, are less than for the metals. If a 0.2 per cent offset line is drawn in Figs. 6-2a and 6-2b to obtain a corresponding yield strength similar to the metals, Fig. 6-1, it will intersect the curve well above the proportional limit and in some cases above the ultimate strength. Therefore, only the proportional limit and ultimate strengths are considered when designing with wood.



a. PLYWOOD — PARALLEL TO FACE GRAIN

REFERENCE 5

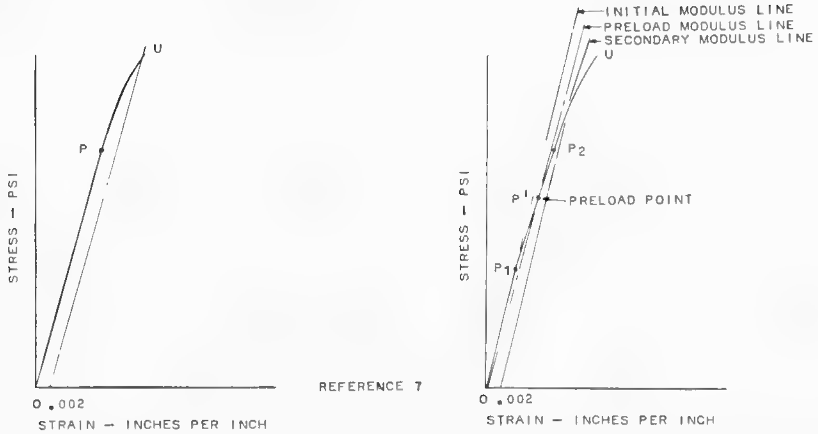
b. SOLID WOOD — PARALLEL TO GRAIN

REFERENCE 6

Fig. 6-2. Typical Tensile Stress-Strain Curves for Wood

The stress-strain curves for fiberglass laminates are generally similar to most structural materials since they exhibit a linear portion followed by a nonlinear portion, Fig. 6-3a. Like some of the metals and like wood no yield point exists. It is important to emphasize that for loading in the direction of warp, the deviation of the upper nonlinear portion of the curve from the lower linear portion is usually small at the point of failure. This limited deviation of the curve indicates that the strain deformations are quite small and the material has low ductility. This low ductility of fiberglass laminates does not allow for stress relief around stress concentration raisers such as notches, holes, reduction in area and sharp angles as the more ductile materials do. Allowance for this low ductility should be made by increased factors of safety for such points.

In some instances stress-strain curves for fiberglass laminates indicate two separate proportional limits and moduli of elasticity, Fig. 6-3b. This behavior is predominant for



REFERENCE 7

a. SINGLE PROPORTIONAL LIMIT

b. DUAL PROPORTIONAL LIMITS

Fig. 6-3. Typical Tensile Stress-Strain Curves for Fiberglass Reinforced Laminates

tension, less noticeable for flexure and practically nonexistent for compression. Parallel laminates made with unidirectional reinforcement do not appear to indicate this dual characteristic when stress is applied parallel to the warp.

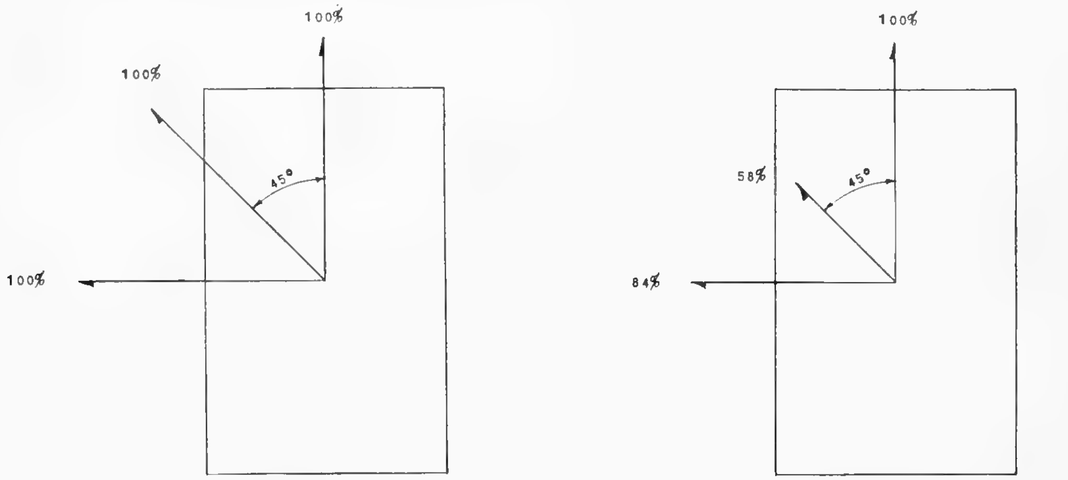
Preloading above the initial proportional limit modifies the lower straight line portion of the curve to the point of preload, P', Fig. 6-3b, and the slope is altered to an intermediate value between the initial and secondary slopes of the preload curve. As the preloading is increased to the second proportional limit the initial straight line portion of the curve disappears and a new single straight line portion is obtained to the secondary proportional limit. Repeated preloading to the same stress level appears to cause no additional change.

This dual proportional limit characteristic, similar to the clad aluminum alloy previously discussed, is believed to be due to the difference in the individual strengths of the combined materials. The initial break in the curve probably occurs at failure of the resin and the entire load is transferred to the fiberglass reinforcement. The effect of preloading beyond the initial break may then simply be the behavior of the fiberglass reinforcement with additional failure or cracking of the resin as the stress level is increased.

If a 0.2 per cent offset line is drawn to obtain an apparent yield stress for fiberglass laminates, Figs. 6-3a and 6-3b, it will intersect the curve well above the proportional limit and for most laminates will be very close to or beyond the ultimate stress. It is obvious that establishing a yield stress at 0.2 per cent strain offset as a basis for design safety factors is quite impractical and should not be done. Therefore it is recommended that factors of safety be based on the ultimate stress of the laminate.

Directional Characteristics

Homogeneous materials such as steel and aluminum can be assumed as isotropic and as having the same physical characteristics at any angle or direction. This is not true for all fiberglass laminates; the exception being mat reinforced laminates which are considered homogeneous as discussed in Chapter 5. Fiberglass cloth and woven roving when used as reinforcement in laminates generally produce orthotropic materials. These laminates will have different ultimate strengths at various angles to the warp direction and must be analyzed accordingly. Fig. 6-4 illustrates the difference in the distribution of ultimate tensile strengths for isotropic and orthotropic materials. Values given in Fig. 6-4b are assumed and will vary with different materials.



a. ISOTROPIC – EQUAL STRENGTHS IN ALL DIRECTIONS

b. ORTHOTROPIC – DIFFERENT STRENGTHS AT VARIOUS ANGLES

Fig. 6-4. Distribution of Tensile Strength for Isotropic and Orthotropic Materials

For an example of the orthotropic characteristics of fiberglass laminates, Fig. 6-5 illustrates the directional properties of a 10 ounce cloth laminate with the warp fibers placed in the vertical or 0 degree direction.

If a load P in tension is applied in the direction of the longitudinal L or 0 degree axis, the laminate exhibits an ultimate tensile strength or tensile strength at rupture that is equal to an average value of 24,100 psi, Table 5-6. This is the strongest value that the 10 ounce cloth laminate will exhibit since it is in the warp direction or the direction with the maximum number of fibers. A tensile load applied in the 45 degree direction will cause the laminate to rupture when the tensile stress reaches a value of approximately 14,000 psi. This will be the weakest value for this laminate. At 90 degrees, or the transverse direction, the laminate will fail when a tensile load, placed in this direction causes a tensile stress of 20,200 psi.

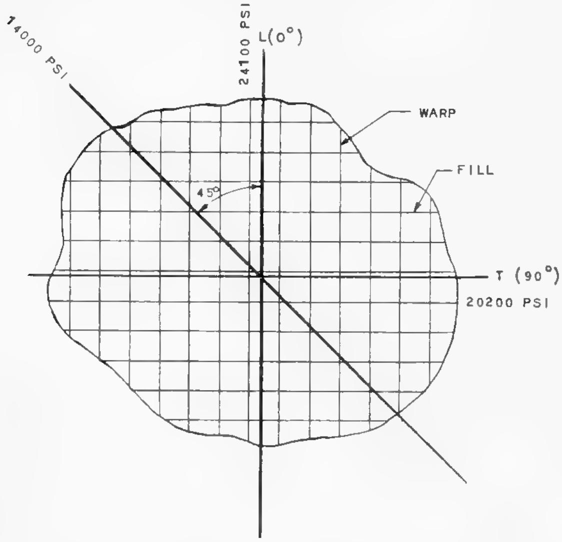


Fig. 6-5. Orthotropic Characteristics of a 10 Ounce Fiberglass Cloth Polyester Laminate

It is apparent from observation of Fig. 6-5 that in order to properly design an orthotropic laminate the strength of the laminate must be known in all directions and its behavior under load must be thoroughly understood.

Before a thorough stress analysis can be performed it becomes necessary to have the values of the physical constants for all angles (8-12). The general procedure for the determination of these constants is to test the laminate at 0 degrees, 45 degrees and 90 degrees to the warp. The two basic values at 0 degrees and 90 degrees can be used to compute, by means of mathematical identities, the values at the intermediate angles. The test value at 45 degrees can be used to verify the calculated value. Once the basic values at 0 degrees and 90 degrees are obtained, graphs can be developed which will give at a glance, the value of any constant for a specific angle.

The following graphs, Figs. 6-7 to 6-12, which are typical of those that can be established, are based upon Fig. 6-6 and the following equations:

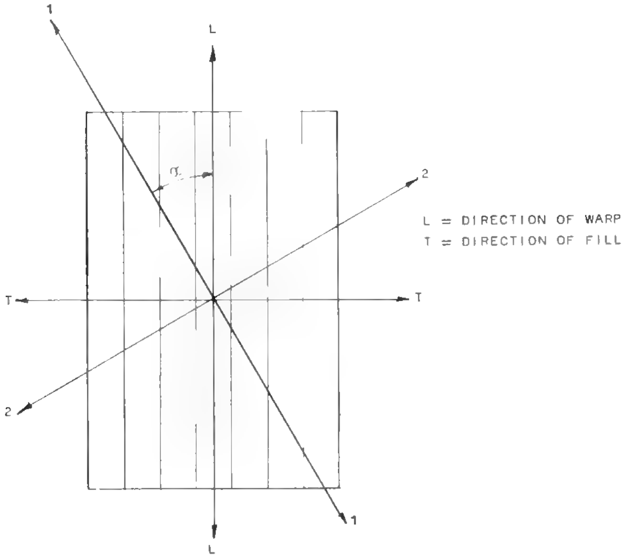


Fig. 6-6. Orthotropic Laminate

The modulus of elasticity, E_1, due to a stress applied in the 1-1 direction at an angle α with the warp direction is obtained from:

$$\frac{E_L}{E_1} = \cos^4\alpha + \frac{E_L}{E_T}\sin^4\alpha + \left[\frac{1}{4}\,\frac{E_L}{G_{LT}} - 2\sigma_{LT}\right]\sin^2 2\alpha \tag{6.2}$$

Poisson's Ratio is obtained from:

$$\sigma_{12} = \frac{E_1}{E_L}\left[\sigma_{LT} - \frac{1}{4}\left(1 + 2\sigma_{LT} + \frac{E_L}{E_T} - \frac{E_L}{G_{LT}}\right)\sin^2 2\alpha\right] \tag{6.3}$$

The shear strain is obtained from:

$$\gamma_{12} = -\,m_1\,\frac{f_1}{E_L} \tag{6.4}$$

where:

$$m_1 = \sin 2\alpha\left[\sigma_{LT} + \frac{E_L}{E_T} - \frac{1}{2}\,\frac{G_L}{G_{LT}} - \cos^2\alpha\left(1 + 2\sigma_{LT} + \frac{E_L}{E_T} - \frac{E_L}{G_{LT}}\right)\right] \tag{6.5}$$

The shear stress causes the following strains in the 1-1 and 2-2 directions respectively:

$$\varepsilon_1 = - m_1 \frac{\tau_{12}}{E_L} \qquad (6.6)$$

$$\varepsilon_2 = - m_2 \frac{\tau_{12}}{E_L} \qquad (6.7)$$

where:

$$m_2 = \sin 2\alpha \left[\sigma_{LT} + \frac{E_L}{E_T} - \frac{1}{2}\,\frac{E_L}{G_{LT}} - \sin^2\sigma \left(1 + 2\sigma_{LT} + \frac{E_L}{E_T} - \frac{E_L}{G_{LT}} \right) \right] \qquad (6.8)$$

The shear stress τ_{12} applied in the 1-1 and 2-2 directions causes a shear strain:

$$\gamma_{12} = \frac{\tau_{12}}{G_{12}} \quad \text{and the shear modulus is obtained from:} \qquad (6.9)$$

$$\frac{G_{LT}}{G_{12}} = \frac{G_{LT}}{E_L} \left[\left(1 + 2\sigma_{LT} + \frac{E_L}{E_T} \right) - \left(1 + 2\sigma_{LT} + \frac{E_L}{E_T} - \frac{E_L}{G_{LT}} \right) \cos^2 2\alpha \right] \qquad (6.10)$$

Some of the physical constants which are important in structural analysis are as follows:

Flexural Modulus = E_{bL} and E_{bT}, where E_{bL} is measured parallel to the warp and E_{bT} is measured perpendicular to the warp.

Tensile Modulus = E_{tL} and E_{tT} measured as above.

Compressive Modulus = E_{cL} and E_{cT} measured as above.

Flexural Stress = f_{bL} and f_{bT} measured as above.

Tensile Stress = f_{tL} and f_{tT} measured as above.

Compressive Stress = f_{cL} and f_{cT} measured as above.

Poisson's Ratio = σ_{LT}, strain in the transverse direction due to a load in the longitudinal direction, and σ_{TL}, strain in the longitudinal direction due to a load in the transverse direction.

Modulus of Rigidity or Shear Modulus = G_{LT}.

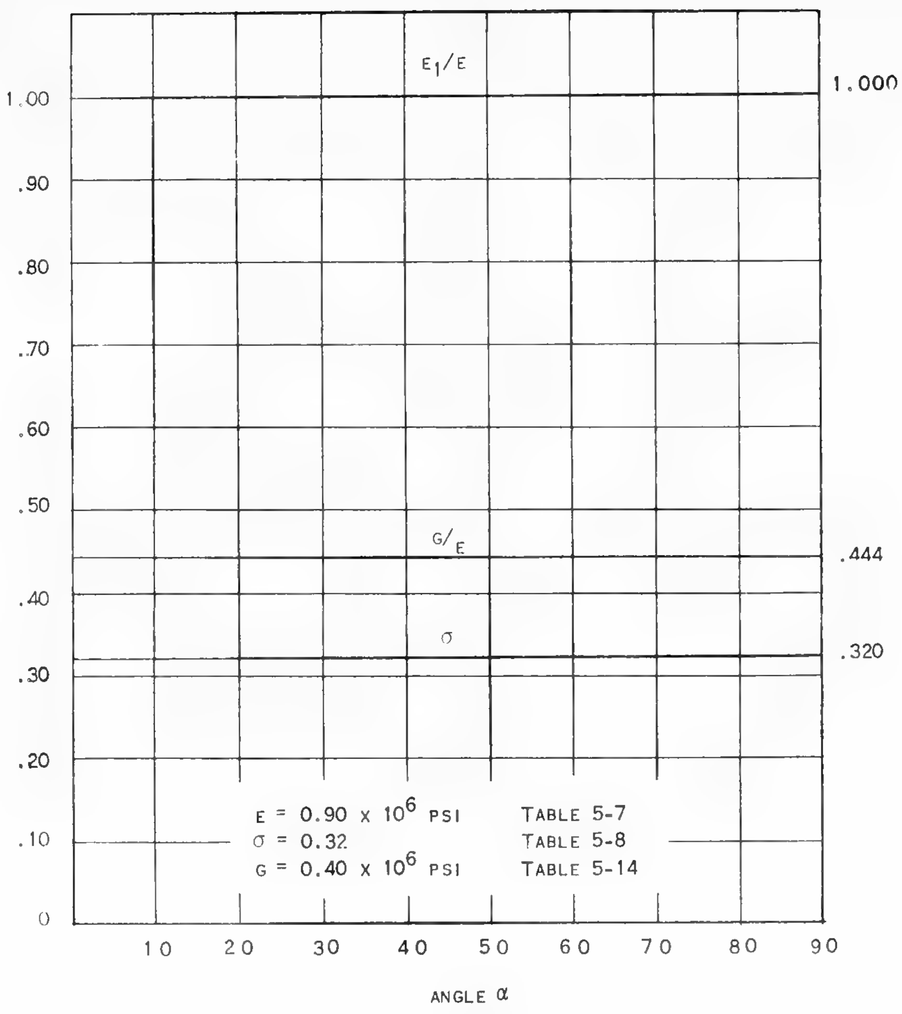


Fig. 6-7. Tensile Elastic Constants of Mat-Polyester Laminate - Wet Condition

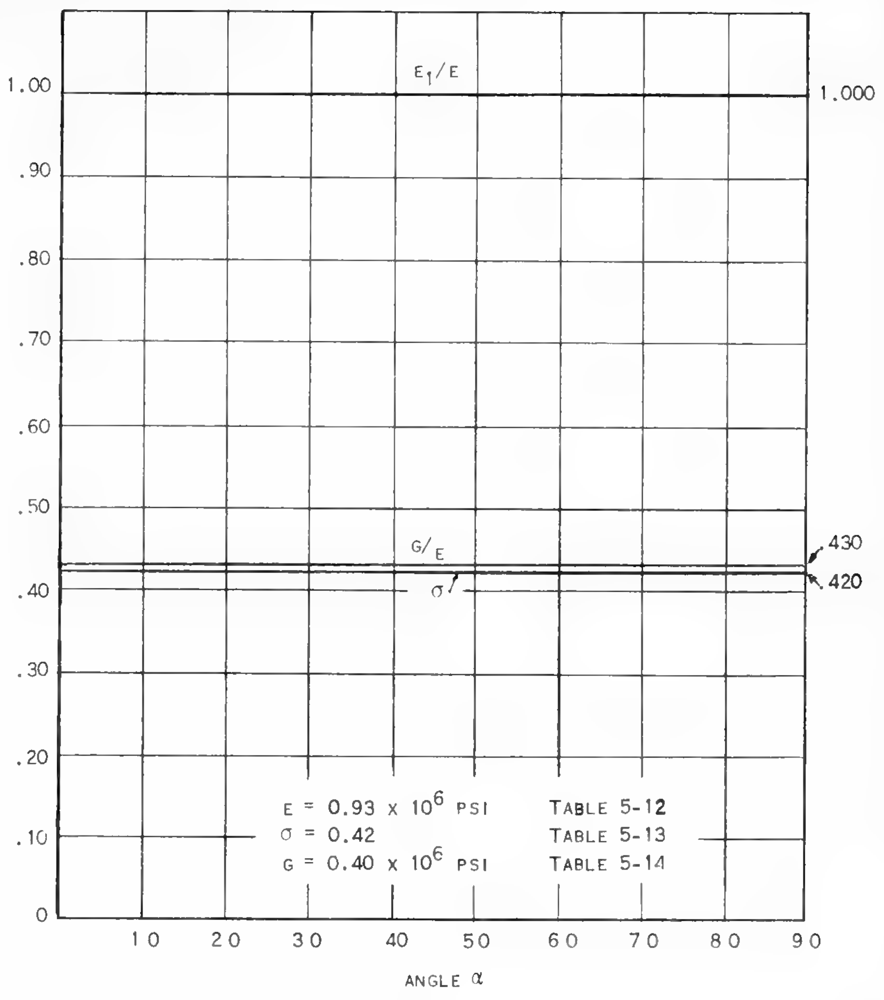


Fig. 6-8. Compressive Elastic Constants of Mat-Polyester Laminate - Wet Condition

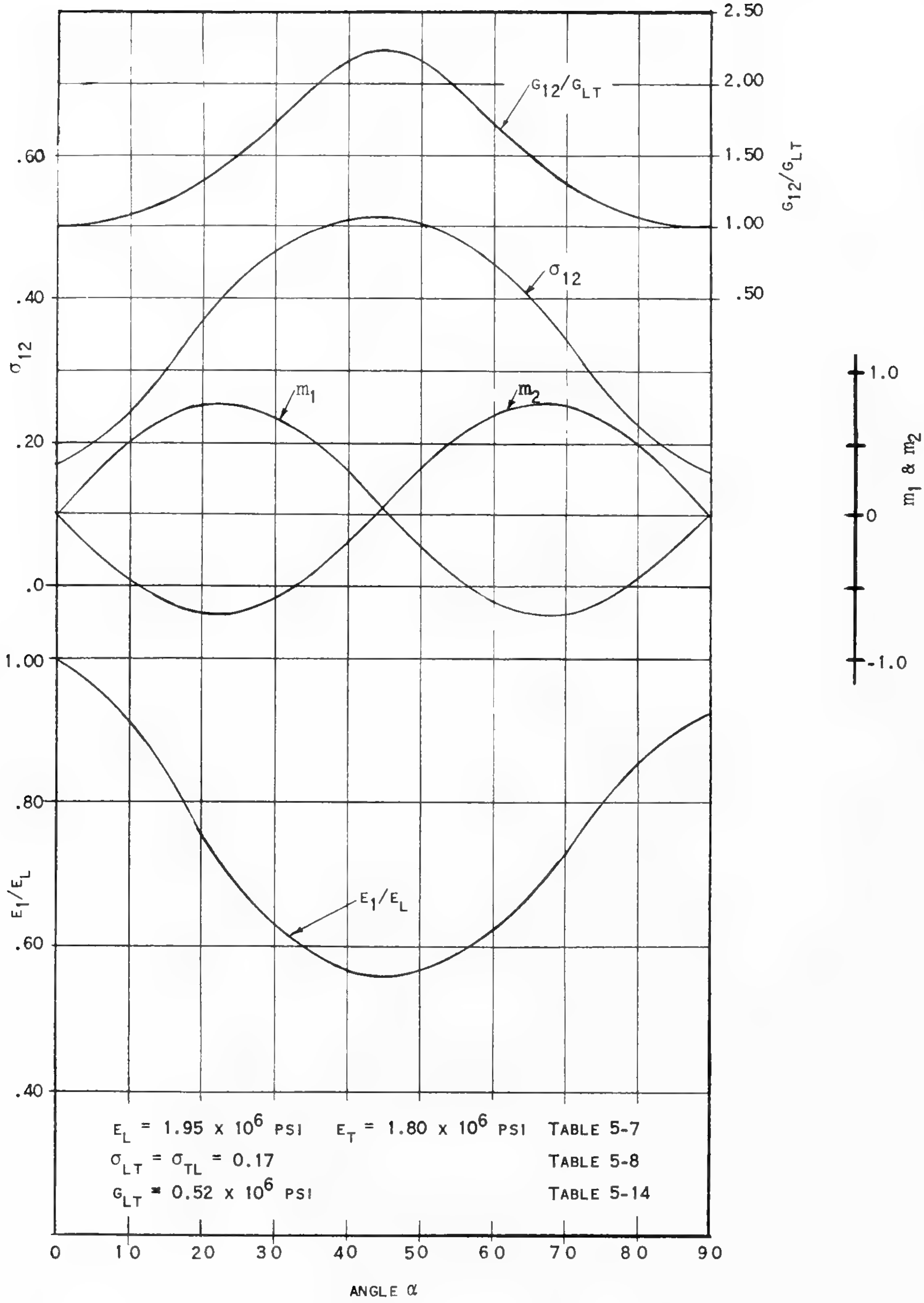


Fig. 6-9. Tensile Elastic Constants of 10 Ounce Cloth-Polyester Laminate - Wet Condition

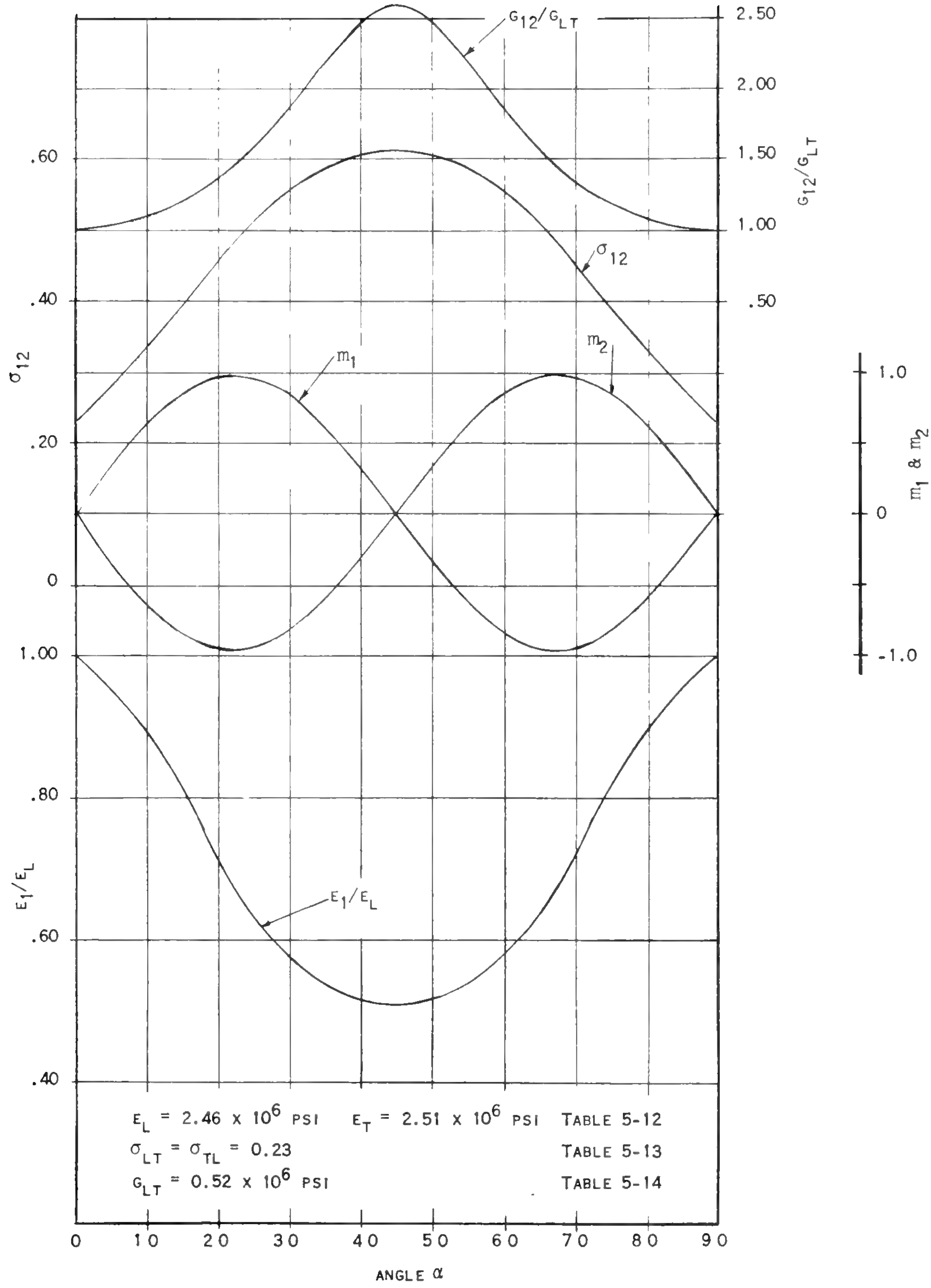


Fig. 6-10. Compressive Elastic Constants of 10 Ounce Cloth-Polyester Laminate - Wet Condition

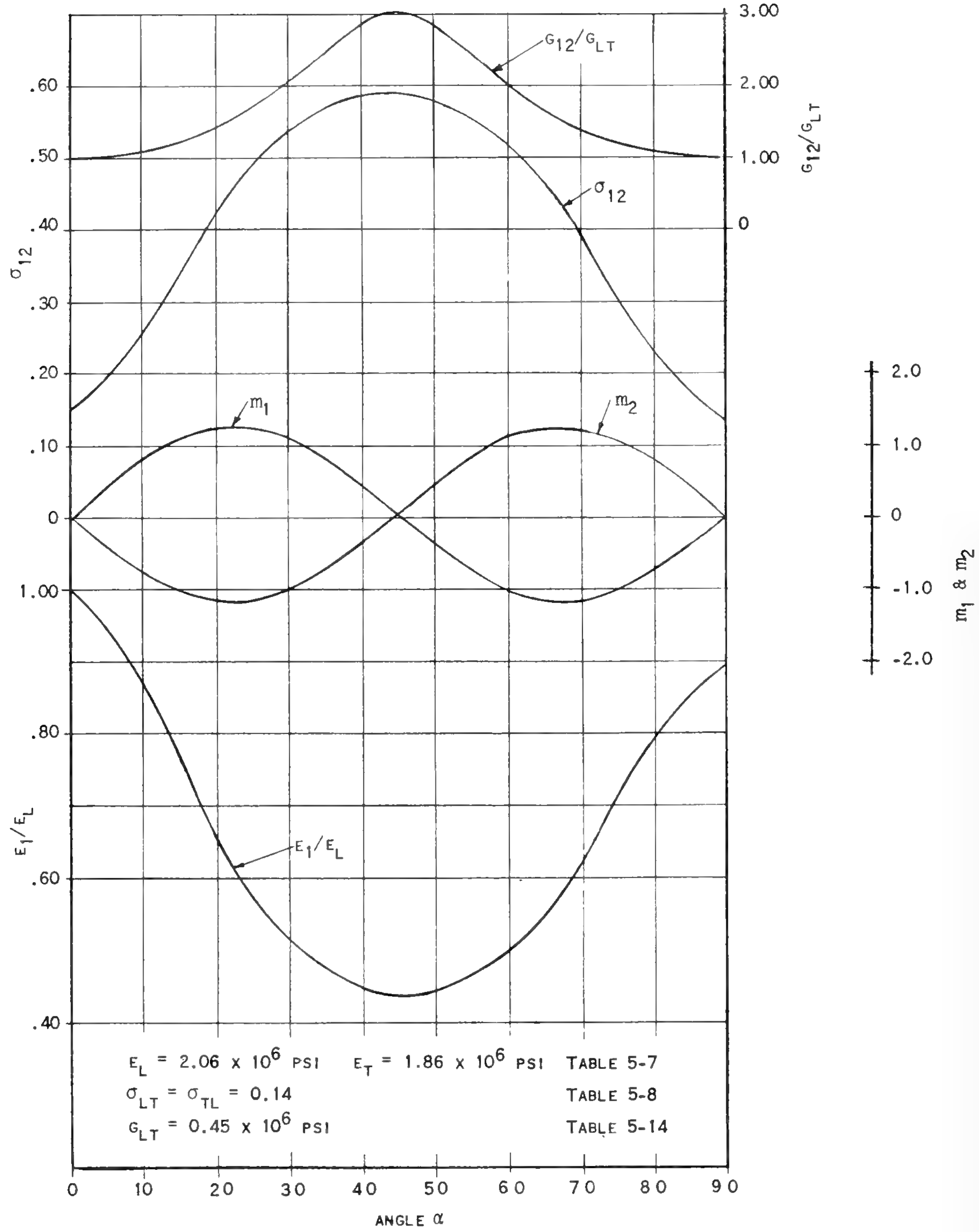


Fig. 6-11. Tensile Elastic Constants of 25-27 Ounce Woven Roving Polyester Laminate - Wet Condition

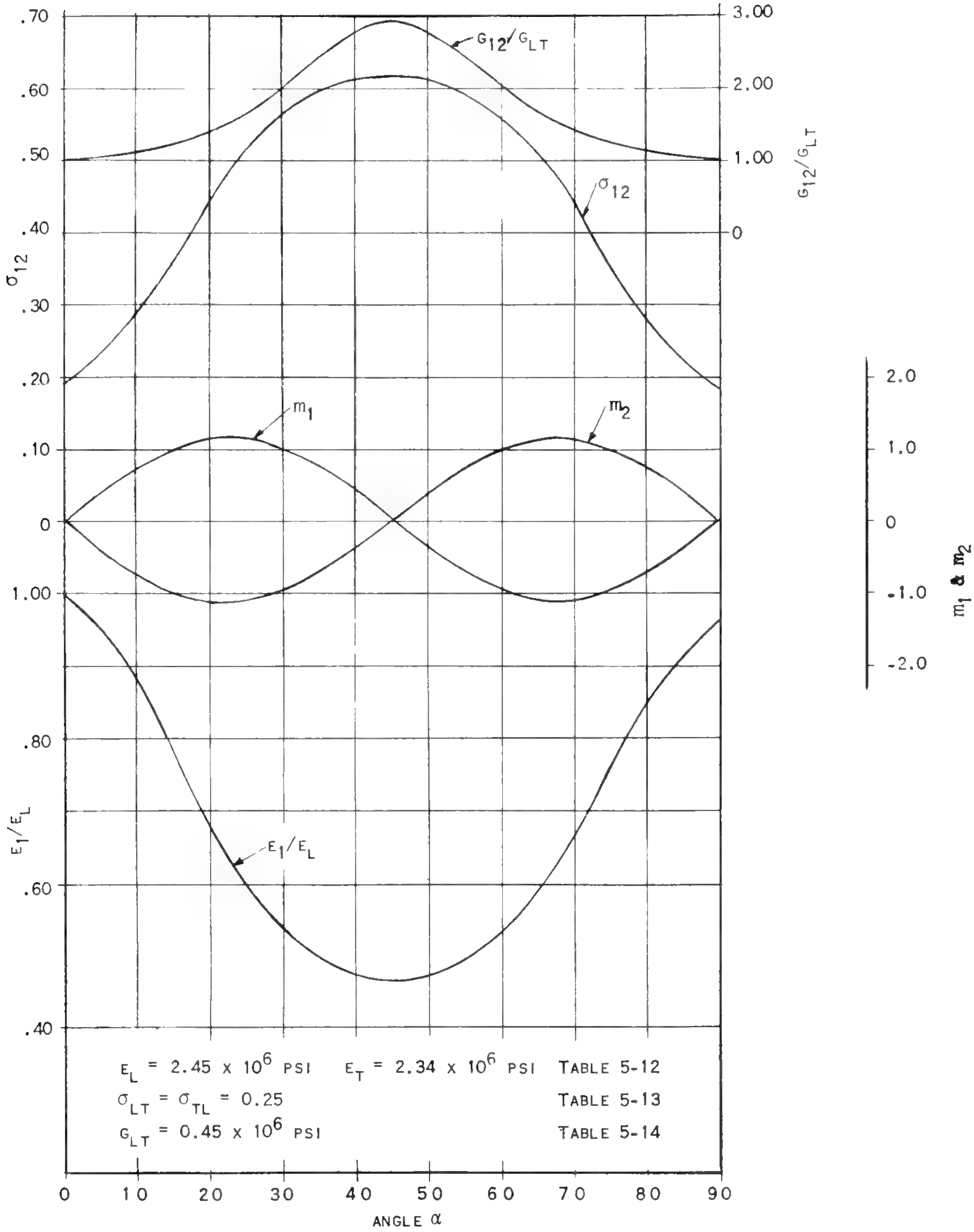


Fig. 6-12. Compressive Elastic Constants of 25-27 Ounce Woven Roving Polyester Laminate - Wet Condition

Fig. 6-7 shows the relation that exists between the various physical constants and the angle to the warp for a laminate in tension made of mat reinforcement. It is readily established that mat reinforcement produces an isotropic laminate, i. e., one that has equal properties at all angles.

Fig. 6-8 is similar to Fig. 6-7 except that it represents a mat laminate in compression.

Figs. 6-9 to 6-12 show the factors that are to be used in determining the elastic constants E_1, G_{12}, and σ_{12} for 10 ounce cloth and 25-27 ounce woven roving laminates. The influence of the angle of loading or the angle between direction of stress and the longitudinal axis, is clearly indicated.

In an orthotropic laminate,shear and direct stress cause shear and direct strains. These strains, at various angles, can be found by substituting the constants from the curves for m_1 and m_2 in equations 6.4, 6.6 and 6.7.

In all of these graphs the angle 0 degree is the longitudinal direction or the warp direction of the cloth and woven roving reinforcements.

The following examples demonstrate the procedure to be followed in using these graphs.

DESIGN EXAMPLE 6-1. TENSILE PHYSICAL PROPERTIES OF MAT AND 10 OUNCE CLOTH LAMINATES AT 30 DEGREES TO WARP

Determine the tensile physical properties at 30 degrees to the warp for the materials shown in Figs. 6-7 and 6-9.

The graphs show the relationships that exist for such constants as modulus of elasticity E, modulus of rigidity G, Poisson's ratio σ, and shear strain constants m_1 and m_2. Constants m_1 and m_2 apply to orthotropic materials only.

a. Modulus of Elasticity

The value of $E_1 = E_{30°}$ can be found as follows:

For mat laminate; from Fig. 6-7, $E_1 = 1.00$ or $E_1 = 1.00\,E = E$.

This indicates that E_1 at a specific angle is equal to E at 0 degrees at all times. This is always the case for an isotropic material.

For 10 ounce cloth laminate, from Fig. 6-9

$$\frac{E_1}{E_L} = 0.634 \text{ (Value at 30°)}$$

$$E_1 = E_{30°} = 0.634\,E_L$$

$$E_{30°} = 0.634 \times 1.95 \times 10^6 = 1.236 \times 10^6 \text{ psi}$$

Modulus of Rigidity G:

For mat laminates, from Fig. 6-7 the plot indicates that $\frac{G}{E} = 0.444$ = a constant. This again is true for isotropic materials.

For 10 ounce cloth laminate, from Fig. 6-9 the plot of $\frac{G_{12}}{G_{LT}}$ indicates a varying value dependent upon the angle. At 30°, $\frac{G_{30°}}{G_{LT}} = 1.650$ and

$$G_{30°} = 1.65 \times G_{LT} = 1.650 \times 0.520 \times 10^6 = 0.858 \times 10^6 \text{ psi}$$

Poisson's Ratio

For mat laminate, from Fig. 6-7 the plot of σ is a straight line having a value of 0.320. This indicates a constant value of σ equal to 0.320. Constant value of σ is always true for an isotropic laminate.

For 10 ounce cloth laminate, Fig. 6-9, indicates a variable plot for the value of σ_{12}. At 30° the value is $\sigma_{30°} = 0.460$.

Example 6-2 will be used to indicate further procedures in the use of these graphs.

DESIGN EXAMPLE 6-2. COMPRESSIVE AND SHEAR STRAINS IN 10 OUNCE CLOTH LAMINATE LOADED AT 30 DEGREES TO WARP

A laminate made of 10 ounce cloth reinforcement is loaded in compression and shear at 30 degrees to the warp, Fig. 6-13. Determine the strains parallel and perpendicular to the direction of load.

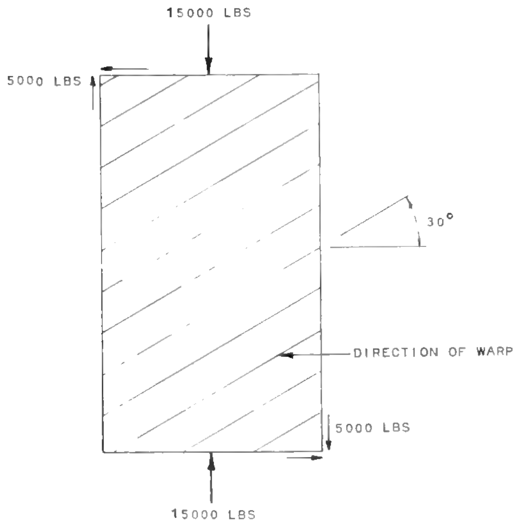


Fig. 6-13. Cloth Laminate Loaded in Compression and Shear at 30 Degrees to Warp

From Fig. 6-10

$$\frac{E_1}{E_L} = 0.575;\ E_1 = E_{30°} = 0.575 \times 2.46 \times 10^6 = 1.415 \times 10^6 \text{ psi}$$

$$\frac{G_{12}}{G_{LT}} = 1.850;\ G_{12} = G_{30°} = 1.850 \times 0.520 \times 10^6 = 0.962 \times 10^6 \text{ psi}$$

$$\sigma_{12} = \sigma_{30°} = 0.558$$

$$m_1 = 0.830$$

$$m_2 = -\ 0.830$$

Strains caused by compressive stress f_1 = 15000 psi are

$$\varepsilon_1 = \frac{f_1}{E_1} = \frac{15000}{1.415 \times 10^6} = 0.0106 \text{ in. (strain in 1 direction)}$$

$$\varepsilon_2 = -\sigma_{12}\,\varepsilon_1 = -0.558 \times 0.0106 = -0.00592 \text{ in. (strain in 2 direction)}$$

$$\gamma_{12} = -m_1 \frac{f_1}{E_L} = -0.830 \times \frac{15000}{2.46 \times 10^6} = -\ .00506 \text{ in. (shear strain)}$$

Strains caused by shear stress τ_{12} = 5000 psi are:

$$\gamma_{12} = \frac{\tau_{12}}{G_{12}} = \frac{5000}{0.962 \times 10^6} = 0.00520 \text{ in.}$$

$$\varepsilon_1 = -m_1 \frac{\tau_{12}}{E_L} = -0.830 \times \frac{5000}{2.46 \times 10^6} = -0.00169 \text{ in.}$$

$$\varepsilon_2 = -m_2 \frac{\tau_{12}}{E_L} = -0.830 \times \frac{5000}{2.46 \times 10^6} = +\ 0.00169 \text{ in.}$$

Total Strains are:

$$\varepsilon_1 + \varepsilon_1 = 0.01060 - 0.00169 = +\ 0089 \text{ in.}$$

$$\varepsilon_2 + \varepsilon_2 = -\ 0.00592 + 0.00169 = -\ 0.0042 \text{ in.}$$

$$\gamma_{12} + \gamma_{12} = -\ 0.00506 + 0.0052 = 0.01026 \text{ in.}$$

The relation between stresses at 0 degrees, 90 degrees, and at any other angle can be found from the expression (9):

$$\frac{1}{F_1^{\,2}} = \frac{\cos^4 \alpha}{F_L^{\,2}} + \frac{\sin^4 \alpha}{F_T^{\,2}} + \frac{\sin^2 \alpha \cos^2 \alpha}{F_s^{\,2}} \tag{6.11}$$

In equation 6.11 it is best to determine F_s, the shear stress, by assigning values F_L at 0° F_T at 90°, and F_1 at 45°, which can be obtained from test results. This is advisable because of the difficulty encountered in obtaining good shear test results in the laboratory. Knowing F_s, the right side of the equation can be completed and the stress at any angle to the warp, F_1, can be computed. Design Example 6-3 illustrates the application of this equation.

DESIGN EXAMPLE 6-3. TENSILE STRESS AT 30 DEGREES TO WARP FOR WOVEN ROVING LAMINATE

The following high range ultimate tensile values are given for a woven roving laminate. See Table 5-6.

F_L at 0° = 41,800 psi

F_1 at 45° = 11,800 psi

F_T at 90° = 37,800 psi

Find the ultimate tensile strength F_2 at 30° to the warp.

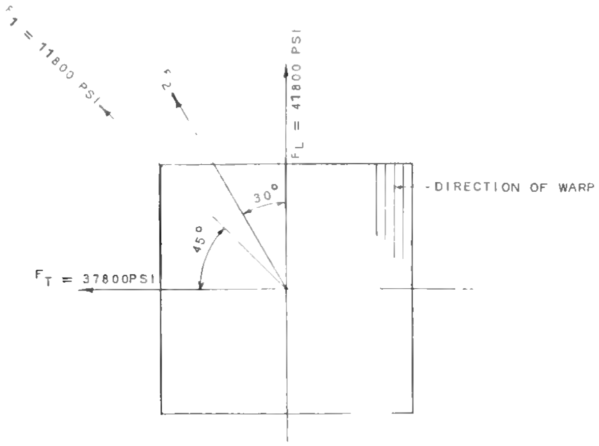


Fig. 6-14. Woven Roving Laminate in Tension at 30 Degrees to Warp

Rearranging equation 6-11 to solve for F_s and using 45° values

$$\frac{1}{F_s^{\,2}} = \frac{1}{\sin^2 \alpha \cos^2 \alpha}\left[\frac{1}{F_1^{\,2}} - \frac{\cos^4 \alpha}{F_L^{\,2}} - \frac{\sin^4 \alpha}{F_T^{\,2}}\right] \tag{6.11a}$$

$\sin^2 45° = 0.4998$ $\sin^4 45° = 0.2498$

$\cos^2 45° = 0.4998$ $\cos^4 45° = 0.2498$

$$\frac{1}{F_s^2} = \frac{1}{0.4998 \times 0.4998}\left[\frac{1}{11800^2} - \frac{0.2498}{41800^2} - \frac{0.2498}{37800^2}\right] \qquad (6.11a)$$

$$F_s = 5960 \text{ psi}$$

Stress at 30°, F_2

$$\sin^2 30° = 0.25 \qquad \sin^4 30° = 0.0625$$

$$\cos^2 30° = 0.750 \qquad \cos^4 30° = 0.563$$

$$\frac{1}{F_2^2} = \frac{0.563}{41800^2} + \frac{0.0625}{37800^2} + \frac{0.25 \times 0.750}{5960^2}$$

$$F_2 = 13{,}300 \text{ psi}$$

FACTOR OF SAFETY

Before actual design problems can be considered it is important to discuss factor of safety. Factor of safety is defined as the ratio of the ultimate strength of the material to the allowable working stress.

$$\text{F.S.} = \frac{\text{Ultimate Strength}}{\text{Allowable Working Stress}}$$

In many fields the allowable working stresses or design stresses are specified by codes or recognized authorities. When allowable stresses are not specified, the factor of safety must be carefully chosen based upon the following considerations:

1. Accuracy of the estimated load on the structure. A precise load value allows for a lower factor of safety.

2. Precision of analysis and stress determination. Where analysis for stresses are accurate and precise a lower factor of safety can be used. Inexact or approximate analysis requires a higher factor of safety.

3. The probable homogeneity and consistency of behavior of the material. Since stress patterns are a function of the homogeneous character of the material this variable must be taken into account in establishing the factor of safety. Metals are considered homogeneous and consistent in behavior while fiberglass laminates, even those made under controlled experimental conditions, show some inconsistency in the physical properties.

4. Deterioration due to environmental conditions.

5. Nature of Loading. Certain types of loads have greater effect than others. The effect on the ultimate strength of the material produced by different types

of loading should be known so that the most appropriate factor of safety can be established. The following factors of safety for various load conditions should be considered for fiberglass structures:

a. Static short term loads FS = 2 minimum

b. Static long term loads FS = 4 minimum on reduced values from tests

c. Variable or changing loads FS = 4 minimum

d. Repeated loads FS = 6 minimum

e. Fatigue or load reversal FS = 6 minimum

f. Impact loads - repeated FS = 10 minimum

6. Service requirement. Where failure of a material can cause personal injury or extensive damage to expensive equipment, a high factor of safety should be used.

Safety factors are dependent on many variables which only the design engineer can analyze. Every problem presents its own peculiarities and requirements and therefore the judgment and experience of the designer plays a most important part. The final selection of a factor of safety, unless established by a specific code or authority, becomes the responsibility of the designer.

TENSION

Members subjected to axial pulling loads are under tensile stress. The magnitude of stress is directly proportional to the load and the resisting area. In isotropic materials the tensile stress distribution is assumed to be uniform throughout the entire cross-sectional area. This assumption is not valid for composite orthotropic materials.

Isotropic Laminates

When a member, such as shown in Fig. 6-15, is subjected to an axial tensile load, the stress relationship in its cross-section is indicated by means of the following formulas:

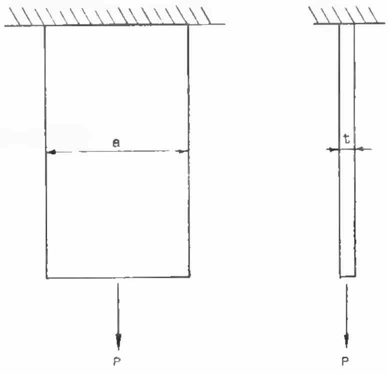


Fig. 6-15. Isotropic Tension Member

$$P = A \times f_t \tag{6.12}$$

$$\text{or} \quad f_t = \frac{P}{A} \tag{6.12a}$$

$$\text{or} \quad A = \frac{P}{f_t} \tag{6.12b}$$

Where P = total tensile load - pounds

A = cross-sectional area - square inches

f_t = tensile stress - psi

DESIGN EXAMPLE 6-4. MAT LAMINATE UNDER TENSILE LOAD

The fiberglass laminate shown in Fig. 6-15 is made of 2 ounce mat and is to support a load P, in tension of 10, 000 lbs. The maximum thickness, t of the laminate is to be 1/8 in. Find the width "a" for a required factor of safety of 2 on the ultimate stress.

The required area is found by using equation 6. 12b.

$$A = \frac{P}{f_t} = \frac{10,000}{f_t}$$

Referring to Table 5-6 the ultimate strength in tension is 11, 000 psi. Higher values of ultimate strength may be used when verified by qualifying tests. Applying a factor of safety of 2 to this ultimate value gives the allowable design stress:

$$f_t = \frac{11000}{2} = 5500 \text{ psi}$$

$$\text{Therefore } A = a \times \frac{1}{8} = \frac{10,000}{5500}$$

from which a = 14.54 in., say 14-5/8 in. wide

DESIGN EXAMPLE 6-5. ULTIMATE TENSILE STRENGTH OF MAT LAMINATE

What is the ultimate load carrying capacity of a 2 ounce mat laminate, 1/2 in. thick and 4 in. wide?

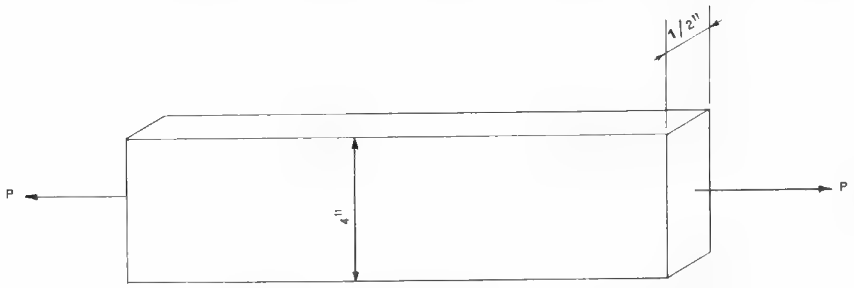


Fig. 6-16. Mat Laminate Under Tensile Load

From Table 5-6 the value for the ultimate strength of a 2 ounce mat laminate is given as 11,000 psi. Referring to Fig. 6-16 and using equation 6.12.

$$P = A \times f_t = 4 \times \frac{1}{2} \times 11{,}000 = 22{,}000 \text{ lbs.}$$

Examples 6-4 and 6-5 outline the procedure for analyzing simple tension members of isotropic materials. In using equations 6.12 to 6.12b it is recommended that the value of the tensile ultimate stress be a test determined value.

Orthotropic Laminates

The following design examples illustrate the method of analysis for orthotropic laminates. All plies are parallel laminated; the direction of warp is the same for all plies.

DESIGN EXAMPLE 6-6. WOVEN ROVING LAMINATE UNDER TENSILE LOAD AT 30 DEGREES TO WARP

A woven roving laminate, with the fibers oriented as shown in Fig. 6-17 is to support a load of 15,000 lbs. What is the required width for a 1/4 in. thick laminate with a factor of safety of 2 on the ultimate strength? Laminate not restrained.

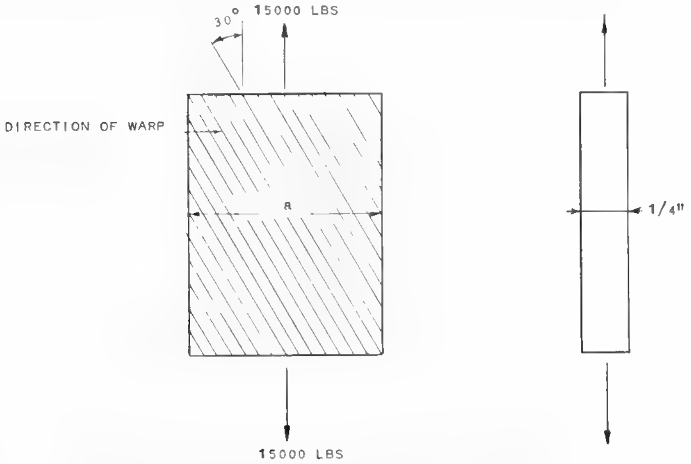


Fig. 6-17. Woven Roving Laminate Under Tensile Load

Since the warp is oriented at an angle of 30 degrees to the applied load, the ultimate tensile strength of the woven roving, at 30 degrees, is required. This value was computed in example 6-3 and was found to be 13,300 psi.

The allowable design stress, for a factor of safety of 2, is then $\frac{13{,}300 \text{ psi}}{2} = 6650$ psi.

Using equation 6-12b, $A = \frac{P}{f_t}$

$$A = a \times \frac{1}{4} = \frac{15000}{6650}$$

or $a = 9.0$ in.

DESIGN EXAMPLE 6-7. CLOTH LAMINATE UNDER LONG TERM TENSILE LOAD PARALLEL TO WARP

A 10 ounce cloth laminate, 8 in. wide, is to support a load of 10,000 lbs. for a period of 1,000 hours. If the load is applied parallel to the warp what should the thickness of the laminate be? Use a factor of safety of 4 on the ultimate.

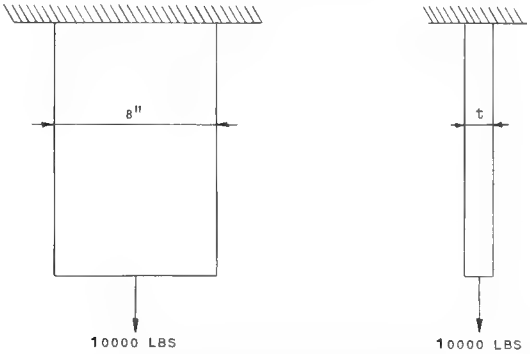


Fig. 6-18. Cloth Laminate Under Tensile Load

The ultimate tensile stress of a 10 ounce cloth laminate at 0 degrees, from Table 5-6, is given as 24,100 psi. Higher values of ultimate strength may be used when verified by qualifying tests. The reduction factor due to long term loading, from Fig. 5-17, for a wet laminate, is 49 per cent. The ultimate design tensile stress is then:

$$F_t = 24{,}100 \times 0.49 = 11{,}809 \text{ psi.}$$

The allowable design stress based on a factor of safety of 4 is:

$$f_t = \frac{11809}{4} = 2952 \text{ psi}$$

Using equation 6.12b, $A = \frac{P}{f_t}$,

$$\text{Area} = 8 \times t = \frac{P}{f_t}$$

$$t = \frac{P}{8 f_t} = \frac{10000}{8 \times 2952} = 0.423 \text{ in.} \quad \text{say } \frac{7}{16} \text{ in.}$$

Composite Orthotropic Laminates

Fig. 6-19 shows a composite laminate made of two laminae of differing physical properties.

When several laminae are combined to form a composite section as shown in Fig. 6-19, the basic formula 6.12b relating stress, load and area, $f = \frac{P}{A}$ must be modified.

A member subjected to a tensile load P will stretch a given amount. The amount that a laminate will stretch or elongate can be expressed as:

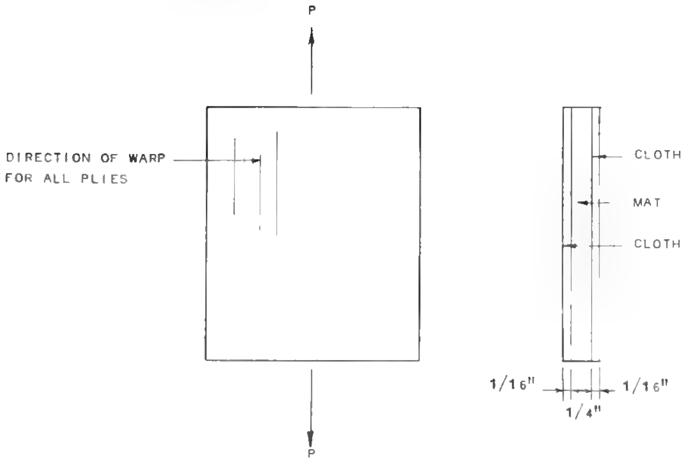


Fig. 6-19. Composite Laminate Under Tensile Load

$$e = \frac{PL}{AE} \tag{6.13}$$

where e = total elongation, in.
P = load, lbs.
L = length, in.
A = area, sq. in.
E = modulus of elasticity in tension, psi

For two laminae of identical length and area, and subjected to the same load P, equation 6.13 indicates that the elongation of each lamina will then be proportional to E_t the modulus of elasticity in tension.

DESIGN EXAMPLE 6-8. ELONGATION OF VARIOUS TYPES OF LAMINATES

Find the total elongation, e, for the laminates shown in Fig. 6-20. The laminates are loaded parallel to the warp direction.

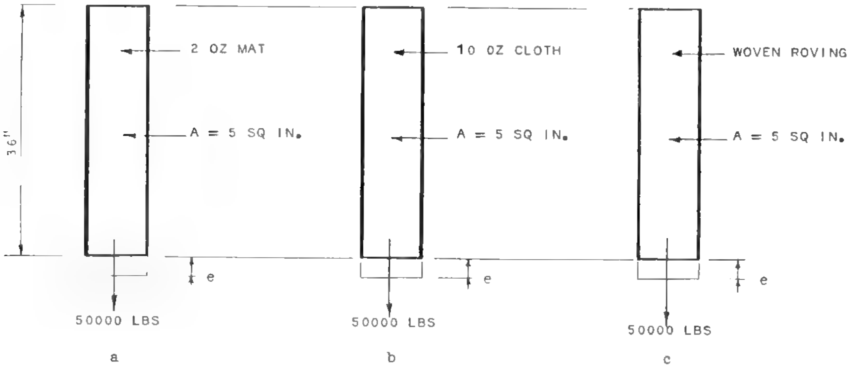


Fig. 6-20. Elongation of Various Laminates

Referring to Table 5-7, the following values for tensile moduli are obtained:

(a) Mat Laminate $E_t = 0.90 \times 10^6$ psi

(b) 10 Ounce Cloth Laminate $E_t = 1.95 \times 10^6$ psi

(c) Woven Roving $E_t = 2.06 \times 10^6$ psi

Substituting the given values in equation 6.13:

(a) Mat $$e = \frac{50{,}000 \times 36}{5 \times 0.90 \times 10^6} = 0.402 \text{ in.}$$

(b) 10 Ounce Cloth $$e = \frac{50{,}000 \times 36}{5 \times 1.95 \times 10^6} = 0.184 \text{ in.}$$

(c) Woven Roving $$e = \frac{50{,}000 \times 36}{5 \times 2.06 \times 10^6} = 0.175 \text{ in.}$$

Design Example 6-8 illustrates the effect of the tensile modulus on the ability of a material to stretch or elongate. The mat laminate stretches approximately 2.25 times as much as the 10 ounce cloth laminate and the woven roving laminate.

In a composite laminate, such as the one shown in Fig. 6-19, the total elongation must be the same for all the laminae that make up the composite laminate. For this condition not to be true would imply that the mat lamina would have to shear away from the cloth lamina. Therefore sufficient shear stress between the laminae must exist. Equation 6.13 can be rearranged to indicate the strain or the elongation per inch in a laminate:

Total elongation: $$e = \frac{PL}{AE} = \frac{fL}{E} \qquad (6.13a)$$

Unit strain: $$\varepsilon = \frac{e}{L} = \frac{f}{E} \qquad (6.13b)$$

where ε = strain; inch per inch and the other terms are as previously defined. Referring to Fig. 6-19 and using equation 6.13b, the strain in the various laminae are as follows:

(a) 10 Ounce cloth: $$\varepsilon_1 = \frac{f_{cl}}{E_{cl}}$$

(b) Mat: $$\varepsilon_2 = \frac{f_m}{E_m}$$

In order for the mat and cloth laminae to be compatible in the same composite laminate, it follows that the strain in the mat lamina must be the same as the strain in the cloth lamina or $\varepsilon_1 = \varepsilon_2$. The following identity therefore is established:

$$\varepsilon_1 = \varepsilon_2 = \frac{f_{cl}}{E_{cl}} = \frac{f_m}{E_m}$$

Equation 6.14 can be rearranged to give the following:

$$f_{cl} = f_m \times \frac{E_{cl}}{E_m} \qquad (6.14a)$$

$$f_m = f_{cl} \times \frac{E_m}{E_{cl}} \qquad (6.14b)$$

Examination of equations 6.14a and 6.14b reveals that the actual stress values for either material will be dependent upon the ratio of the moduli or the values of the right hand portion of the equations. The only restriction that must be placed on equations 6.14a and 6.14b is that the actual stress in any lamina cannot exceed its ultimate stress value. The ultimate stress is used since no actual proportional limit has been established for these materials. The stress strain curves are almost straight lines indicating that the ultimate value can be used without appreciable error. Example 6-9 will serve to illustrate the recommended procedure.

DESIGN EXAMPLE 6-9. ULTIMATE TENSILE LOAD OF A COMPOSITE LAMINATE

Determine the ultimate tensile load P, per inch of width, that the composite laminate of Fig. 6-19 can support.

From Table 5-7, the following lower limit values for E are chosen for the individual laminae:

$$E_m = 0.70 \times 10^6 \text{ psi}$$

$$E_{cl} = 1.40 \times 10^6 \text{ psi}$$

From Table 5-6, the following lower limit values for ultimate tensile strength are chosen:

$$F_m = 6600 \text{ psi}$$

$$F_{cl} = 17900 \text{ psi}$$

Values for f_{cl} and f_m can now be calculated using equations 6.14a and 6.14b:

$$\text{(a)} \quad f_{cl} = 6600 \times \frac{1.40 \times 10^6}{0.70 \times 10^6} = 13200 \text{ psi}$$

$$\text{(b)} \quad f_m = 17900 \times \frac{0.70 \times 10^6}{1.40 \times 10^6} = 8950 \text{ psi}$$

Part (a) above states that if the stress in the mat laminate is assumed as the controlling stress, then for the ultimate values selected, the maximum stress in the cloth laminate will never exceed 13,200 psi. Since this value of 13,200 psi is less than the ultimate for the 10 ounce cloth laminate of 17,900 psi, the composite laminate is not overstressed in any lamina.

Part (b) states that if the ultimate stress for cloth, 17,900 psi, is assumed as the controlling stress then the stress indicated in the mat lamina will reach a value of 8,950 psi. Since this value exceeds the ultimate value of 6,600 psi given for the mat lamina this clearly indicates that the mat lamina will be overstressed if the cloth lamina is assumed to govern. Consequently, this condition of overstress cannot be allowed for a safe design.

The stresses of part (a) are then chosen as the ultimate values for the composite laminate, namely:

$$f_m = 6{,}600 \text{ psi}$$

$$f_{cl} = 13{,}200 \text{ psi}$$

The ultimate load that the laminate can carry can now be computed by using the basic equation, $P = f_t A$ where $f_t A$ is the summation for both mat and cloth laminae as follows:

$$P = f_{tcl} A_{cl} + f_{tfm} A_m \qquad (6.15)$$

$$= 6600 \times \frac{1}{4} + 13{,}200 \times \frac{1}{8}$$

$$= 3300 \text{ lbs. per in. of width}$$

Example 6-9 indicates the need for establishing the correct values of the stress f in the basic formula $P = fA$. The value of the stress f to be used is dependent upon the compatibility condition that all layers of a composite laminate are equally strained and follow the equation $\varepsilon = \frac{f}{E}$.

DESIGN EXAMPLE 6-10. ULTIMATE TENSILE LOAD OF A COMPOSITE LAMINATE

The composite laminate of Fig. 6-21 is assumed to be made of several different materials as follows:

One lamina of 1/8 in. thick woven roving

One lamina of 1/4 in. thick mat

One lamina of 1/16 in. thick cloth

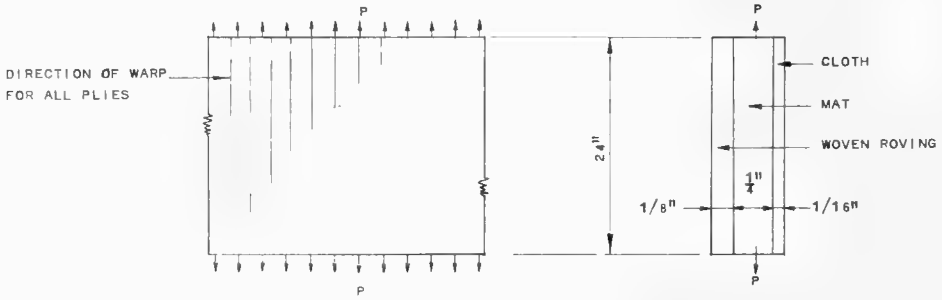


Fig. 6-21. Composite Laminate Under Tensile Load

Find: the ultimate load carrying capacity in tension of the composite laminate per inch of width.

Using equation 6.13b, the strain in each layer can be found:

$$\varepsilon_{mat} = \frac{F_m}{E_m}$$

$$\varepsilon_{cloth} = \frac{F_{cl}}{E_{cl}}$$

$$\varepsilon_{WR} = \frac{F_{WR}}{E_{WR}}$$

Since the strain in all layers must be equal

$$\varepsilon_m = \varepsilon_{cl} = \varepsilon_{WR} \quad \text{or}$$

$$\frac{F_m}{E_m} = \frac{F_{cl}}{E_{cl}} = \frac{F_{WR}}{E_{WR}} \quad \text{or}$$

$$\text{(a)} \quad F_m = E_m \times \frac{F_{cl}}{E_{cl}} = E_m \times \frac{F_{WR}}{E_{WR}}$$

$$\text{(b)} \quad F_{cl} = E_{cl} \times \frac{F_m}{E_m} = E_{cl} \times \frac{F_{WR}}{E_{WR}}$$

$$\text{(c)} \quad E_{WR} = E_{WR} \times \frac{F_m}{E_m} = E_{WR} \times \frac{f_{cl}}{E_{cl}}$$

Values for F_t are selected from Table 5-6 and values for E_t are selected from Table 5-7 as follows:

	Mat	Cloth	Woven Roving
F_t =	6600 psi	17,900 psi	23,800 psi
E_t =	0.90×10^6 psi	1.40×10^6 psi	1.34×10^6 psi

Substituting the values for the stress F in the left hand portion of equations (a), (b) and (c) above, the following relative stresses are obtained:

$$\text{(a)} \quad 6600 \text{ psi} = 0.90 \times 10^6 \times \frac{f_{cl}}{1.40 \times 10^6} = 0.90 \times 10^6 \times \frac{f_{WR}}{1.34 \times 10^6}$$

from which f_{cl} = 10,267 psi

f_{WR} = 9,827 psi

$$\text{(b)} \quad 17{,}900 \text{ psi} = 1.40 \times 10^6 \times \frac{f_m}{0.90 \times 10^6} = 1.40 \times 10^6 \times \frac{f_{WR}}{1.34 \times 10^6}$$

from which f_m = 11,507 psi

f_{WR} = 17,133 psi

$$\text{(c)} \quad 23{,}800 \text{ psi} = 1.34 \times 10^6 \times \frac{f_m}{0.90 \times 10^6} = 1.34 \times 10^6 \times \frac{f_{cl}}{1.40 \times 10^6}$$

from which f_m = 15,985 psi

f_{cl} = 24,866 psi

Part (a) states that if the mat ultimate stress of 6,600 psi is assumed as the controlling stress then the ultimate stresses obtained in the cloth and woven roving laminae are 10,267 psi and 9,827 psi respectively. Since all values do not exceed the ultimate, part (a) stresses can be used.

Part (b) states that if the cloth ultimate stress is assumed as the controlling stress then the ultimate values for the mat and woven roving laminae would be 11,507 psi and 17,133 psi respectively. Since the mat stress of 11,507 psi exceeds the ultimate of 6,600 psi this combination cannot occur without failure.

Part (c) also indicates an ultimate value for mat of 15,985 psi which cannot occur.

Therefore Part (a) is the only condition under which the laminate will be stable without overstressing an individual lamina. The final stresses to be used are therefore:

f_m = 6,600 psi

f_{cl} = 10,267 psi

f_{WR} = 9,827 psi

The total ultimate load P that the composite laminate can carry is now found as the sum of the individual carrying capacity of each lamina:

$$P = f_m A_m + f_{cl} A_{cl} + f_{WR} A_{WR} \tag{6.15}$$

$$= 6600 \text{ psi} \times 0.25 + 10{,}267 \text{ psi} \times 0.0625 + 9{,}827 \times 0.125$$

$$= 1650 + 602 + 1228$$

$$= 3520 \text{ lbs. per in. of width}$$

In Design Example 6-10 the composite laminate is made of 3 separate materials, mat, cloth and woven roving. These three materials each have their own value for the modulus of elasticity, E. The value of E for the composite laminate is not equal to any of the individual lamina values but is a function of these values and the individual lamina areas. equation 6.16 expresses this relationship.

$$E \times A = \sum_{i=1}^{i=n} E_i A_i \tag{6.16}$$

where E = composite modulus of elasticity, psi

A = composite area, sq. in.

E_i = modulus of elasticity of i-th lamina

A_i = area of i-th lamina

$\sum$ = means summation of all laminae

DESIGN EXAMPLE 6-11. MODULUS OF ELASTICITY OF COMPOSITE LAMINATE

For the laminate in Design Example 6-10 find the modulus of elasticity, E of the composite laminate.

From Design Example 6-10 the following values are:

	Modulus of Elasticity E, psi	Area sq.in. per in.
Mat Lamina	0.90×10^6	0.25
Cloth Lamina	1.40×10^6	0.0625
Woven Roving Lamina	1.34×10^6	0.125

Using equation 6.16

$$EA = \sum_{i=1}^{i=n} E_i A_i$$

$$= 0.90 \times 10^6 \times 0.25 + 1.40 \times 10^6 \times 0.0625 + 1.34 \times 10^6 \times 0.125$$

$$= 0.225 \times 10^6 + 0.0875 \times 10^6 + 0.1675 \times 10^6$$

$$EA = 0.48 \times 10^6 \text{ lbs.}$$

Area of composite = (0.25 + 0.0625 + 0.125) x 1 = 0.4375 sq.in. = 7/16 sq.in.

Therefore

$$E = \sum \frac{E_i A_i}{A} = \frac{0.48 \times 10^6}{0.4375} = 1.10 \times 10^6 \text{ psi} \tag{6.16a}$$

DESIGN EXAMPLE 6-12. ELONGATION OF COMPOSITE LAMINATE

Find the elongation of the composite laminate described in Design Examples 6-10 and 6-11.

From Design Example 6-10 the total load P is 3520 lbs. per in. of width. From Design Example 6-11, the final modulus of elasticity, E is 1.10×10^6 psi and the area of the composite, A is 0.4375 sq. in. Substituting these values in equation 6.13 the following elongation results:

$$e = \frac{PL}{AE} = \frac{3520 \times 24}{0.4375 \times 1.10 \times 10^6} = 0.176 \text{ in.}$$

Where L = 24 in. from Fig. 6-21

DESIGN EXAMPLE 6-13. ELONGATION OF COMPOSITE LAMINATE AT ANGLE TO WARP

A composite laminate is made up of 2 laminae of 10 ounce cloth reinforcement and one lamina of mat reinforcement as shown in Fig. 6-22. The following properties of the composite are required:

1. Total ultimate tensile load, per in. of width, that the laminate can carry when the load is applied at an angle of 15 degrees to the warp direction.
2. Elongation of the composite in the direction of the applied load.

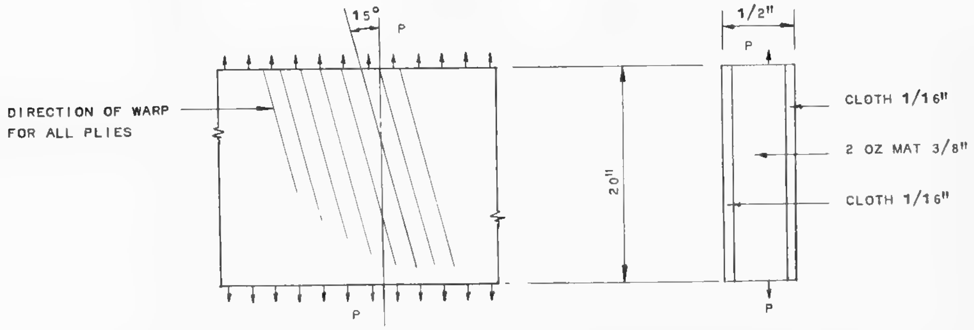


Fig. 6-22. Composite Laminate Under Tensile Load at an Angle to Warp

Information required for solution of problem:

Tensile strength of mat and cloth laminates at 15 degrees to warp direction.

Moduli of elasticity for mat and cloth laminates at 15 degrees to warp direction.

Properties of Mat Laminate: Since mat laminates are considered to be isotropic in behavior, the values for F_t and E can be chosen from Tables 5-6 and 5-7.

$$F_{mat} = 6600 \text{ psi}$$

$$E_{mat} = 0.81 \times 10^6 \text{ psi}$$

Properties of 10 Ounce Cloth Laminate: Cloth laminates are considered to behave as orthotropic materials therefore the values for F and E at 15 degrees must be calculated since they vary with the angle chosen.

(a) Value of the tensile strength can be found by using the method of Design Example 6-3, based on equation 6.11 as follows:

$$\frac{1}{F_1^2} = \frac{\cos^4 \alpha}{F_L^2} + \frac{\sin^4 \alpha}{F_T^2} + \frac{\sin^2 \alpha \quad \cos^2 \alpha}{F_s^2} \qquad (6.11)$$

Finding first the value of F_S from the physical properties given for 0°, 45° and 90°, where F_1 is the value at 45°:

$$\frac{1}{F_s^2} = \frac{1}{\sin^2 \alpha \cos^2 \alpha}\left[\frac{1}{F_1^2} - \frac{\cos^4 \alpha}{F_L^2} - \frac{\sin^4 \alpha}{F_T^2}\right] \qquad (6.11a)$$

where $\sin 45° = 0.70711$ $\quad\cos 45° = 0.70711$ $\quad\sin^2 \alpha \cos^2 \alpha = 0.2498$

$\sin^2 45° = 0.4998$ $\quad\cos^2 45° = 0.4998$

$\sin^4 45° = 0.2498$ $\quad\cos^4 45° = 0.2498$

and from Tables 5-6 and 5-7:

$F_L = 17{,}900$ psi $\quad F_1 = 8400$ psi $\quad F_T = 14000$ psi

$E_L = 1.40 \times 10^6$ psi

Therefore

$$\frac{1}{F_s^2} = \frac{1}{0.2498}\left[\frac{1}{8400^2} - \frac{0.2498}{17900^2} - \frac{0.2498}{14000^2}\right]$$

from which $F_S = 4540$ psi.

The value at 15 degrees can now be computed; again using equation 6.11a.

$$\frac{1}{F_2^2} = \frac{\cos^4 \alpha}{F_L^2} + \frac{\sin^4 \alpha}{F_T^2} + \frac{\sin^2 \alpha \cos^2 \alpha}{F_s^2} \qquad (6.11a)$$

where $\sin 15° = 0.25882$ $\quad\cos 15° = 0.96593$

$\sin^2 15° = 0.6699$ $\quad\cos^2 15° = 0.93302$

$\sin^4 15° = 0.00449$ $\quad\cos^4 15° = 0.8705$

$$\frac{1}{F_2^2} = \frac{0.0625}{4540^2} + \frac{0.8705}{17900^2} + \frac{0.0045}{14000^2}$$

from which $F_2 = 13170$ psi $= F_{cl}$ at 15°

(b) The value of E can be found by referring to Fig. 6-9. From the graph for $\frac{E_1}{E_L}$

the ratio at 15° is equal to 0.845

Then $\frac{E_{15°}}{E_L} = 0.845$ or $E_{15°} = E_L \times 0.845 = 1.40 \times 10^6 \times 0.845$

$$E_{15°} = 1.183 \times 10^6 \text{ psi}$$

(c) With the required F and E values known at 15 degrees the maximum stress that each lamina of the composite can withstand is now found by means of equations 6.14a and 6.14b:

$$f_{cl} = F_m \times \frac{E_{cl}}{E_m} \qquad (6.14a)$$

$$f_m = F_{cl} \times \frac{E_m}{E_{cl}} \qquad (6.14b)$$

or $$f_{cl} = 6600 \times \frac{1.183 \times 10^6}{0.81 \times 10^6} = 9639 \text{ psi}$$

$$f_m = 13170 \times \frac{0.81 \times 10^6}{1.183 \times 10^6} = 9017 \text{ psi}$$

If the cloth laminate ultimate tensile stress of 13,170 psi is used as the controlling stress, the mat laminate would attain a value of 9017 psi. This value exceeds the allowable ultimate and therefore failure would occur.

The cloth laminate attains a safe stress of 9639 psi since the mat laminate tensile ultimate controls. Consequently these values are the values to be used, namely:

$$f_{cl} = 9639 \text{ psi}$$

$$f_m = 6600 \text{ psi}$$

The total load on the composite laminate is then found by means of equation 6.15;

$$P = A_m \times f_m + A_{cl} \times f_{cl}$$

$$P = 9639 \times 0.125 + 6600 \times 0.375$$

$$= 1205 + 825 = 2030 \text{ lbs. per in. of width}$$

The elongation of the laminate is given by equation 6. 13, where the factor E is for the entire laminate and has to be determined according to equation 6. 16;

$$EA = \sum E_i A_i$$

$$\text{where } A = (0.0625 + 0.375 + 0.0625) \times 1 = 0.50 \text{ sq.in.}$$

Therefore

$$\frac{E}{A} = 1.183 \times 10^6 \times 0.0625 + 0.81 \times 10^6 \times 0.375 + 1.183 \times 10^6 \times 0.0625$$

$$= 0.4515 \times 10^6 \text{ lbs.}$$

$$\text{and} \quad E = \frac{0.4515 \times 10^6}{0.50} = 0.903 \times 10^6 \text{ psi}$$

and the elongation is calculated from equation 6. 13;

$$e = \frac{PL}{AE} = \frac{2030 \times 20}{0.50 \times 0.903 \times 10^6} = 0.0899 \text{ in.}$$

COMPRESSION

The behavior of fiberglass laminates in compression such as columns, struts, etc. is complex and many tests are required before definite conclusions can be made as to the appropriate method of analysis. Materials that behave isotropically can be analyzed by analytical methods that have been developed for homogeneous isotropic materials. Glass reinforced laminates however may fail by interlaminar shear or at the bond between the glass fibers and resin. Therefore any compressive design criteria is dependent on the behavior of the laminate and precautions should be taken in the compression analysis of reinforced plastic laminates whether they are isotropic or orthotropic.

The data presented here is primarily for laminates that are used individually or as part of a member in compression. The compression buckling of plates is discussed later in this Chapter.

Short Members

For laminates whose dimensions are such that buckling is precluded, the basic relation of equation 6. 12, $P = A f$, can be applied. These laminates will usually fail under ultimate axial compressive loads by crushing or delamination.

DESIGN EXAMPLE 6-14. WOVEN ROVING LAMINATE IN COMPRESSION WITHOUT BUCKLING

A woven roving reinforced laminate, 1/2 in. thick, is to support a load of 35, 000 lbs. Find the width of the laminate. The length is such that the laminate will not buckle. Use a factor of safety of 2 on the ultimate compressive strength. See Fig. 6-23.

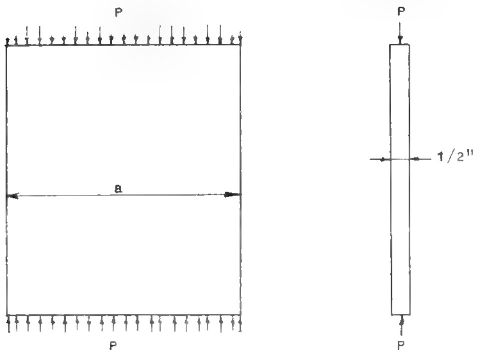


Fig. 6-23. Woven Roving Laminate in Compression

From Table 5-11 the ultimate compressive strength, F_c, selected is 9600 psi.

The allowable design stress, based on a factor of safety of 2, is then:

$$f_c = \frac{9600}{2} = 4800 \text{ psi}$$

$$\text{Then: } A = \frac{P}{f_c} = \frac{35000}{4800} = 7.29 \text{ sq.in.} \tag{6.12e}$$

$$\text{and: } a = \frac{A}{t} = \frac{7.29}{0.50} = 14.58 \text{ in.}$$

Column Characteristics of Laminates

When the length of the compression member is such that buckling will occur, the critical load, P_{cr}, can be calculated with equation 6.12 provided that the ultimate stress, F_c, is reduced to allow for the unsupported length of the member (13). Structural members, in the buckling range, can be divided into two groups, namely:

1. Members in which the compressive stress is less than the proportional limit of the material or follows Hooke's Law under a critical load P_{cr}.
2. Members in which the compressive stress exceeds the proportional limit of the material, under a critical load P_{cr}.

If the member is in the first group the following equations can be used to determine the load P_{cr}:

$$P_{cr} = \frac{\pi^2 EI}{L^2} \tag{6.17}$$

$$= \frac{\pi^2 EA}{\left(\frac{L}{r}\right)^2} \tag{6.17a}$$

$$\text{or} \quad F_{cr} = \frac{P_{cr}}{A} = \frac{\pi^2 E}{\left(\frac{L}{r}\right)^2} \qquad (6.18)$$

$$\text{and} \quad r = \sqrt{\frac{I}{A}} \qquad (6.19)$$

where P_{cr} = critical load - lbs.

E = modulus of elasticity below the proportional limit - psi

I = moment of inertia - in.^{4}

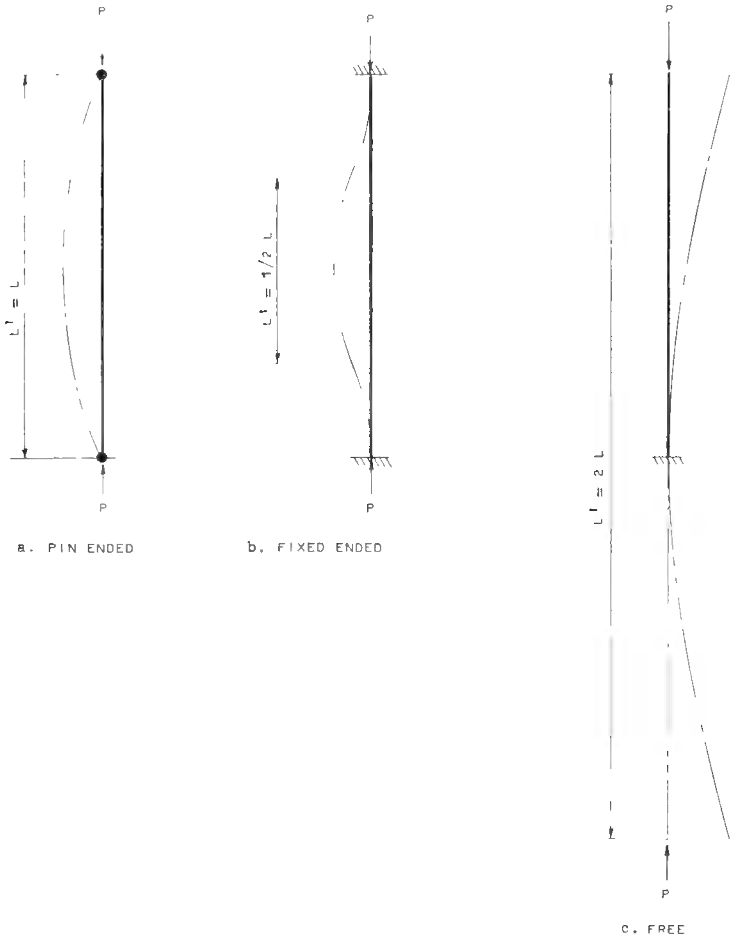
A = area - in.^{2}

r = radius of gyration - in.

L' = effective length - in.

F_{cr} = critical stress - psi

The effective length, L', will be the length of the specimen for a pin-ended element, one half the length for a fix-ended element and twice the length for a free-ended element as shown in Fig. 6-24.



a. PIN ENDED b. FIXED ENDED c. FREE

Fig. 6-24. Effective Length of Column

$\frac{L}{r}$ or the slenderness ratio is associated with the ability of a section to resist buckling. Since the $\frac{L}{r}$ ratio is based on the geometry and length of the element it can be readily determined by the cross-section of the member. Also by substituting various values of stress with the appropriate modulus of elasticity, E, in equation 6.18, corresponding values for $\frac{L}{r}$ can be obtained.

When the member is in the second group or does not follow Hooke's Law, the critical buckling load can be determined if the value of E used is the value corresponding to the particular stress. The buckling formula then becomes:

$$P_{cr} = \frac{\pi^2 E_a I}{L'^2} \tag{6.20}$$

where the value of E_a is the tangent modulus and is obtained from a stress-strain curve. Consequently for every P_{cr} there exists a value of E_a.

When the stress exceeds the proportional limit, the buckled member no longer obeys Hooke's Law. The critical stresses are now dependent not only upon the critical load P_{cr} but also upon the bending of the member. The compressive stresses will increase on the concave side and decrease on the convex side.

Under this condition two values of the modulus of elasticity are involved. A new tangent modulus E_a for an increased load on the concave side will be necessary while on the convex side of the material the usual modulus E for the decreased load will be applicable (13).

The critical load, therefore, will now be a function of a new reduced bending rigidity $E_r I$. It can be shown that the value of E_r can be determined by the following expression:

$$E_r = \frac{4E \times E_a}{\left(\sqrt{E} + \sqrt{E_a}\right)^2} \tag{6.21}$$

where E_r = reduced modulus of elasticity

E = as previously defined

E_a = modulus of elasticity above the proportional limit, or tangent modulus of elasticity

The critical buckling load is then:

$$P_{cr} = \frac{\pi^2 E_r I}{L'^2} \tag{6.22}$$

P_{cr}, I and L' as previously defined.

Figs. 6-25, 6-26 and 6-27 indicate ultimate compressive strength curves for mat, woven roving and 10 ounce cloth laminates for various slenderness ratios; $\frac{L}{r}$. The curves are for laminates in the wet condition and tested parallel to the warp. Tables 6-1, 6-2 and 6-3 give the slenderness ratios at various compressive stresses and for the appropriate moduli of elasticity obtained from the stress-strain diagrams. Further testing should be conducted to verify these curves or similar curves for other laminates.

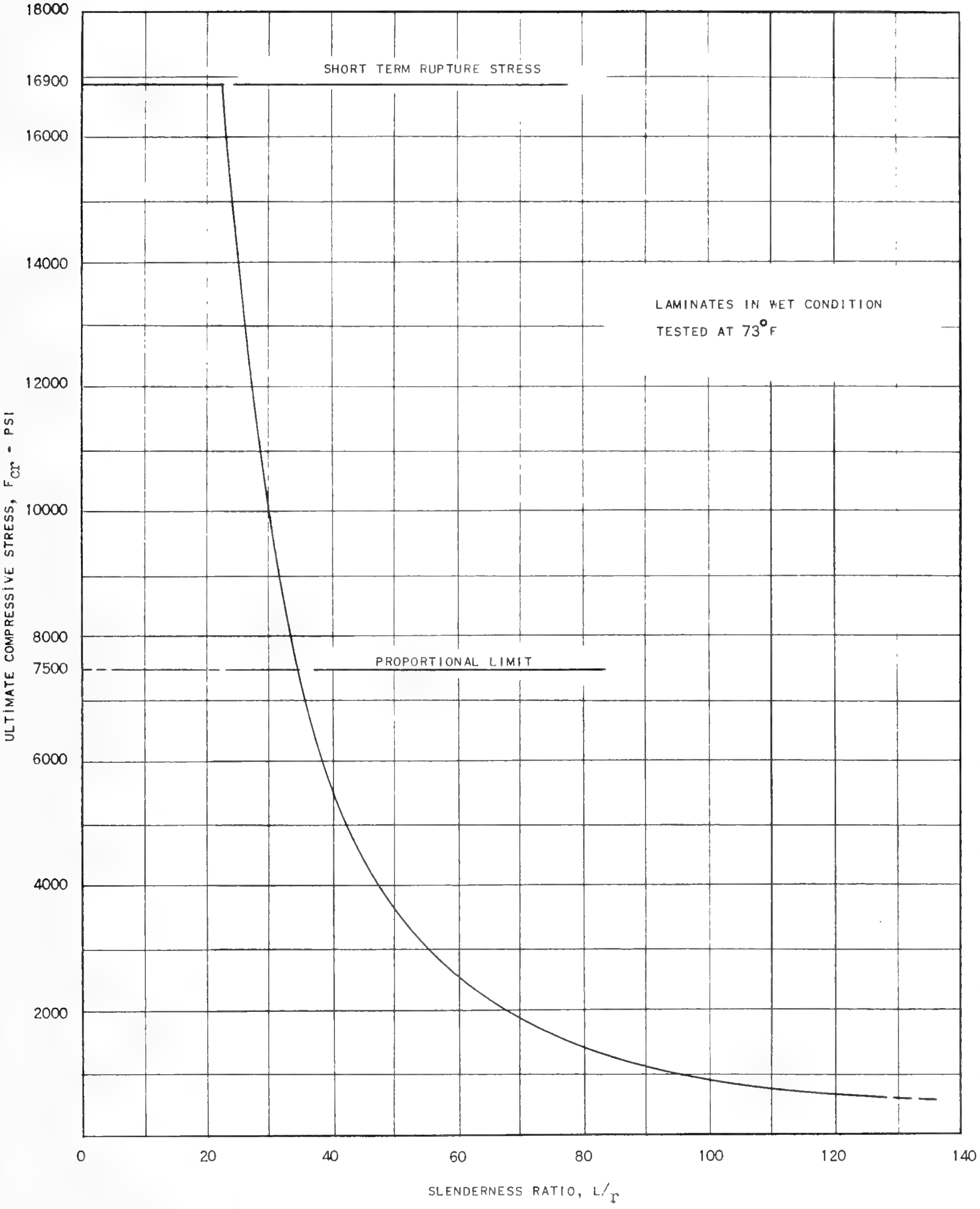


Fig. 6-25. Ultimate Compressive Stress Versus Slenderness Ratio for Mat-Polyester Laminates - Contact Molded

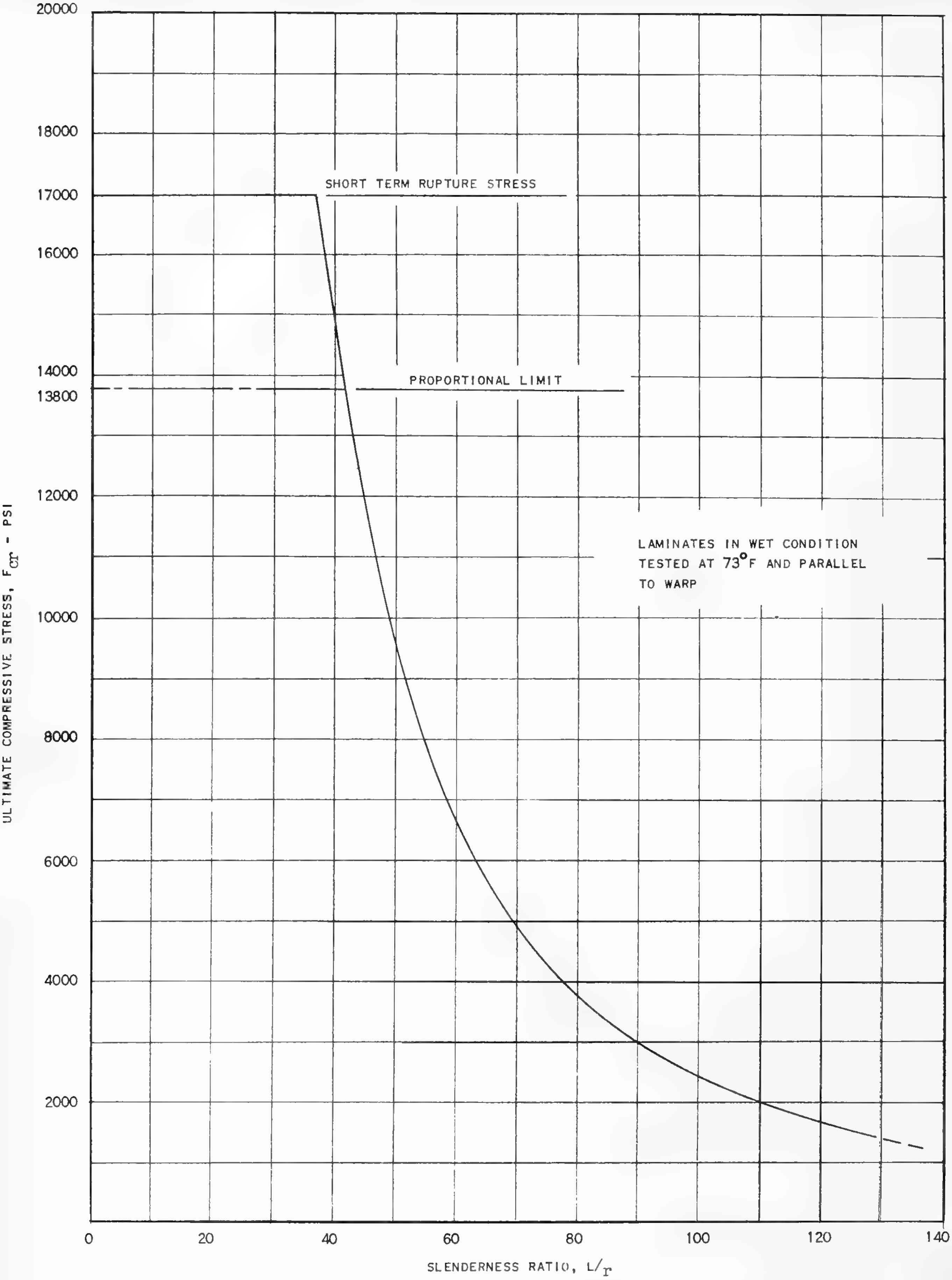


Fig. 6-26. Ultimate Compressive Stress Versus Slenderness Ratio for 25-27 Ounce Woven Roving-Polyester Laminates - Contact Molded

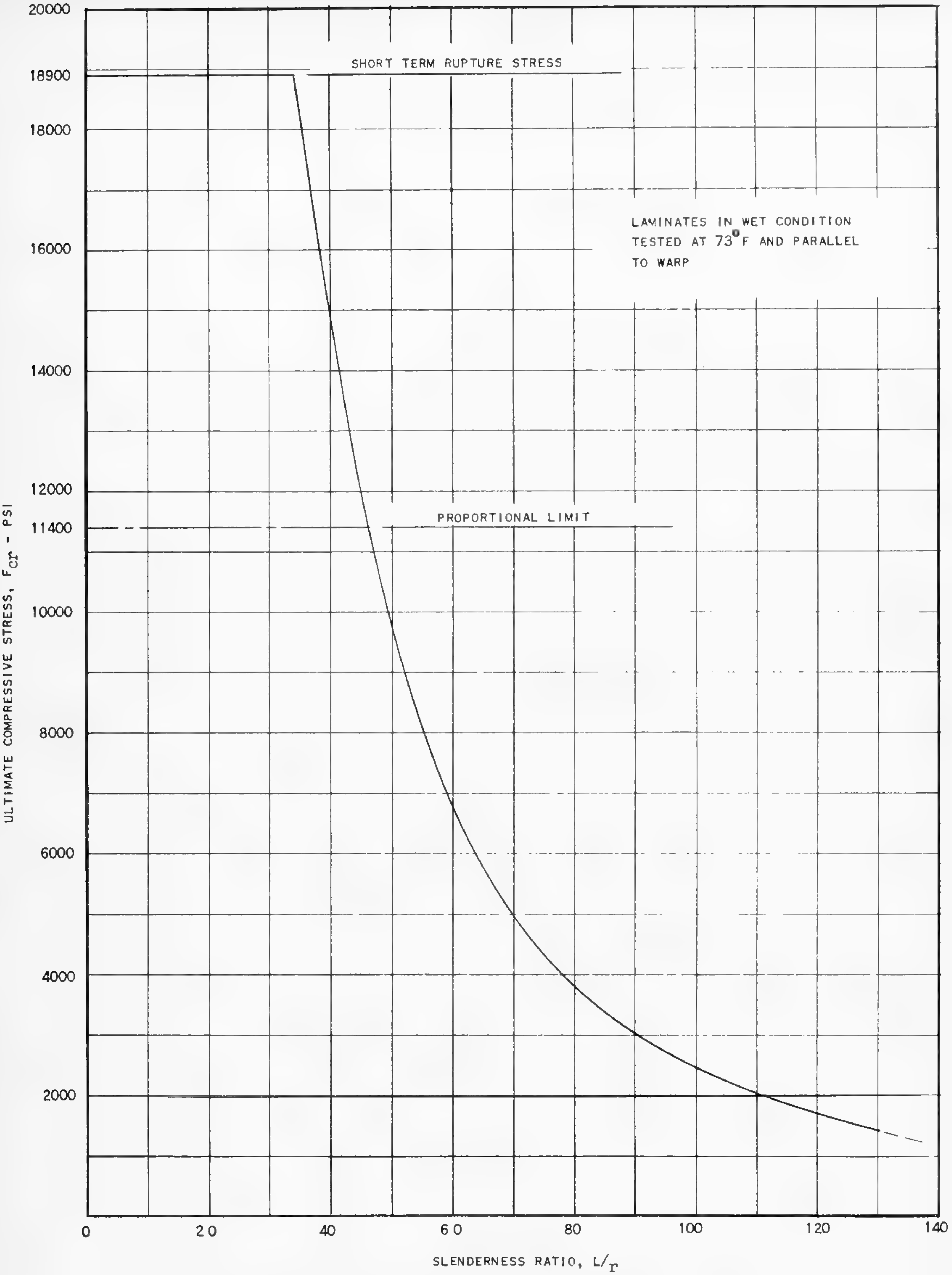


Fig. 6-27. Ultimate Compressive Stress Versus Slenderness Ratio for 10 Ounce Cloth-Polyester Laminates - Contact Molded

TABLE 6-1. SLENDERNESS RATIOS FOR MAT-POLYESTER LAMINATES CONTACT MOLDED - WET CONDITION

Compressive Stress psi	Modulus of Elasticity psi x 10^6 E	Tangent Modulus of Elasticity psi x 10^6 E_a	Slenderness Ratio for E_a $\frac{L}{r}$	Reduced Modulus of Elasticity psi x 10^6 E_r	Slenderness Ratio for E_r $\frac{L}{r}$
16,900 (Rupture)		0.821	21.90	0.873	22.59
16,000		0.832	22.71	0.879	23.28
15,000		0.844	23.56	0.886	24.16
14,000		0.858	24.60	0.893	25.10
13,000		0.873	25.76	0.901	26.17
12,000		0.887	27.02	0.908	27.33
11,000		0.902	28.46	0.916	28.68
10,000		0.913	30.03	0.921	30.16
9,000		0.923	31.64	0.926	31.82
8,000		0.929	33.87	0.930	33.93
7,500 (Proportional Limit)	0.930	0.930	34.93	0.930	34.93
7,000	0.930		36.19	0.930	36.19
6,000	0.930		39.05	0.930	39.05
5,000	0.930		42.79	0.930	42.79
4,000	0.930		47.85	0.930	47.85
3,000	0.930		55.29	0.930	55.29
2,000	0.930		67.80	0.930	67.80
1,000	0.930		95.82	0.930	95.82
800	0.930		107.38	0.930	107.38
600	0.930		123.78	0.930	123.78

TABLE 6-2. SLENDERNESS RATIOS FOR 25-27 OUNCE WOVEN ROVING-POLYESTER LAMINATES CONTACT MOLDED - WET CONDITION

Compressive Stress psi	Modulus of Elasticity psi x 10^6 E	Tangent Modulus of Elasticity psi x 10^6 E_a	Slenderness Ratio $\frac{L}{r}$
17,000 (Rupture)		2.37	37.04
16,000		2.40	38.48
15,000		2.43	39.99
14,000		2.44	41.44
13,800 (Proportional Limit)	2.45	2.45	41.85
13,000	2.45		43.13
12,000	2.45		44.89
11,000	2.45		46.87
10,000	2.45		49.17
9,000	2.45		51.84
8,000	2.45		54.98
7,000	2.45		58.78
6,000	2.45		63.49
5,000	2.45		69.56
4,000	2.45		77.75
3,000	2.45		89.79
2,000	2.45		109.96
1,500	2.45		126.86

TABLE 6-3. SLENDERNESS RATIOS FOR 10 OUNCE CLOTH-POLYESTER LAMINATES CONTACT MOLDED - WET CONDITION

Compressive Stress psi	Modulus of Elasticity psi x 10^6 E	Tangent Modulus of Elasticity psi x 10^6 E_a	Slenderness Ratio $\frac{L}{r}$
18,900 (Rupture)		2.27	34.02
18,000		2.30	35.50
17,000		2.33	36.76
16,000		2.36	38.11
15,000		2.39	39.62
14,000		2.42	41.28
13,000		2.44	43.04
12,000		2.45	44.86
11,400 (Proportional Limit)	2.46	2.46	46.12
11,000	2.46		46.87
10,000	2.46		49.26
9,000	2.46		51.87
8,000	2.46		55.07
7,000	2.46		58.81
6,000	2.46		63.62
5,000	2.46		69.68
4,000	2.46		77.91
3,000	2.46		89.98
2,000	2.46		110.18
1,500	2.46		127.23

Table 6-1 gives the values for $\frac{L}{r}$ ratios based on E below the proportional limit, E_a above the proportional limit and E_r the reduced modulus above the proportional limit. A comparison of these values indicate that for materials that have continuous sloping stress-strain curves with no abrupt point of inflection, the $\frac{L}{r}$ values based on E_a and E_r are almost identical. Therefore, the more complex method of solving for P_{cr} based on the reduced modulus need not be used. For practical purposes the value of F_{cr} based on E_a can be used without appreciable error. The $\frac{L}{r}$ values above the proportional limit in Tables 6-2 and 6-3 have been based on E_a.

DESIGN EXAMPLE 6-15. CRITICAL COMPRESSIVE LOAD OF MAT LAMINATE

Compute the critical compressive load, P_{cr}, for a mat-polyester laminate, 6 in. wide x 1/2 in. thick and 15 in. long, simply supported at the ends, Fig. 6-28.

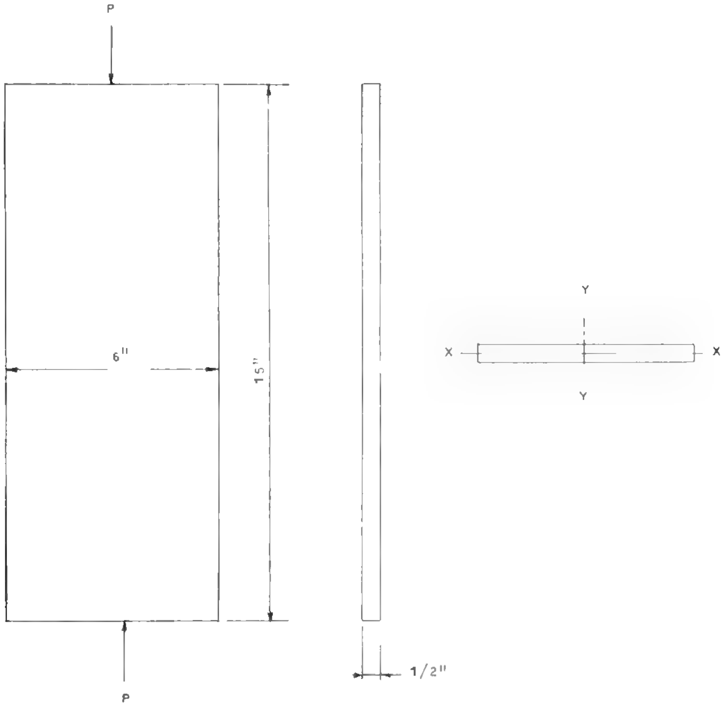


Fig. 6-28. Mat Laminate in Compression

Area = 6 x 0.50 = 3.0 sq.in.

$$\text{Moment of Inertia, } I = \frac{bd^3}{12} \tag{6.23}$$

$$I_{xx} = \frac{6 \times (0.50)^3}{12} = 0.0625 \text{ in}^4$$

$$I_{yy} = \frac{(0.50)\ 6^3}{12} = 9.0 \text{ in}^4$$

$$\text{Radius of Gyration, } r = \sqrt{\frac{I}{A}} \qquad (6.19)$$

$$r_{xx} = \sqrt{\frac{9.0}{3.0}} = 1.73 \text{ in.}$$

$$r_{yy} = \sqrt{\frac{0.0625}{3.0}} = 0.144 \text{ in.}$$

$$\text{Maximum } \frac{L}{r} = \frac{15}{0.144} = 104$$

$$\text{From Fig. 6-25} \quad F_{cr} = 850 \text{ psi}$$

$$P_{cr} = A\,F_{cr} = 3.0 \times 850 = 2550 \text{ lbs.}$$

DESIGN EXAMPLE 6-16. COMPRESSION IN WOVEN ROVING LAMINATE

A simply supported woven roving laminate 36 in. long and 12 in. wide is to support a compressive load of 7,500 lbs. in the warp direction. What must its thickness be for a factor of safety of 2 on the ultimate compressive stress? See Fig. 6-29.

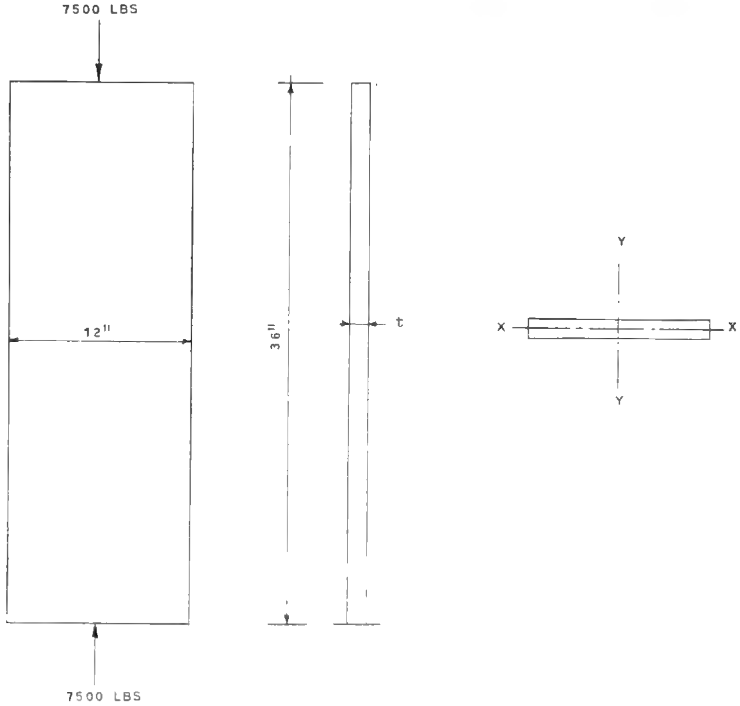


Fig. 6-29. Woven Roving Laminate in Compression

$$\text{Area} = 12 \times t$$

$$I_{Min} = I_{xx} = \frac{12\ t^3}{12} = t^3$$

$$r_{xx} = \sqrt{\frac{t^3}{12 \times t}} = \frac{t}{2 \times \sqrt{3}} = \frac{t}{3.464}$$

$$\frac{L}{r} = \frac{36 \times 3.464}{t} = \frac{124.70}{t}$$

$$P = \frac{F_{cr}}{2} \times 12t = 7500 \text{ lbs.}$$

Assume $t = 1$ in.; then $\frac{L}{r} = \frac{124.70}{1.00} = 124.70$

From Figure 6-26, $F_{cr} = 1550$ psi

For a FS $= 2$; $f_c = \frac{1550}{2} = 775$ psi

$P = 775 \times 12 \times 1.00 = 8600$ lbs. Greater than required.

Try 15/16: $\frac{L}{r} = \frac{124.70}{.9375} = 133$

From Figure 6-26 $F_{cr} = 1350$ psi

For a FS of 2; $f_c = \frac{1320}{2} = 675$ psi

$P = 675 \times 12 \times .9375 = 7594$ lbs.

Use a 15/16 in. thick laminate.

Composite laminates made of several laminae of different materials have properties which are different from the physical properties of any of the individual laminae. These properties for composite laminates have to be computed before the ultimate compressive stress can be determined. The properties for a composite laminate can be found by means of the following equations:

Neutral Axis $$x = \frac{\sum E_i A_i x_i}{E_i A_i} \tag{6.24}$$

Stiffness Factor $$EI = \sum E_i I_i \tag{6.25}$$

Modulus of Elasticity $$E = \frac{1}{A} \sum E_i A_i \tag{6.26}$$

Shear Modulus $$G = \frac{1}{A} \sum G_i A_i \tag{6.27}$$

Where E_i = modulus of elasticity of i-th lamina about the neutral axis.

I_i = moment of inertia of i-th lamina about the neutral axis.

A_i = area of i-th lamina.

G_i = modulus of rigidity of i-th lamina.

x_i = distance from some reference line to the center of gravity of the i-th lamina.

DESIGN EXAMPLE 6-17. CRITICAL COMPRESSIVE LOAD OF COMPOSITE LAMINATE

Given the laminate of Fig. 6-30, compute the following constants: x, I, E, r, and the critical compressive load parallel to the warp for simply supported ends.

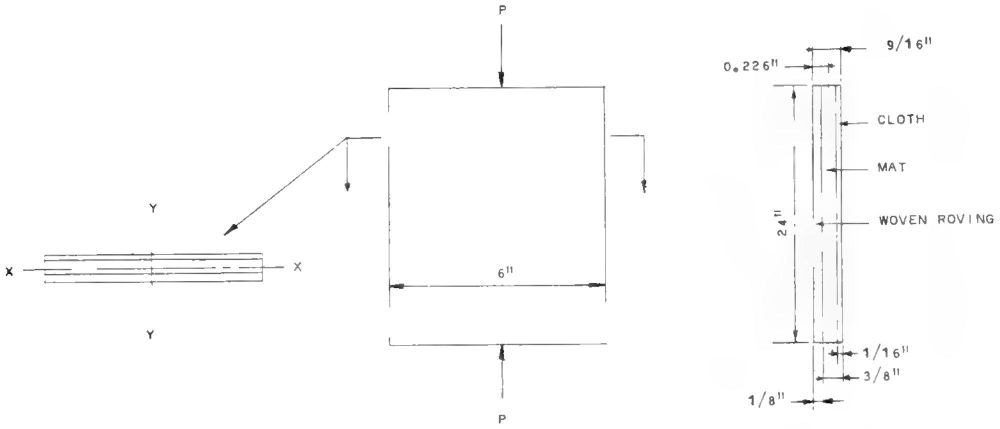


Fig. 6-30. Composite Laminate in Compression

Neutral Axis:

A_1 = Area Cloth = $6 \times 1/16$ = 0.375 in^2

A_2 = Area Mat = $6 \times 3/8$ = 2.250 in^2

A_3 = Area W.R. = $6 \times 1/8$ = 0.750 in^2

Given: E_1: Cloth = 2.46×10^6 at 0° or warp direction

E_2: Mat = 0.93×10^6 at 0° or warp direction

E_3: W.R. = 2.45×10^6 at 0° or warp direction

$$x = \frac{\sum E_i A_i x_i}{\sum E_i A_i} \tag{6.24}$$

x_1, x_2 and x_3 from woven roving face.

$$x = \frac{2.46\text{x}10^6\text{x}0.375\text{x}0.5313 + 0.93\text{x}10^6\text{x}2.250\text{x}0.3125 + 2.45\text{x}10^6\text{x}0.750\text{x}0.0625}{2.46\text{x}10^6\text{x}0.375 + 0.93\text{x}10^6\text{x}2.250 + 2.45\text{x}10^6\text{x}0.750}$$

$x = 0.226$ from face of woven roving.

Solving for E:

$$E = \frac{1}{A}\sum E_i A_i \qquad (6.26)$$

	Cloth	Mat	W.R.
E_i	2.46×10^6	0.93×10^6	2.45×10^6
$I_{i_{xx}}$	1.22×10^{-6}	264×10^{-4}	977×10^{-6}
A_i	0.375	2.250	0.750

$$EA = 2.46\text{x}10^6\text{x}0.375 + 0.93\text{x}10^6\text{x}2.250 + 2.45\text{x}10^6\text{x}0.750$$

$$= 2.967 \times 10^6$$

$$E = \frac{2.967 \times 10^6}{3.375} = 0.879 \times 10^6 \text{ psi}$$

Solving for EI

$$EI_{xx} = E_i I_{i_{xx}} \qquad (6.25)$$

$$EI_{xx} = 2.46\text{x}10^6(122\text{x}10^{-6}+0.375\text{x}0.3053^2)+0.93\text{x}10(264 \times 10^{-6} + 2.250 \times 0.0865^2)$$
$$+2.45\text{x}10^6(977\text{x}10^{-6}+0.750\text{x}0.1635^2)$$

$$= 178002 \text{ lbs-in}^2$$

$$I_{xx} = \frac{178002}{0.879\text{x}10^6} = 0.2025 \text{ in}^4$$

$$I_{yy} = \frac{d^3}{12E}\left[t_1E_1 + t_2E_2 + t_3E_3\right] \qquad (6.28)$$

$$= \frac{6^3}{12\text{x}0.879\text{x}10^6}\left[.0625\text{x}2.46\text{x}10^6+.375\text{x}0.93\text{x}10^6+.125\text{x}2.45\text{x}10^6\right]$$

$$= 16.567 \text{ in}^4$$

Solving for the radius of gyration, r

$$r = \sqrt{\frac{I}{A}} \qquad (6.19)$$

$$r_{xx} = \sqrt{\frac{0.2025}{3.375}} = \sqrt{.060} = 0.245 \text{ in.}$$

$$\frac{L}{r_{xx}} = \frac{24}{0.245} = 97.96$$

$$r_{yy} = \sqrt{\frac{16.567}{3.375}} = \sqrt{4.909} = 2.22 \text{ in.}$$

$$\frac{L}{r_{yy}} = \frac{24}{2.22} = 10.81$$

Critical Load

$$P_{cr} = \frac{\pi^2 \times EA}{\left(\frac{L}{r}\right)^2} \qquad (6.17a)$$

$$= \frac{\pi^2 \times 2.967 \times 10^6}{(97.96)^2} = 3052 \text{ lbs.}$$

FLEXURE

As previously stated fiberglass laminates may be homogeneous and isotropic or composite and orthotropic depending on the type of reinforcement used. Mat reinforced laminates are considered to be isotropic with equal strength and elastic properties in every direction and can be analyzed with the same elastic theories as used for metals. Cloth and woven roving laminates are considered orthotropic with different strength and elastic properties in different directions and the method of analysis will depend on the direction of load in relation to the glass fibers. For laminates reinforced with a single type of reinforcement and for loading parallel to the direction of the glass fibers, the method of analysis will be similar to the method used for mat laminates. For composite laminates reinforced with two or more types of reinforcement and for loading parallel to the direction of the glass fibers, the same type of analysis as used for any other composite section where the moduli are considered is applicable. The method of analysis for stiffener and plate construction is the same as for composite laminates with loading in the direction of the glass fibers. In the development of stiffeners molded or bonded to the skin laminate, care must be taken to be sure that the horizontal shear stress at the plane between the stiffeners and plate does not exceed the laminate interlaminate or bond stress.

Simple One-Way Plates

The differences in analysis for the homogeneous and composite laminates in simple one-way bending will be illustrated in the design examples which follow. A discussion on the bending of plates loaded normal to their surface is presented later in this Chapter. For guidance, graphs of section moduli and moments of inertia have been prepared for several composite laminates, Figs. 6-31 to 6-33, commonly used in boat hull construction.

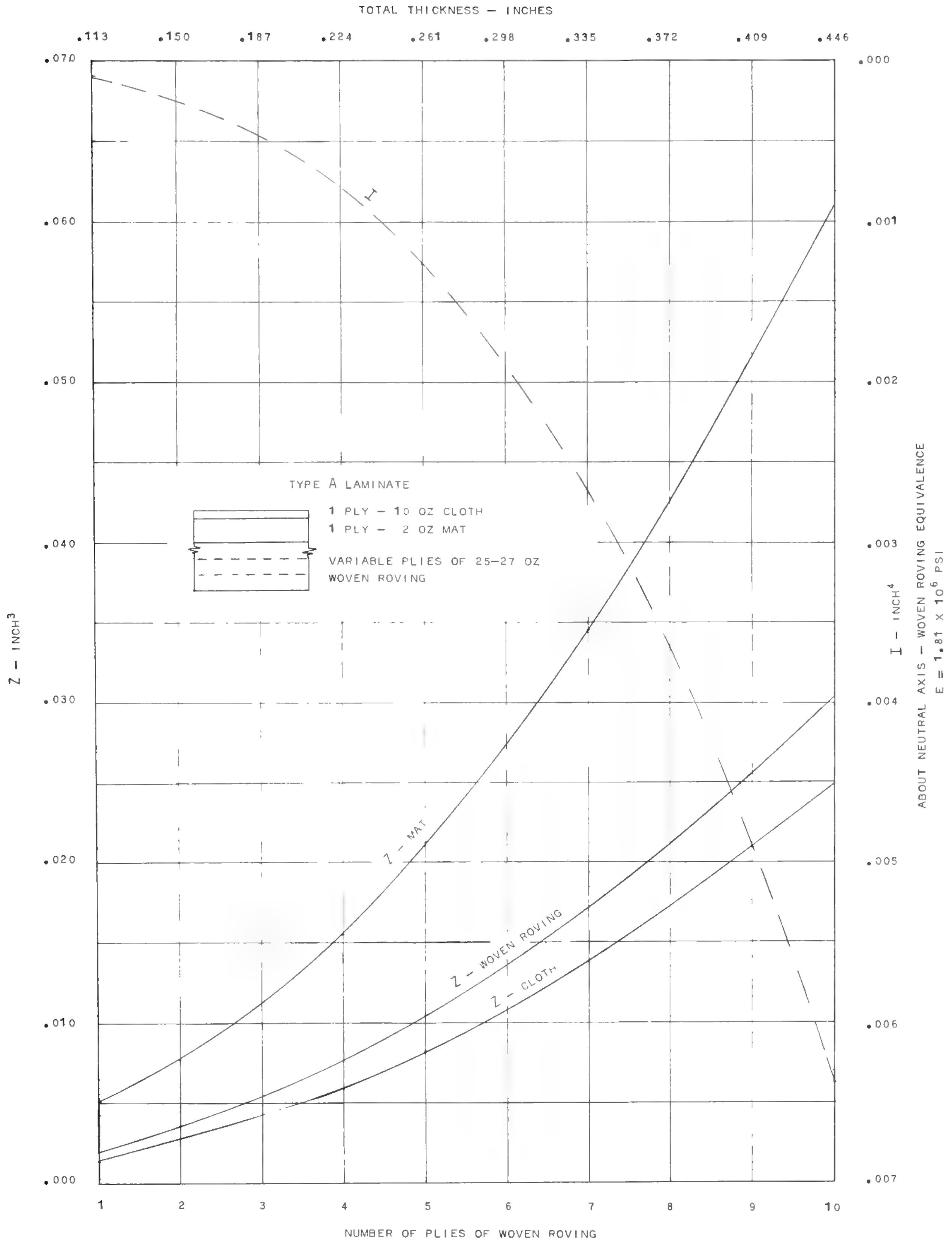


Fig. 6-31. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, Type A Laminate - 1 In. Wide Strip

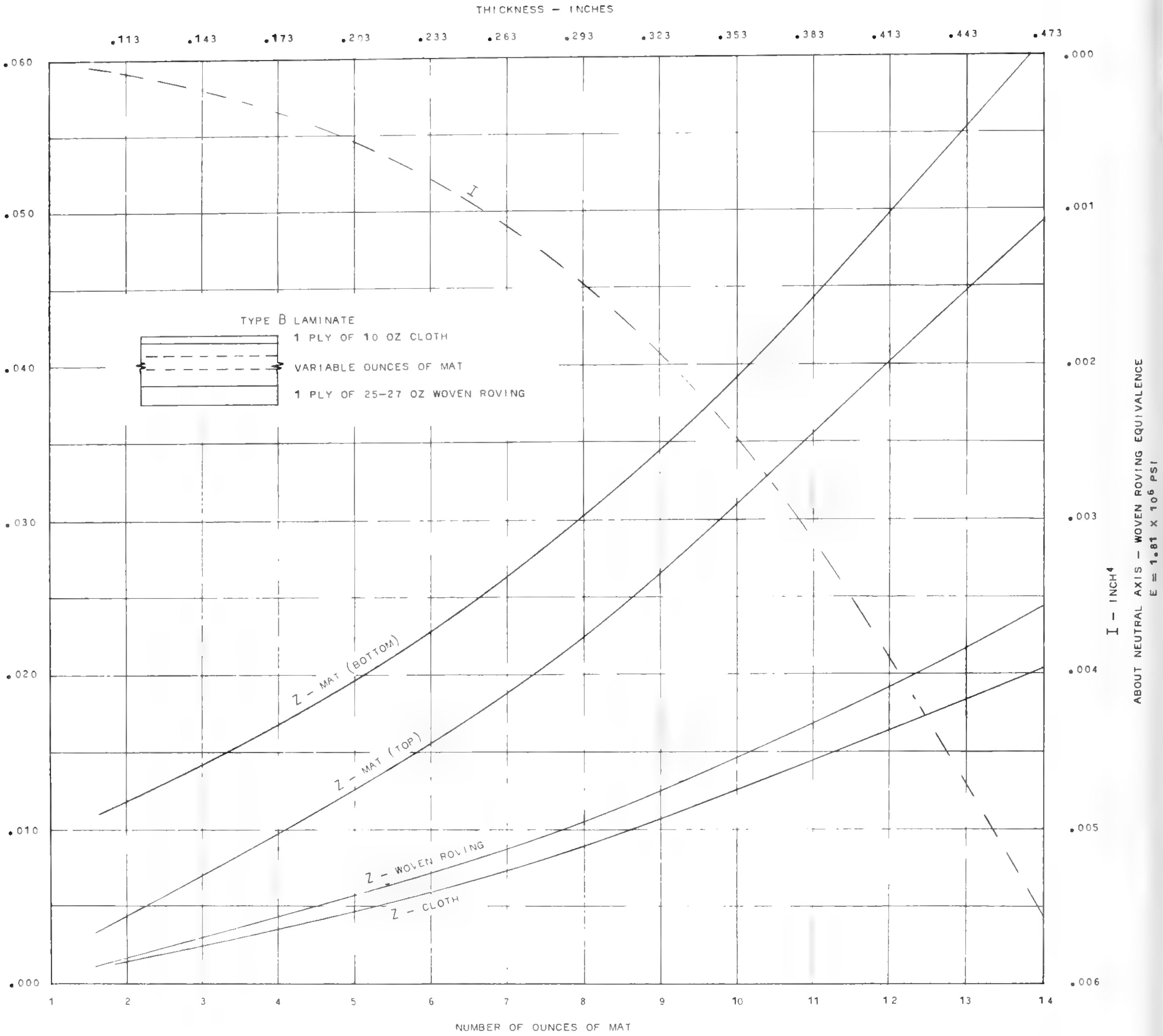


Fig. 6-32. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, Type B Laminate - 1 In. Wide Strip

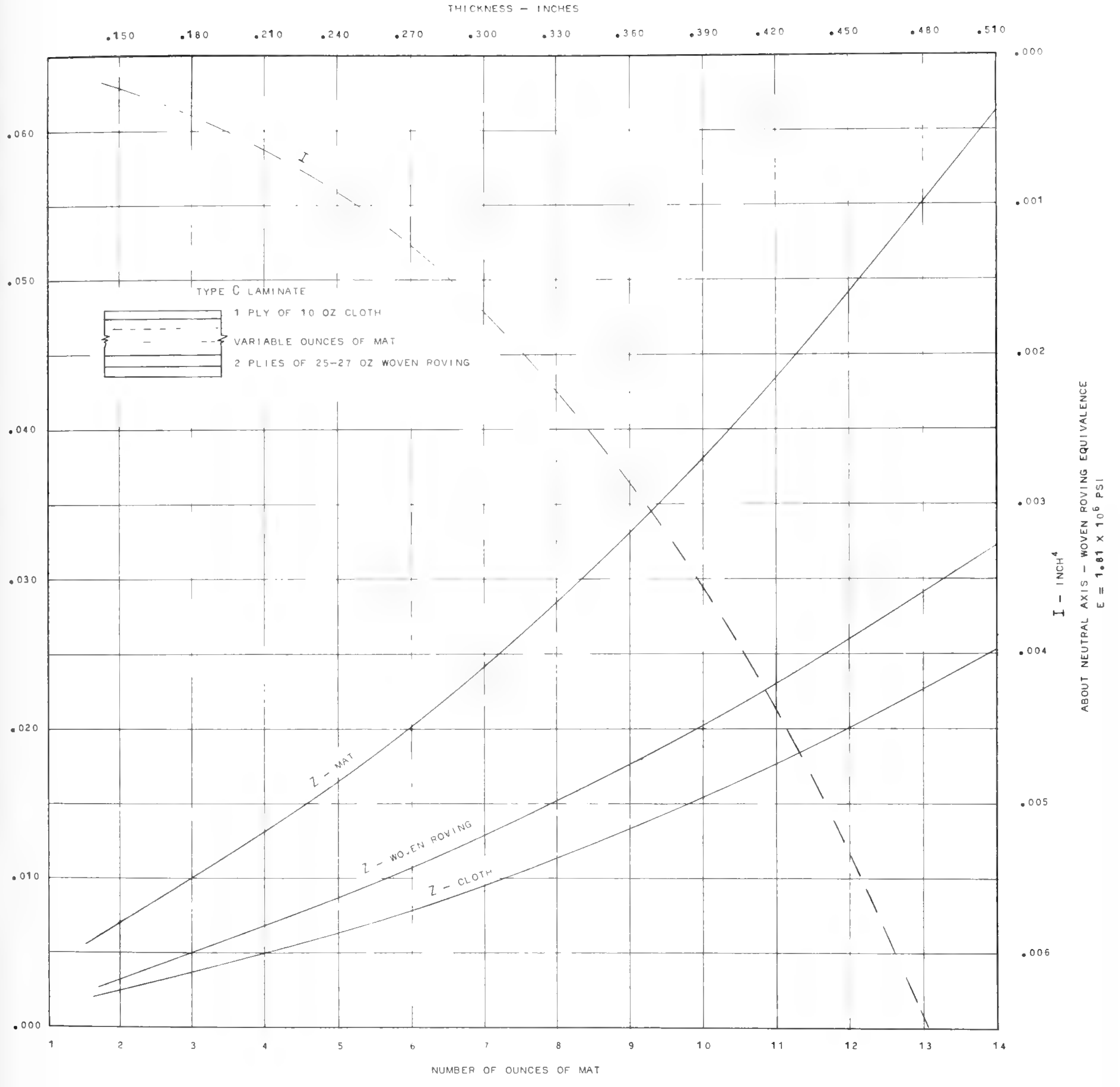


Fig. 6-33. Fiberglass Polyester Laminates, Section Modulus, Z, and Moment of Inertia, I, Type C Laminate - 1 In. Wide Strip

In obtaining the deflection of a laterally loaded member, the effect of shear may be appreciable depending upon the material used and the depth to span ratio. When considering the shear effect in fiberglass reinforced laminates, the shear modulus, G, is important. The shear modulus for a composite laminate will vary with the different types of reinforcements used and an assumed value based on any one of the reinforcements may not be correct. Therefore, when the accuracy of the deflection is important, tests on the particular composite laminate in question should be made.

For a uniformly loaded simply supported beam the total deflection for flexure and shear deformation is (14):

$$d = \frac{5}{384}\frac{pL^4}{EI} + \frac{pL^2}{8AG} \qquad (6.28)$$

where d = deflection, in.

p = load, lbs. per in.

L = span, in.

E = flexural modulus of elasticity, psi

I = moment of inertia, in.^4

A = shear area, in.^2

G = shear modulus, psi

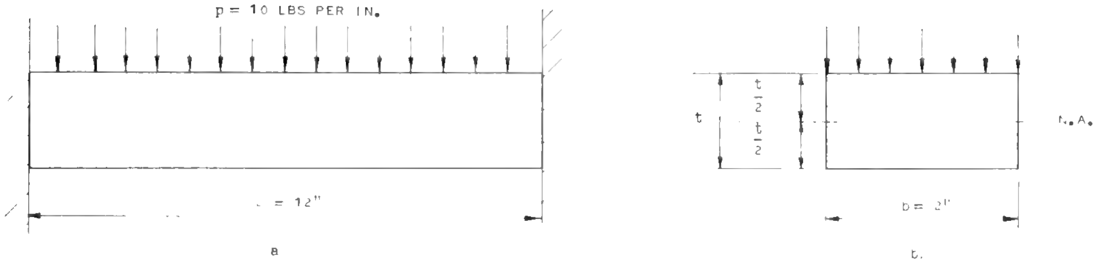
The above equation assumes uniform shear distribution across the section and can be considered approximately correct for sections with thin deep webs where all the shear is taken by the web, similar to an I-beam.

For rectangular sections where the shear is taken by the entire section and the shear distribution across the section is non-uniform with a maximum at the neutral axis, equation 6.28 becomes:

$$d = \frac{5}{384}\frac{pL^4}{EI} + \frac{6}{5} \times \left[\frac{pL^2}{8AG}\right] \qquad (6.28a)$$

DESIGN EXAMPLE 6-18. BENDING OF A MAT OR ISOTROPIC LAMINATE

The fixed ended beam indicated in Fig. 6-34 is made of mat reinforcement and is 12 in. long and 2 in. wide. What should the thickness of the laminate be if it is to support a uniform load of 10 lbs. per linear in. and have a factor of safety of 4 on the ultimate strength? Also compute the beam deflection.



a

b.

Fig. 6-34. Bending of Mat Laminate

$$\text{Bending Moment} \quad M = \frac{pL^2}{12} \qquad (6.29)$$

where M = bending moment, in. lbs.

p = unit load, lbs. per in.

L = span, in.

$$\text{Therefore } M = 10 \times \frac{12^2}{12} = 120.0 \text{ in. lbs.}$$

The maximum shear on the section is equal to the end reaction:

$$V = \frac{pL}{2} \qquad (6.30)$$

where V = maximum shear, lbs.

and

$$V = 10 \times \frac{12}{2} = 60.0 \text{ lbs.}$$

For the required factor of 4 on the ultimate strength of the laminate, the ultimate moment and shear becomes:

$$Mu = 4 \times 120 = 480 \text{ in. lbs.}$$

$$Vu = 4 \times 60 = 240 \text{ lbs.}$$

The following properties of the mat laminates are obtained from the tables in Chapter 5:

Ultimate flexural strength, F_b = 20500 psi Table 5-9

Flexural modulus of elasticity, $E = 0.86 \times 10^6$ psi Table 5-10

Ultimate shear strength, perpendicular, F_s = 9900 psi Table 5-14

By use of the standard beam formula, the required section modulus, Z is obtained:

$$f_b = \frac{My}{I} = \frac{M}{Z} \tag{6.31}$$

where f_b = bending stress, psi

y = distance from neutral axis to the outermost fiber, in.

I = moment of inertia, in.^{4}

Z = section modulus, in.^{3}

Rearranging the terms in the formula the required section modulus is:

$$Z = \frac{M}{f_b} \tag{6.31a}$$

$$Z = \frac{480}{20500} = 0.0234 \text{ in.}^3$$

The section modulus, Z, for the outermost fiber of the beam is obtained from:

$$Z = \frac{I}{y} = \frac{bt^2}{6} \tag{6.32}$$

where I, the moment of inertia is:

$$I = \frac{bt^3}{12} \tag{6.23}$$

b = width, in.

t = thickness, in.

Therefore the required depth or thickness of the laminate is:

$$t = \sqrt{\frac{6 \times Z}{b}} \tag{6.32a}$$

$$t = \sqrt{\frac{6 \times 0.0234}{2}} = 0.265 \text{ in.}$$

The maximum shear stress at the neutral axis is obtained from:

$$f_s = \frac{VQ}{Ib} = \frac{3}{2}\frac{V}{bt} \qquad (6.33)$$

where f_s = shear stress, psi

Q = static moment of area above the neutral axis

$$Q = b \times \frac{t}{2} \times \frac{t}{4} = \frac{bt^2}{8} \quad \text{in}^3$$

Rearranging the terms and substituting the known values, the required depth or thickness is:

$$t = \frac{3}{2}\frac{V}{bf_s} \qquad (6.33a)$$

$$t = \frac{3 \times 240}{2 \times 2 \times 9900} = 0.018 \text{ in.}$$

The thickness required is governed by flexure and is 0.265 in.

The maximum deflection of the fixed ended uniformly loaded beam, including the effect of shear is obtained from:

$$d = \frac{pL^4}{384EI} + \frac{6}{5} \times \left[\frac{pL^2}{8AG}\right] \qquad (6.34)$$

Shear modulus, G, for mat laminate = 0.40×10^6 psi (Table 5-14)

$$I = \frac{bt^3}{12} = \frac{2 \times 0.265^3}{12} = .00310 \text{ in}^4 \qquad (6.23)$$

$$\text{Deflection } d = \frac{10 \times 12^4}{384 \times 0.86 \times 10^6 \times .00310} + \frac{6}{5} \times \left[\frac{10 \times 12^2}{8 \times 2 \times 0.265 \times 0.40 \times 10^6}\right]$$

$$= 0.2026 + 0.0011 = 0.2037 \text{ in.}$$

DESIGN EXAMPLE 6-19. BENDING OF A COMPOSITE LAMINATE

Compute the ultimate carrying capacity per in. of width of the simply supported composite laminate when uniformly loaded, Fig. 6-35. Assume the cloth and woven roving plies to be parallel laminated in the direction of the span.

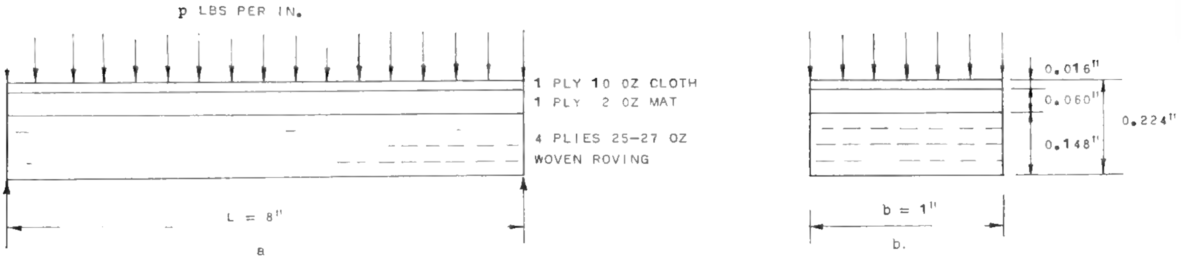


Fig. 6-35. Bending of Composite Laminate

The engineering properties for the three laminae are different and the analysis for a composite section must be used. To obtain the necessary properties of the section such as neutral axis, x, stiffness factor, EI, etc. equations 6.24 to 6.27 can be used.

The section modulus may be obtained from:

$$Z = \frac{EI}{E_y y} \qquad (6.35)$$

where y = distance from the neutral axis to any point, in.

E_y = modulus of elasticity of lamina at that point, lbs./in.

$EI = \sum E_i I_i$ = stiffness factor of the entire section, lbs.-in.^{2}

And the flexural stress may be obtained from:

$$f_b = \frac{M}{Z} = \frac{M E_y y}{EI} \qquad (6.36)$$

The maximum flexural stress may not occur at the extreme fiber as for isotropic materials but may occur at any fiber in the section depending on its distance from the neutral axis and its modulus of elasticity.

The maximum shear stress may be obtained from:

$$f_s = \frac{VQ'}{EIb} \qquad (6.37)$$

where V, EI and b are as previously defined.

Q' = Weighted static moment, $\sum E_i A_i y'$, of the areas between the extreme edge and the plane being considered about the neutral axis of the section.

It is considered advantageous when obtaining the section properties of a composite laminate to transform the areas of the different laminae to equivalent areas of one of the lamina. This method will be used in this design example.

The necessary physical and mechanical properties for the different laminae are assumed to be the same as for a laminate of the same reinforcement. The values are obtained from Chapter 5.

Property	Cloth	Mat	W. R.	Table No.
Thickness, t, in.	1 ply = 0.016	1 ply = 0.060	4 ply = 0.148	5-1
Flexural Modulus of Elasticity, E x 10^6 psi	1.96	0.86	1.81	5-10
Ultimate Flexural Stress F_b, psi	31,100	20,500	28,200	5-9
Ultimate Interlaminar Shear Stress, F_{IS}, psi	2,570	2,780	2,600	5-1

Transforming the respective areas of the cloth and mat laminae to equivalent area of a woven roving lamina, the areas as indicated in Fig. 6-36 are obtained.

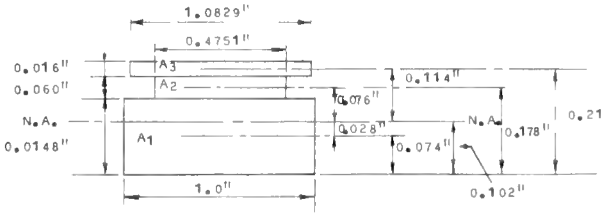


Fig. 6-36. Equivalent Laminate

$$A_1 = \text{W.R. area} = 0.148 \times 1.0 = 0.148 \text{ in}^2$$

$$A'_2 = \text{Mat area} = A_2 \times \frac{E_2}{E_1} \qquad (6.38)$$

where A'_2 = Equivalent area for woven roving lamina.

A_2 = Area of mat lamina

E_1 = Flexural modulus of elasticity for woving roving lamina

E_2 = Flexural modulus of elasticity for mat lamina

$$A_2 = \frac{0.060 \times 0.86 \times 10^6}{1.81 \times 10^6} = 0.060 \times 0.4751 = 0.0285 \text{ in}^2$$

$$A'_3 = \text{Cloth area} = A_3 \times \frac{E_3}{E_1} \qquad (6.38a)$$

$$A_3 = \frac{0.016 \times 1.96 \times 10^6}{1.81 \times 10^6} = 0.016 \times 1.0829 = 0.0173 \text{ in}^2$$

The neutral axis of the transformed area can now be found as follows:

$$x = \frac{\sum A'_i x_i}{\sum A'_i{}'} \tag{6.39}$$

where x = distance to neutral axis, in.

A'_i = Equivalent area of i-th lamina, in^2

x_i = Distance to center of i-th lamina, in.

Taking moments about the bottom face of the woven roving lamina:

$$x = \frac{(0.0173 \text{ x } 0.216 + 0.0285 \text{ x } 0.178 + 0.148 \text{ x } 1 \text{ x } 0.074)}{(0.0173 + 0.0285 + 0.148)}$$

$$x = \frac{0.0198}{0.1938} = 0.102 \text{ in. from bottom face of woven roving lamina}$$

Obtaining the neutral axis by using equation 6.24:

$$x = \frac{\sum E_i A_i x_i}{\sum E_i A_i} \tag{6.24}$$

$$x = \frac{(0.016\text{x}1.96\text{x}10^6\text{x}0.216+0.060\text{x}0.86\text{x}10^6\text{x}0.178+0.148\text{x}1.81\text{x}10^6\text{x}0.074)}{(0.016\text{x}1.96\text{x}10^6+0.060\text{x}0.86\text{x}10^6+0.148\text{x}1.81\text{x}10^6)} = 0.102 \text{ in.}$$

The results are the same. The transformed section method, however, gives the designer a clearer indication of how the components of the laminate behave.

The equivalent moment of inertia and section modulus of the composite section can now be obtained.

Moment of inertia:

$$I' = \sum \left[\frac{b'_i t_i^3}{12} + A'_i x_i^2 \right] \tag{6.40}$$

where b' = equivalent width for woven roving lamina

$$I' = \frac{1.0829\text{x}0.016^3}{12} + 0.0173 \text{ x } 0.114^2 + \frac{0.4751\text{x}0.060^3}{12} + 0.0285\text{x}0.076^2 + \frac{0.148^3}{12} + 0.148\text{x}0.028^2$$

$$= (3700\text{x}10^{-9} + 2252\text{x}10^{-9}) + (8552\text{x}10^{-9} + 1646\text{x}10^{-9}) + (2701\text{x}10^{-9} + 1160\text{x}10^{-9})$$

$$= 7849 \text{ x } 10^{-9} = 0.00078 \text{ in}^4$$

Section moduli to various laminae:

$$Z_i = \frac{I'}{y_i} \times \frac{E_1}{E_i} \qquad (6.41)$$

where Z_i = section modulus of i-th lamina

E_i = modulus of elasticity of i-th lamina

Cloth top fiber:

$$Z_{cl} = \frac{0.00078}{0.122} \times \frac{1.81 \times 10^6}{1.96 \times 10^6} = 0.0059 \text{ in}^3$$

Mat top fiber:

$$Z_m = \frac{0.00078}{0.106} \times \frac{1.81 \times 10^6}{0.86 \times 10^6} = 0.0155 \text{ in}^3$$

Woven roving bottom fiber:

$$Z_{WR} = \frac{0.00078}{0.102} \times \frac{1.81 \times 10^6}{1.81 \times 10^6} = 0.0076 \text{ in}^3$$

The ultimate moments for the ultimate flexural stresses are obtained from:

$$M = F_b \times Z \qquad (6.31b)$$

Cloth, $M_{cl} = 31{,}100 \times 0.0059 = 183$ in-lbs.

Mat, $M_m = 20{,}500 \times 0.0155 = 318$ in-lbs.

Woven Roving, $M_{WR} = 28{,}200 \times 0.0076 = 214$ in-lbs.

The minimum resisting moment of the laminate is $M_{min} = 183$ in-lbs.

The ultimate uniform load for the minimum resisting moment and simply supported laminate:

$$P_u = \frac{8M_{min}}{L^2} \qquad (6.42)$$

where P_u = maximum uniform load, lbs. per in.

M_m = maximum resisting moment, in-lbs.

L = span length, in.

$$P_u = \frac{8 \times 183}{8^2} = 22.9 \text{ lbs. per in.}$$

The ultimate vertical shear that the composite laminate will resist due to the ultimate horizontal shear at the neutral axis and at the shear planes between the different laminae is obtained from:

$$V_i = \frac{fs_i I'b'_i}{Q'_i} \times \frac{E_1}{E_i} \tag{6.43}$$

where $Q'_i = \sum A'_i y'_i$ = equivalent weighted static moment of the equivalent areas between the extreme edge and the plane being considered, about the neutral axis.

Woven roving at neutral axis:

$$V_1 = \frac{2600 \times 0.00078 \times 1.0}{1.0 \times 0.102 \times 0.05} \times \frac{1.81 \times 10^6}{1.81 \times 10^6} = 389.9 \text{ lbs.}$$

Shear plane between woven roving and mat laminae:

Woven roving:

$$V_1 = \frac{2600 \times 0.00078 \times 1.000}{1.0 \times 0.148 \times 0.028} \times \frac{1.81 \times 10^6}{1.81 \times 10^6} = 489.4 \text{ lbs.}$$

Mat:

$$V_2 = \frac{2780 \times 0.00078 \times 0.4751}{1.0 \times 0.148 \times 0.028} \times \frac{1.81 \times 10^6}{0.86 \times 10^6} = 523.1 \text{ lbs.}$$

Shear plane between mat and cloth laminae:

Mat:

$$V_2 = \frac{2780 \times 0.00078 \times 0.4751}{1.0829 \times 0.016 \times 0.114} \times \frac{1.81 \times 10^6}{0.86 \times 10^6} = 1097.5 \text{ lbs.}$$

Cloth:

$$V_3 = \frac{2570 \times 0.00078 \times 1.0829}{1.0829 \times 0.016 \times 0.114} \times \frac{1.81 \times 10^6}{1.96 \times 10^6} = 1014.9 \text{ lbs.}$$

The minimum shear strength of the laminate is, V_{min} = 389.9 lbs.

The ultimate uniform load for the minimum shear strength and simply supported laminae:

$$P_u = \frac{2V_m}{L} \tag{6.30a}$$

$$P_u = \frac{2 \times 389.9}{8} = 97.5 \text{ lbs.}$$

The ultimate flexural stress controls and the ultimate carrying capacity per in. of width of the composite laminate is 22.9 lbs. per in.

In order to eliminate the work required in calculating the flexural strength of a given composite laminate, the graphs of Figs. 6-31 through 6-33 may be used. Given the bending moment and the bending stress for a particular laminate various values of section moduli can be found for the components mat, cloth and woven roving. Entering the graphs with the various section moduli the required laminate may be obtained. The largest number of plies would control the construction of the laminate.

The composite laminate problem in Design Example 6-19 will now be done by using the graphs, to obtain the minimum resisting moment of the laminate.

From the graph in Fig. 6-31 for a Type A laminate:

The equivalent moment of inertia for woven roving:

$$I' = 0.00079 \text{ in}^4$$

and the section moduli are:

Cloth $Z_C = 0.0060 \text{ in}^3$

Mat $Z_M = 0.0156 \text{ in}^3$

Woven Roving $Z_{WR} = 0.0077 \text{ in}^3$

These values are approximately equal to the values previously calculated and the final resisting moments should be the same.

Stiffener and Plate Construction

Beams of reinforced fiberglass can be molded in numerous shapes with various combinations of reinforcements and core materials. To list all the possibilities would be a voluminous task beyond the scope of this manual. For this reason only a few sections have been chosen as representative.

To expedite the work of the designer the graphs of Figs. 6-37 through 6-40 have been prepared.

Figs. 6-37 and 6-38 give the section modulus, Z, and moment of inertia, I, for hat stiffeners made up of woven roving. Fig. 6-37 is for hat stiffeners in conjunction with type A laminate, where the number of plies of woven roving in the laminate is the same as the number of plies in the stiffener. Fig. 6-38 is for hat stiffeners in conjunction with type B laminate, where the number of ounces of mat in the laminate is approximately one and one-half times the number of plies of woven roving in the stiffener. The exact relationship used is indicated on each Figure. In all cases the effective width of the plate laminate assumed acting with the stiffener is taken as twice the width of the top of the stiffener. Similar to the laminates Figs. 6-31 to 6-33, the section moduli given for the cloth face of the laminate and the woven roving face of the stiffener are corrected so that stress values may be calculated without modification for moduli values of the different reinforcements. The moment of inertia, I, values are based on woven roving equivalence with a tension modulus of elasticity approximately equal to 2.06×10^6 psi. The tension moduli have been used since it is questionable which moduli will control. Tests of these hat sections are necessary to ascertain the correct moduli. The stiffener laminate faying, or touching flange has been taken as twice the width of the top of the stiffener to ensure that the horizontal secondary bond shear stress at the interface is never critical.

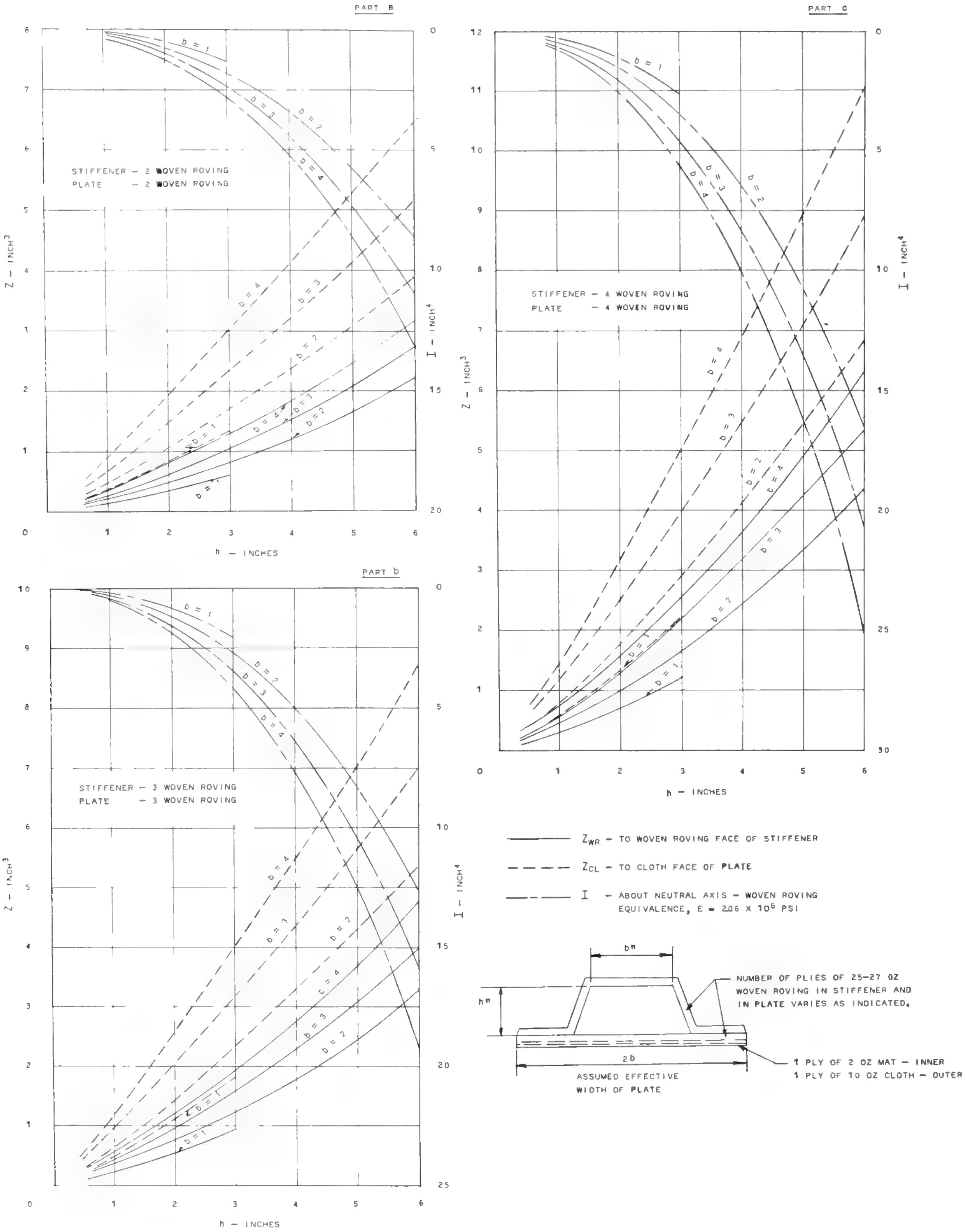


Fig. 6-37. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Hat Stiffeners with Type A Laminate. Core Considered Ineffective

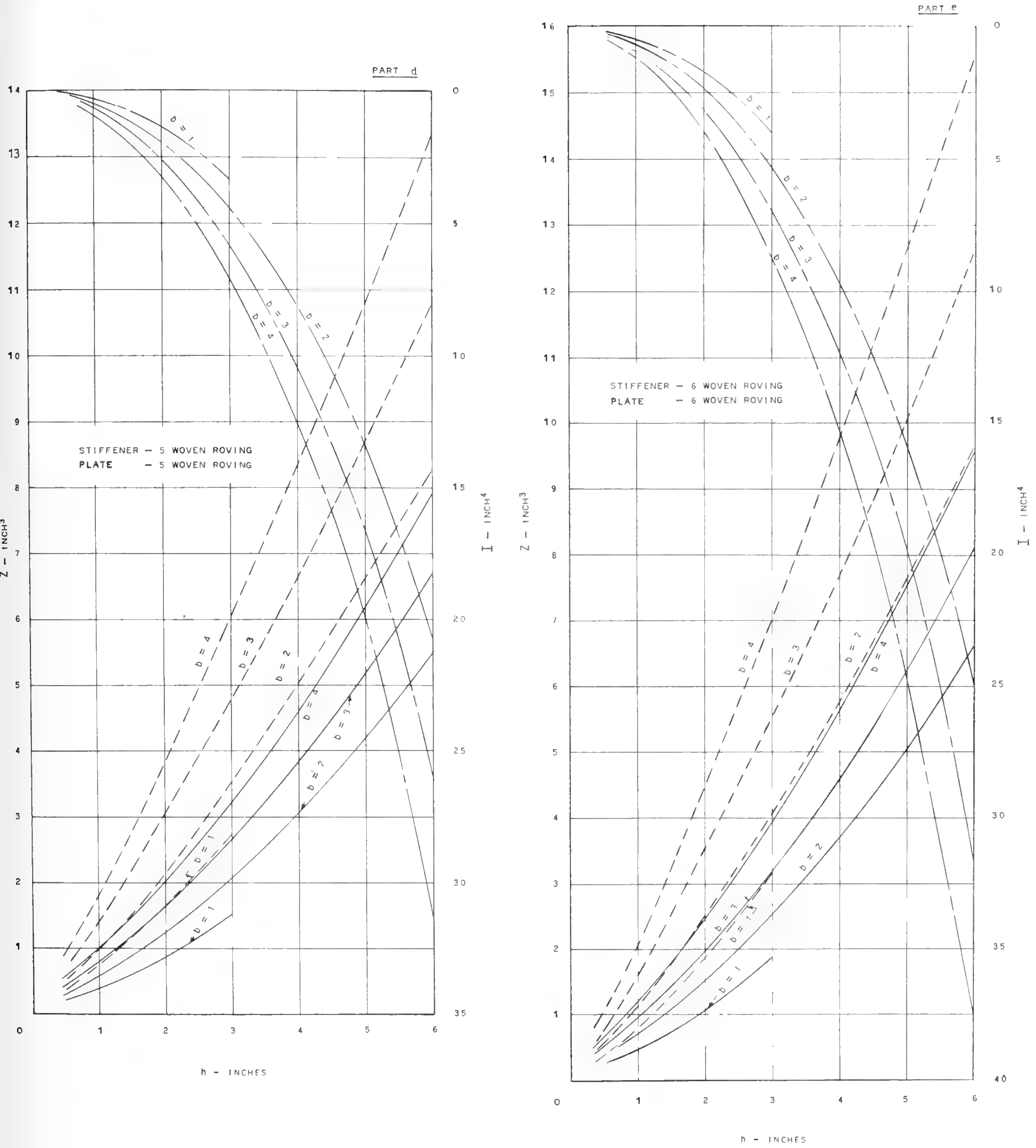


Fig. 6-37. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Hat Stiffeners with Type A Laminate. Core Considered Ineffective (Cont'd)

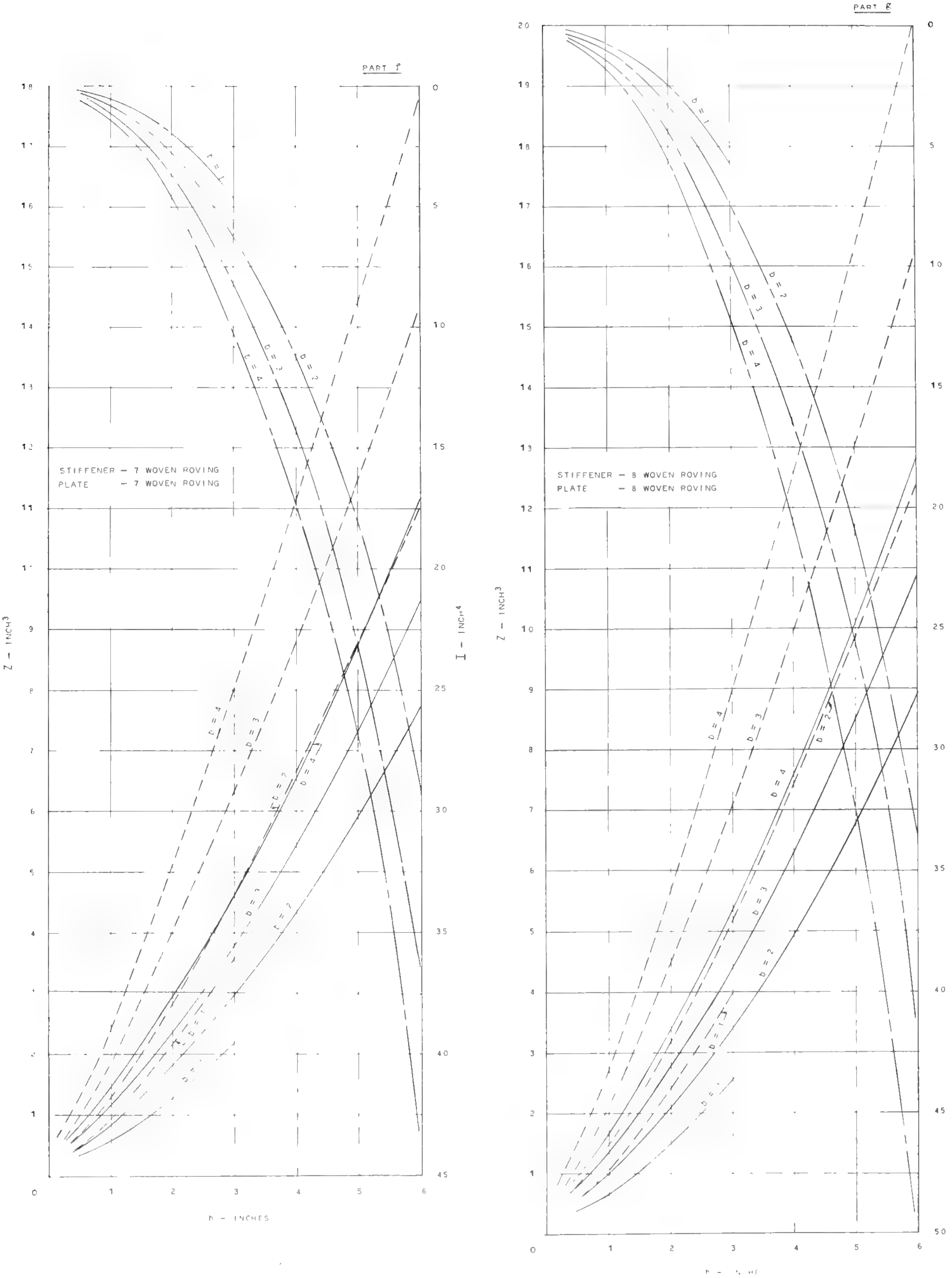
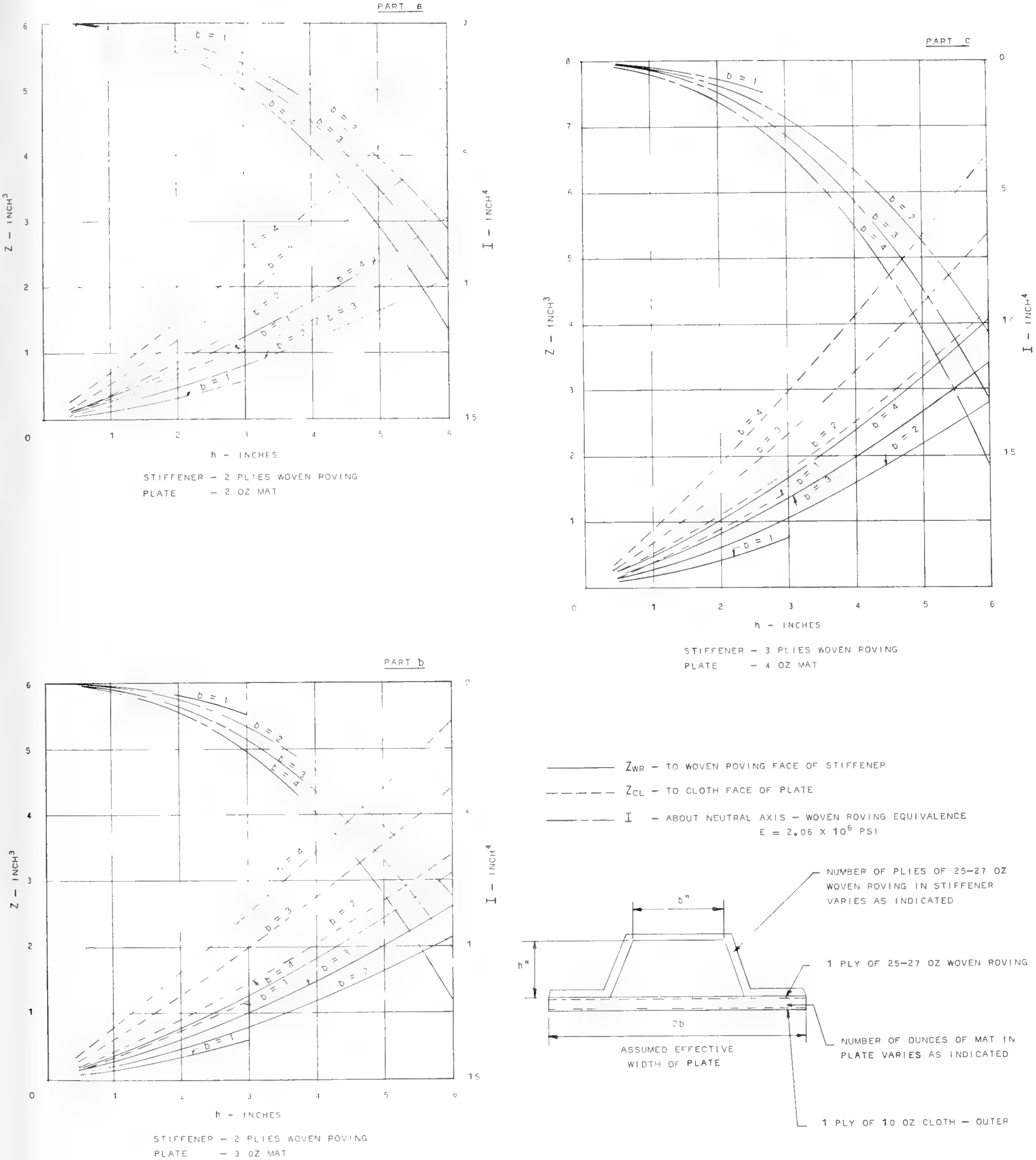


Fig. 6-37. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Hat Stiffeners with Type A Laminate. Core Considered Ineffective (Cont'd)

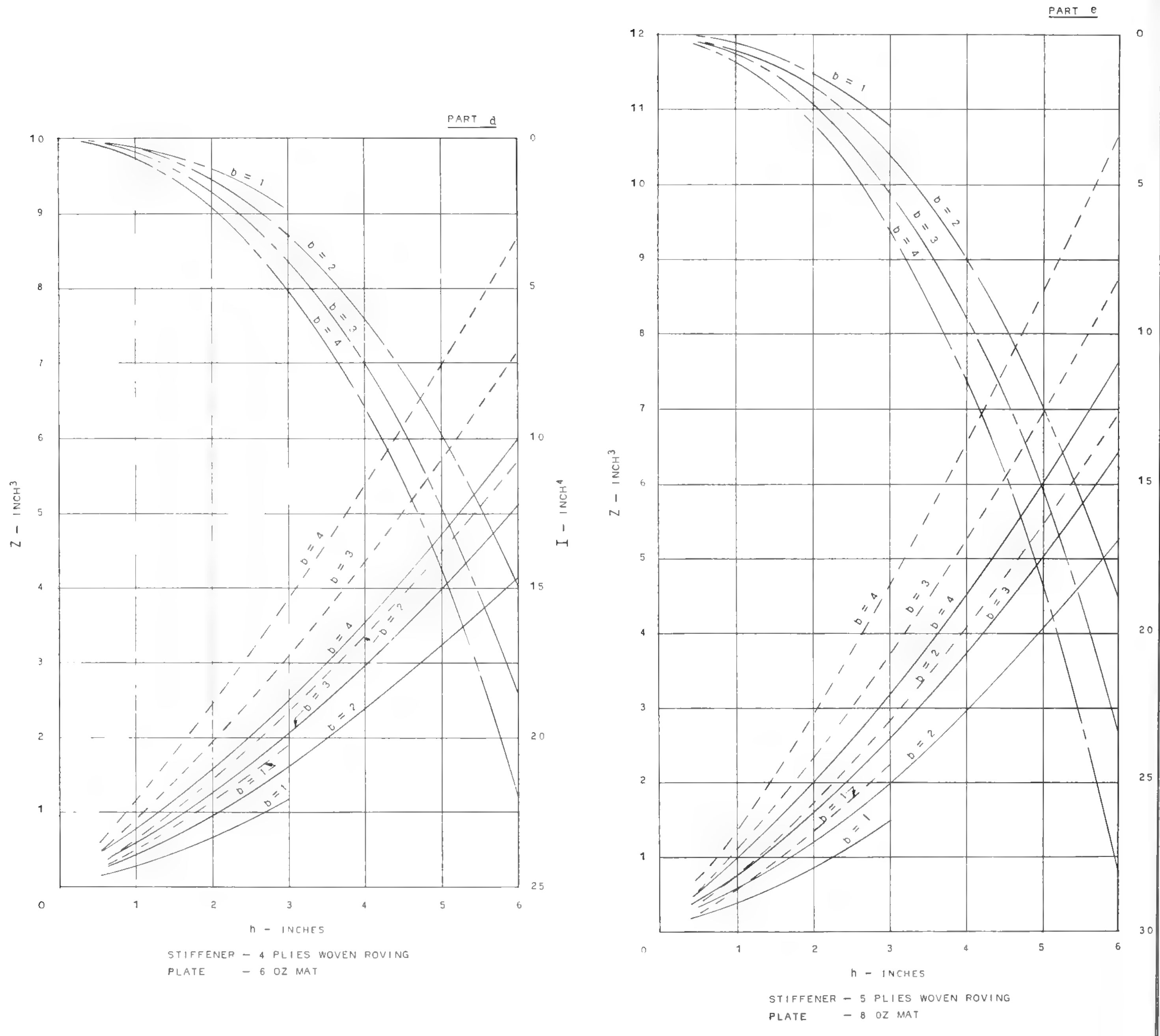


PART a: STIFFENER - 2 PLIES WOVEN ROVING
PLATE - 2 OZ MAT

PART c: STIFFENER - 3 PLIES WOVEN ROVING
PLATE - 4 OZ MAT

PART b: STIFFENER - 2 PLIES WOVEN ROVING
PLATE - 3 OZ MAT

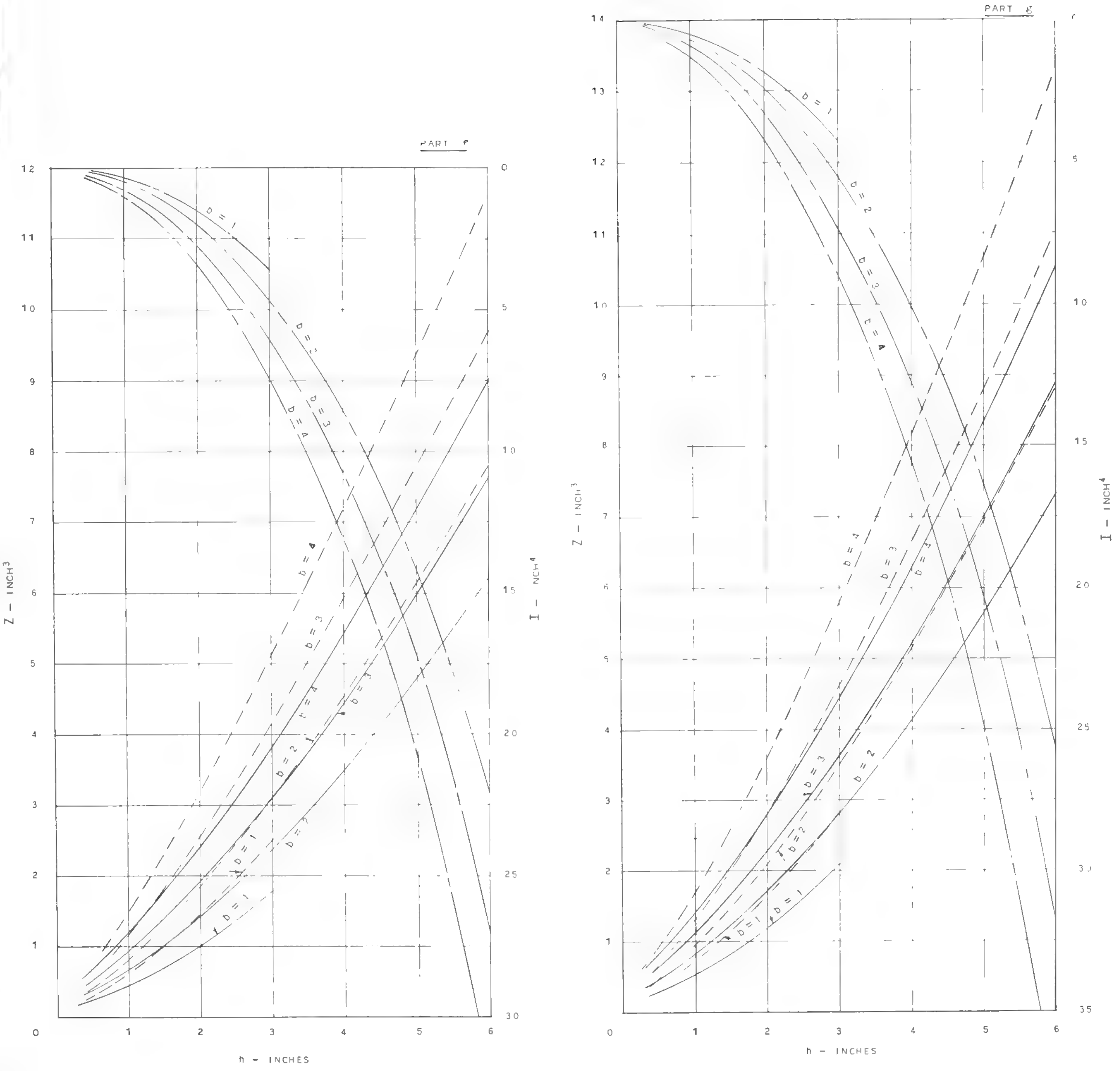
Fig. 6-38. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Hat Stiffeners with Type B Laminate. Core Considered Ineffective



STIFFENER — 4 PLIES WOVEN ROVING
PLATE — 6 OZ MAT

STIFFENER — 5 PLIES WOVEN ROVING
PLATE — 8 OZ MAT

Fig. 6-38. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Hat Stiffeners with Type B Laminate. Core Considered Ineffective (Cont'd)



STIFFENER — 6 PLIES WOVEN ROVING
PLATE — 9 OZ MAT

STIFFENER — 7 PLIES WOVEN ROVING
PLATE — 10 OZ MAT

Fig. 6-38. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Hat Stiffeners with Type B Laminate. Core Considered Ineffective (Cont'd)

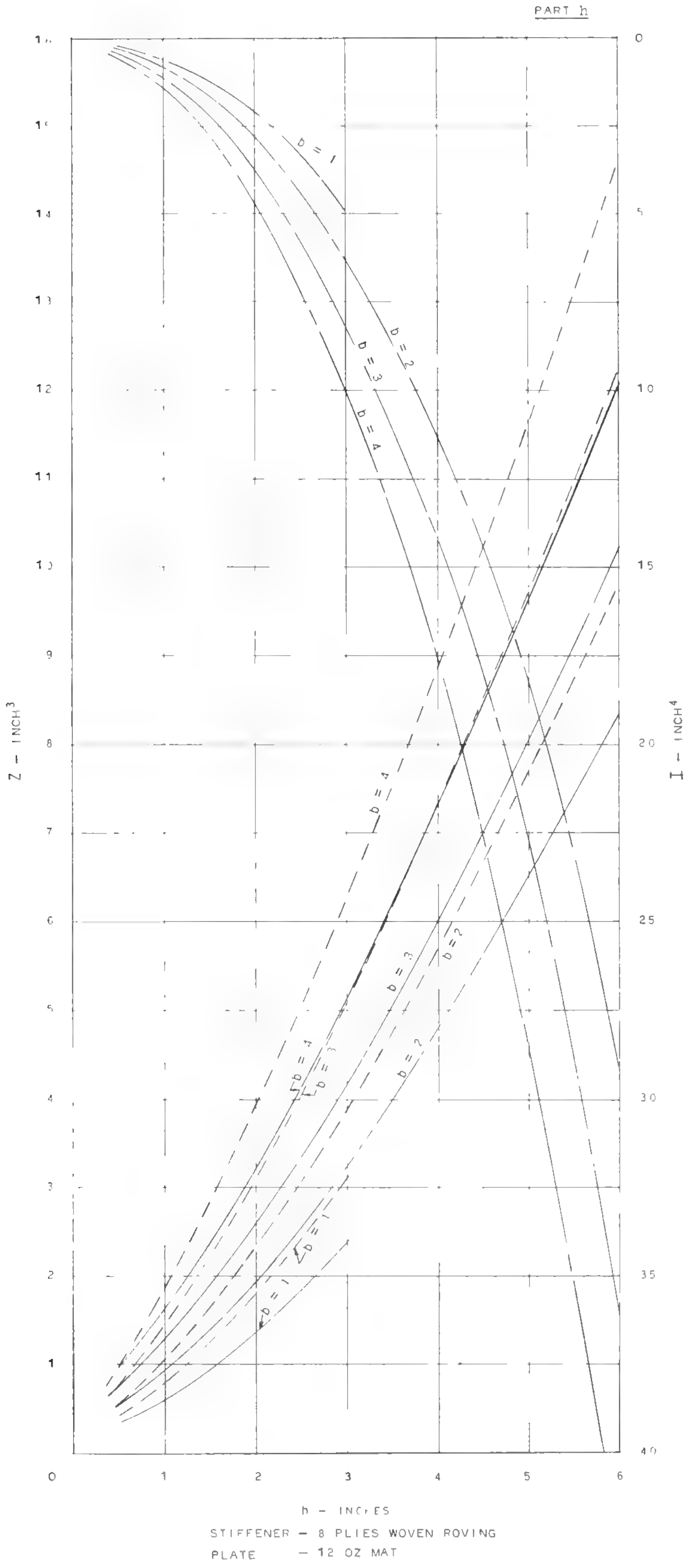


Fig. 6-38. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Hat Stiffeners with Type B Laminate. Core Considered Ineffective (Cont'd)

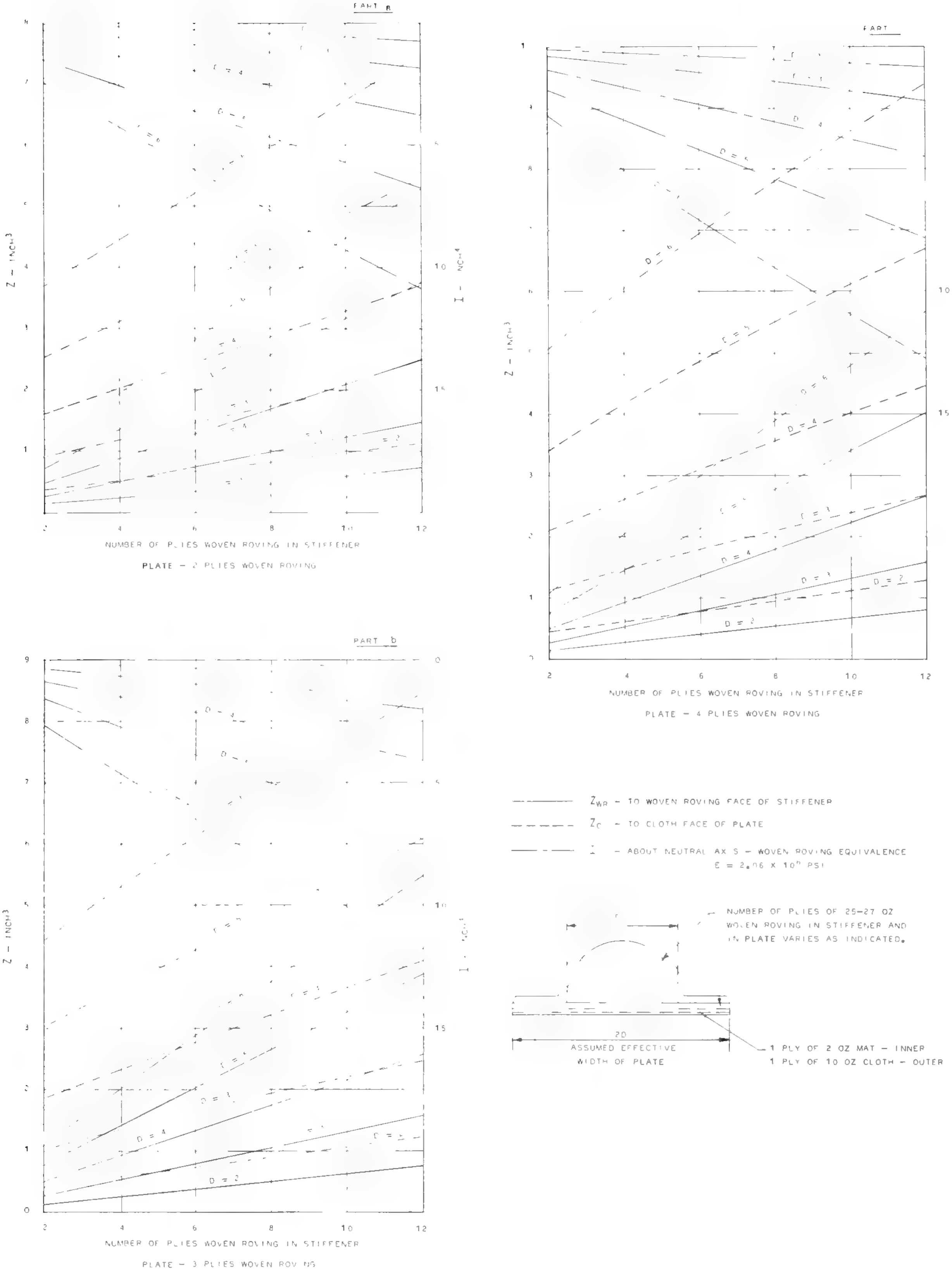


Fig. 6-39. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Half-Round Stiffeners with Type A Laminate. Core Considered Ineffective

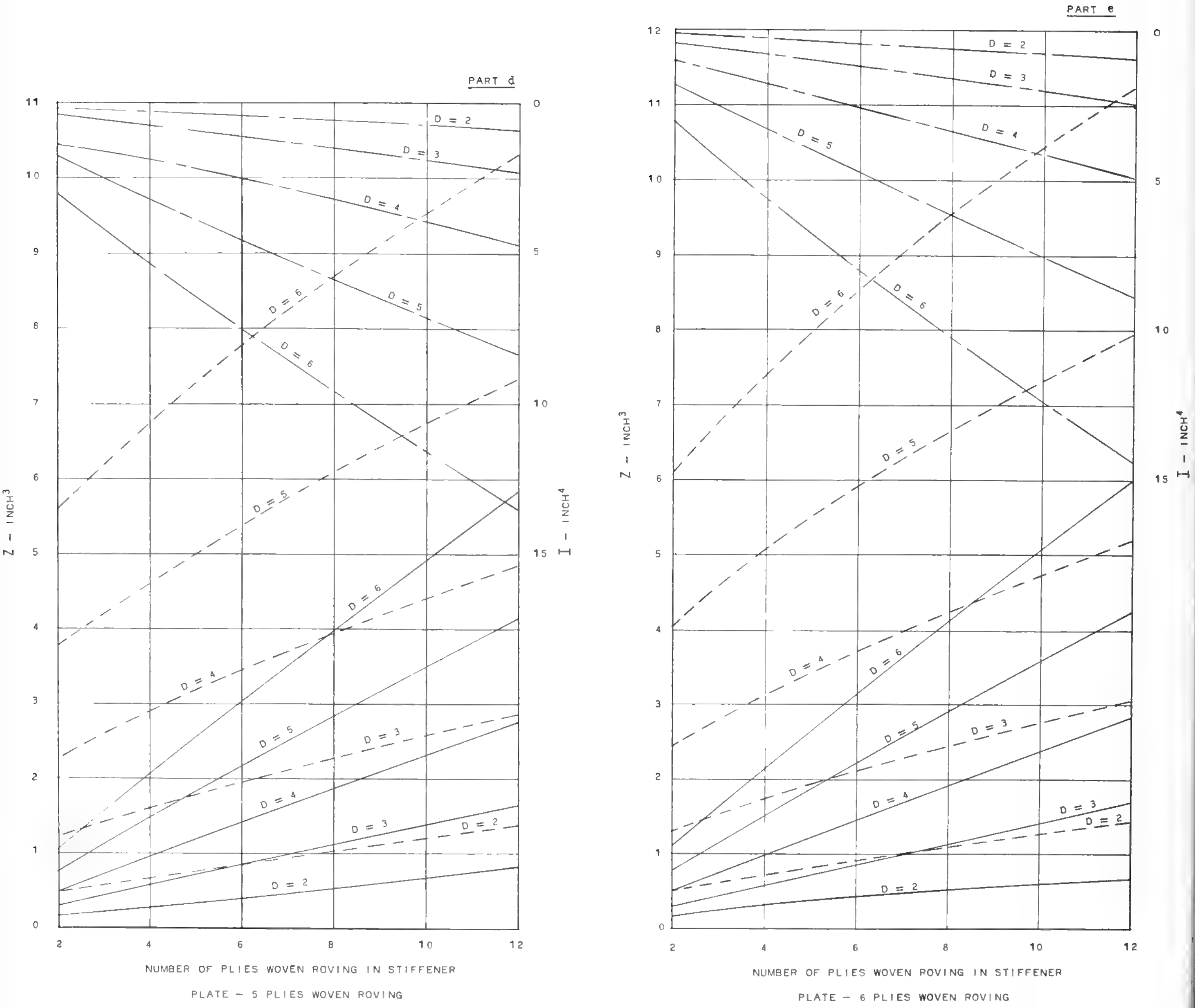


Fig. 6-39. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Half-Round Stiffeners with Type A Laminate. Core Considered Ineffective (Cont'd)

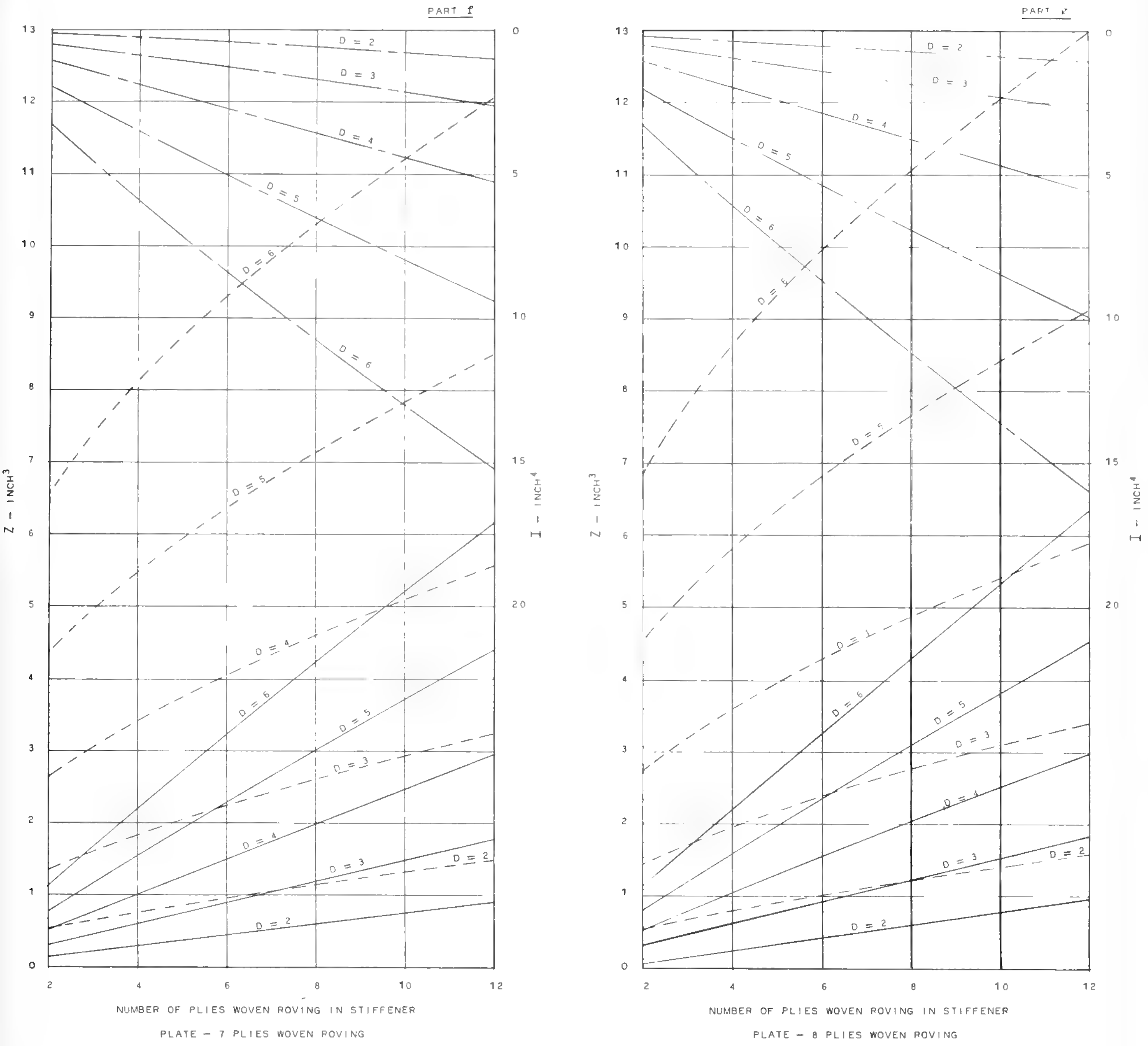


Fig. 6-39. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Half-Round Stiffeners with Type A Laminate. Core Considered Ineffective (Cont'd)

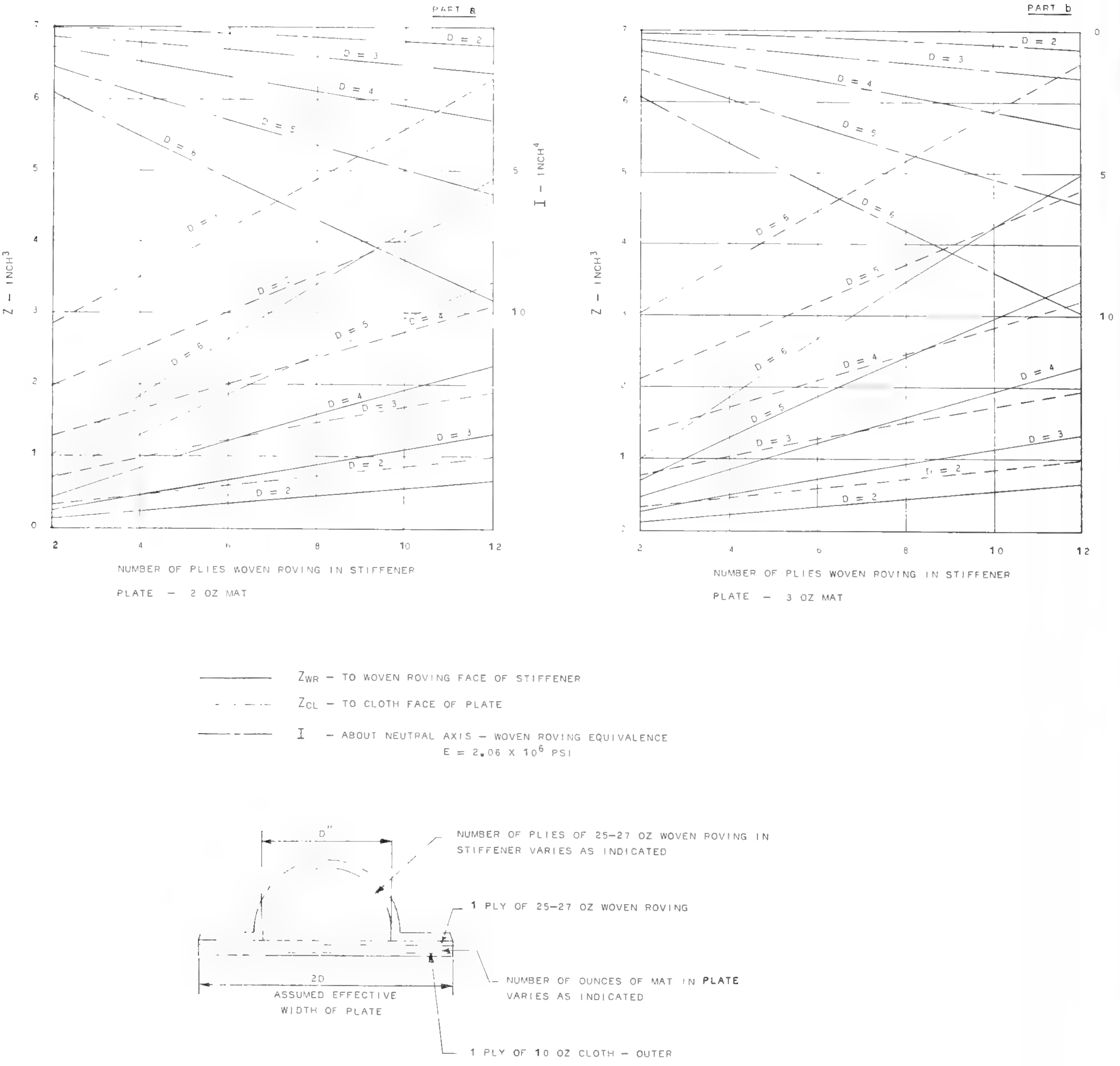


Fig. 6-40. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Half-Round Stiffeners with Type B Laminate. Core Considered Ineffective

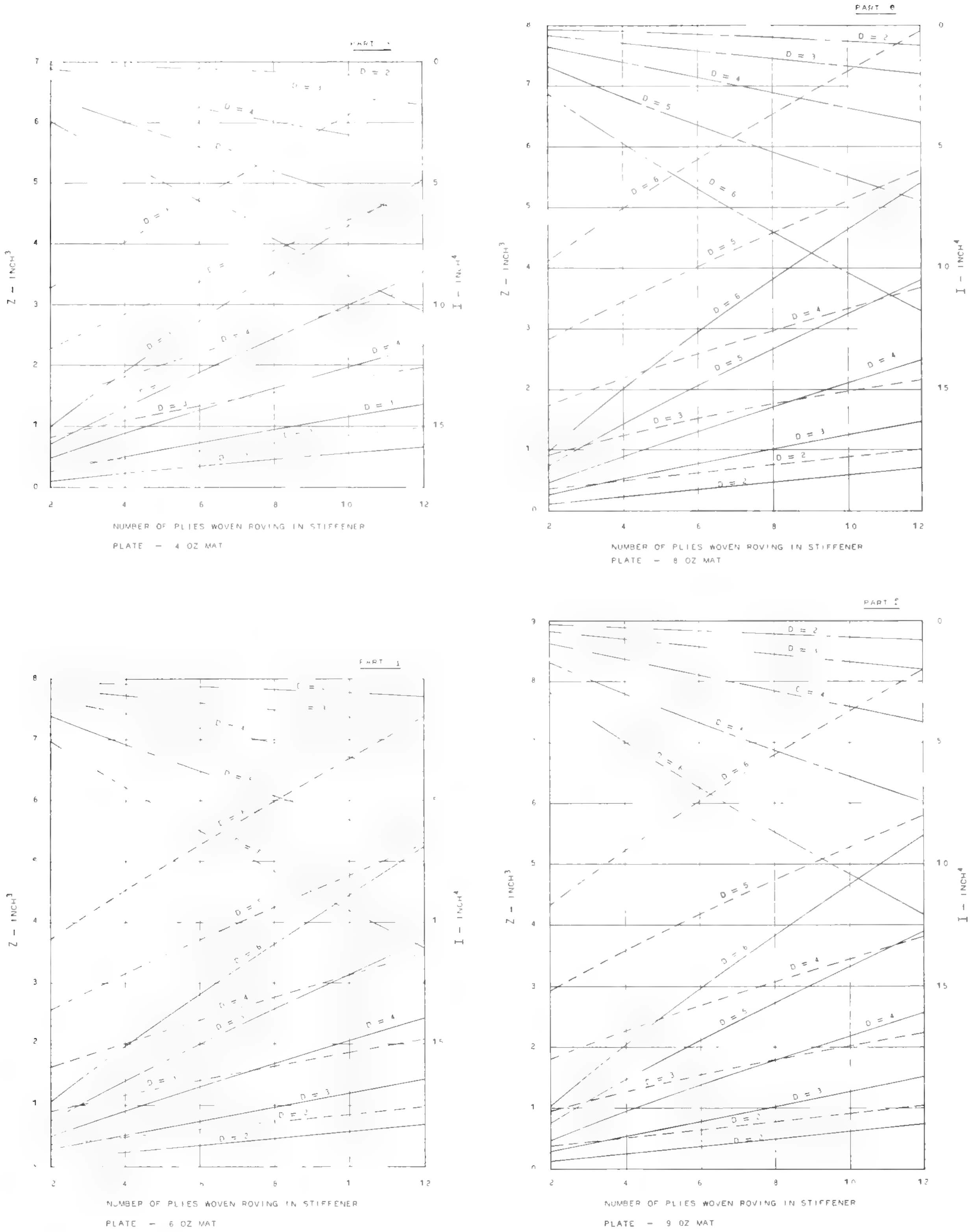


Fig. 6-40. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Half-Round Stiffeners with Type B Laminate. Core Considered Ineffective (Cont'd)

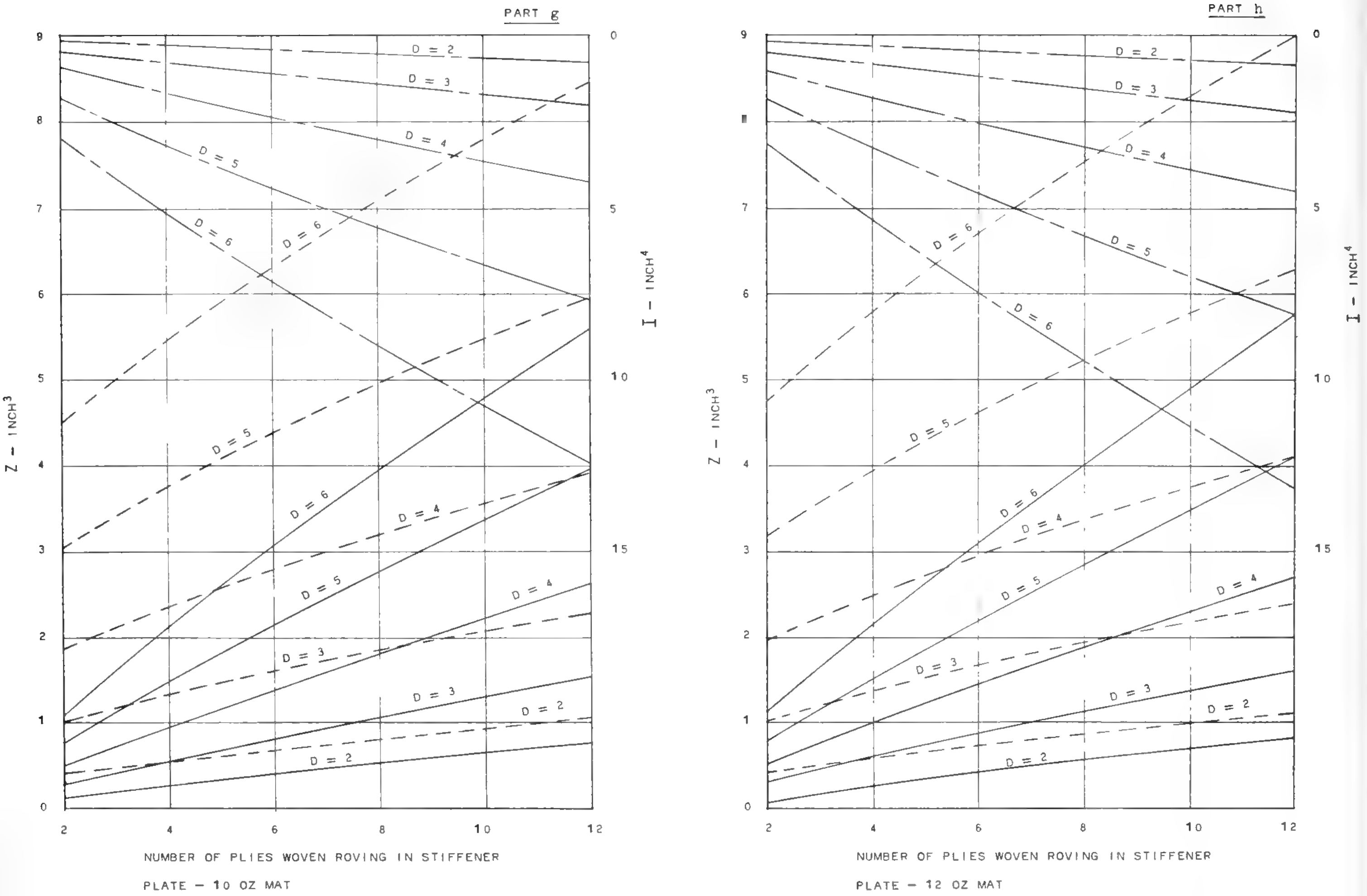


Fig. 6-40. Fiberglass Polyester Laminates - Section Modulus, Z, and Moment of Inertia, I, for 25-27 Oz. Woven Roving Half-Round Stiffeners with Type B Laminate. Core Considered Ineffective (Cont'd)

Figs. 6-39 and 6-40 give the same information for woven roving half-round stiffeners as is given for hat stiffeners. The Figures provide for varying stiffener core diameter and varying thickness of shell laminate for a given number of plies of woven roving in the stiffener laminate. The effective width of the laminate is taken as twice the stiffener diameter. Using "low average" ultimate stresses, as given in the physical properties tables in Chapter 5, the critical bending stress will be in the compression face, cloth or woven roving as the case may be for all stiffener sizes shown in these graphs.

If a type C laminate is used, the section properties will be intermediate between those given for types A and B laminates.

DESIGN EXAMPLE 6-20. BENDING OF A STIFFENER AND PLATE SECTION

The member whose cross-section is given in Fig. 6-41 has a span of 48 in. and is simply supported. Compute the ultimate carrying capacity and deflection when uniformly loaded. Assume all the plies of the various reinforcements to be parallel laminated in the direction of the span and the core material is ineffective.

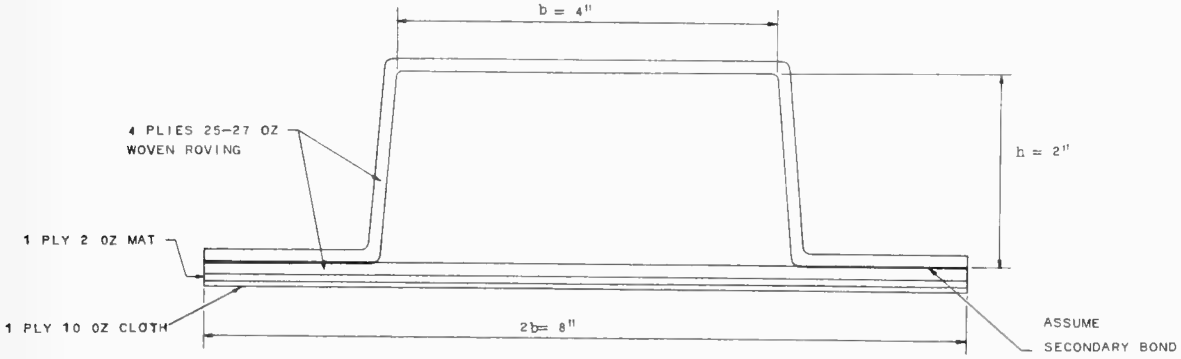


Fig. 6-41. Composite Stiffener and Plate Section

The necessary physical and mechanical properties for the different laminae are assumed to be the same as for a laminate of the same reinforcement. The values are obtained from Chapter 5.

Property	Cloth	Mat	W. R.	Table No.
Thickness, t, in.	1 ply = 0.016	1 ply = 0.060	4 ply = 0.148	5-1
Tensile Modulus of Elasticity, E, 10^6 psi	1.95	0.91	2.06	5-7
Ultimate Compressive Stress, F_c, psi	18,900	15,900	15,800	5-11

The transform area method and equations similar to those used in Design Example 6-19 will be used.

Transforming the respective widths of the cloth and mat laminae to the equivalent width of a woven roving lamina, the dimensions of the composite section will be as indicated in Fig. 6-42.

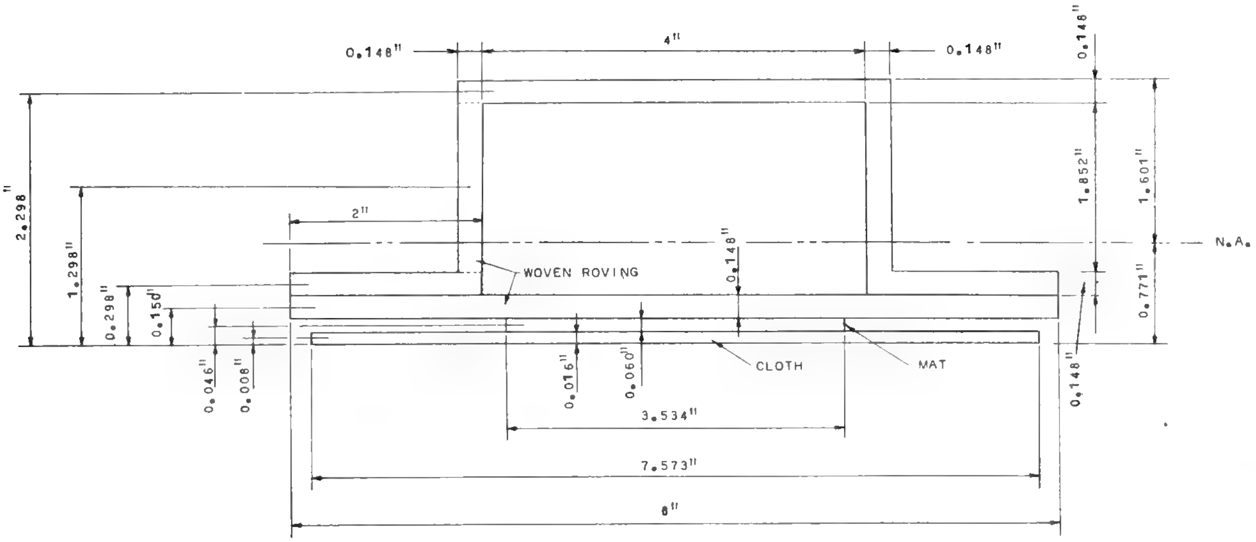


Fig. 6-42. Equivalent Stiffener and Plate Section

Equivalent width of cloth lamina:

$$b'_{cl} = b_{cl} \times \frac{E_{cl}}{E_{WR}} = 8.0 \times \frac{1.95}{2.06} = 7.573 \text{ in.} \qquad (6.38b)$$

Equivalent width of mat lamina:

$$b'_{m} = b_{m} \times \frac{E_{m}}{E_{WR}} = 8.0 \times \frac{0.91}{2.06} = 3.534 \text{ in.} \qquad (6.38b)$$

Equivalent woven roving laminate moment of inertia and section moduli to the face furthest from the neutral axis of the cloth, mat and woven roving laminae are obtained from equations 6.40 and 6.41.

Calculation of properties of section:

Section	Dimensions	A'	x	$A'x$	$A'x^2$	I_o	$A'x^2 + I_o$
Plate							
Cloth	7.573 x .016	0.121	0.008	0.0010	-	-	-
Mat	3.534 x .060	0.212	0.046	0.0098	0.0005	0.0001	0.0006
W.R.	8.0 x .148	1.184	0.150	0.1776	0.0266	0.0022	0.0288
W.R. Stiffener							
Bottom Flanges	2 x 2.0 x .148	0.592	0.298	0.1764	0.0526	0.0011	0.0537
Webs	2 x 1.852 x .148	0.548	1.298	0.7113	0.9233	0.1567	1.0800
Top Flange	4.296 x .148	0.636	2.298	1.4615	3.3585	0.0012	3.3597
		3.293		2.5376			4.5228
				$\sum A'x^2$ =	1.9565		- 1.9565
						I'_{NA} =	2.5663 in^4

Neutral axis from equation 6.39

$$x = \frac{2.5376}{3.293} = 0.771 \text{ in.}$$

Section moduli to outermost fibers and various laminae in plate, from equation 6.41.

Stiffener; woven roving outermost top fiber:

$$Z_{WR} = \frac{2.5663}{1.601} \times \frac{2.06 \times 10^6}{2.06 \times 10^6} = 1.603 \text{ in}^3$$

Plate

Cloth outermost bottom fiber:

$$Z_{cl} = \frac{2.5663}{0.771} \times \frac{2.06 \times 10^6}{1.95 \times 10^6} = 3.515 \text{ in}^3$$

Mat bottom fiber:

$$Z_m = \frac{2.5663}{0.755} \times \frac{2.06 \times 10^6}{0.91 \times 10^6} = 7.695 \text{ in}^3$$

Woven roving bottom fiber:

$$Z_{WR} = \frac{2.5663}{0.695} \times \frac{2.06 \times 10^6}{2.06 \times 10^6} = 3.693 \text{ in}^3$$

Values for the moment of inertia and section moduli to cloth, and woven roving can be easily obtained from Fig. 6-37 part c. The corresponding values from the curves are:

$I'_{NA} = 2.53 \text{ in}^4$

Stiffener : $Z_{WR} = 1.62 \text{ in}^3$

Plate : $Z_{cl} = 3.33 \text{ in}^3$

The ultimate moments for the ultimate compressive stresses are obtained from:

$$M = F_c \times Z \tag{6.31b}$$

Stiffener

Woven roving: $M_{WR} = 15800 \times 1.603 = 25{,}330$ in-lbs.

Plate

Cloth: $M_{cl} = 18900 \times 3.515 = 66{,}430$ in-lbs.

Mat: $M_m = 15900 \times 7.695 = 122{,}350$ in-lbs.

Woven roving: $M_{WR} = 15800 \times 3.693 = 58{,}350$ in-lbs.

The minimum resisting moment of the section is:

$$M_{min} = 25{,}330 \text{ in-lbs.}$$

The ultimate uniform load for the minimum resisting moment and simply supported beam from equation 6.42 is:

$$P_u = \frac{8M_{min}}{L^2} = \frac{8 \times 25{,}330}{48^2} = 88.0 \text{ lbs. per in.}$$

The ultimate vertical shear that the composite section will resist due to the ultimate horizontal shear at the neutral axis and at the secondary bond at the interface between the stiffener and plate is obtained from equation 6.43.

For ultimate shear at neutral axis:

$$Q'_1 = 4.296 \times 0.148 \times 1.527 + 2 \times 1.453 \times 0.48 \times \frac{1.453}{2}$$
$$= 1.283 \text{ in}^3$$

Ultimate parallel shear stress for woven roving, $F_s = 9{,}300$ psi

$$V_1 = \frac{9{,}300 \times 2.566 \times 0.148 \times 2}{1.283} \times \frac{2.06 \times 10^6}{2.06 \times 10^6} = 5{,}510 \text{ lbs.}$$

For ultimate shear of secondary bond at interface of stiffener and plate:

$$Q'_2 = 4.296 \times 0.148 \times 2.074 + 2 \times 1.852 \times 0.148 \times 1.074 + 2 \times 2.000 \times 0.148 \times 0.074$$
$$= 1.952 \text{ in}^3$$

Ultimate secondary bond shear stress, $F_{Bs} = 1{,}000$ psi

$$V_2 = \frac{1{,}000 \times 2.566 \times 2 \times 2.000}{1.952} \times \frac{2.06 \times 10^6}{2.06 \times 10^6} = 5{,}260 \text{ lbs.}$$

The minimum shear strength of the section is:

$$V_{min} = 5{,}260 \text{ lbs.}$$

The ultimate uniform load for the minimum shear and simply supported composite section is obtained from equation 6.30a.

$$P_u = \frac{2 \times 5{,}260}{48} = 219.2 \text{ lbs. per in.}$$

The ultimate flexural stress controls and the ultimate carrying capacity of the composite section is 88.0 lbs. per in.

The maximum deflection of the simply supported uniformly loaded beam, including the effect of shear is obtained from equation 6.28).

Shear modulus for woven roving, $G_{WR} = 0.45 \times 10^6$ (Table 5-14)

$$\text{Deflection, } d = \frac{5}{384} \frac{88.0 \times 48^4}{2.06 \times 10^6 \times 2.566} + \frac{88.0 \times 48^2}{8 \times 0.148 \times 2.148 \times 2 \times 0.45 \times 10^6}$$

$$d = 1.1507 + 0.0886 = 1.2393 \text{ in.}$$

FLAT RECTANGULAR PLATES

A laminate whose thickness is much smaller than its width and length can be classified as a plate. The analysis of plate sections is both complex and lengthy because of the many variables which enter into the configuration of a plate. The problem of plate analysis is further complicated by the fact that plates can be either orthotropic or isotropic in behavior. Most of the research to date has been based on isotropic materials, such as steel and aluminum. When a laminate behaves isotropically, such as a mat reinforced laminate, the methods generally used for steel plates can be adopted. When the plate is made of materials that produce an orthotropic laminate however, different approaches to the problem must be used.

During World War II, a good deal of use was made of plywood plate sections. Forest Products Laboratory conducted a series of experiments and performed basic research on this material to better understand its behavior. This effort led to several publications which outlined methods that could be used for the analysis of plywood plate sections. Since fiberglass reinforced plastic laminates are, in general, orthotropic in behavior, it is possible to use the approaches and formulas developed for plywood plates. In the final analysis, however, the results would have to be verified by actual experimentation.

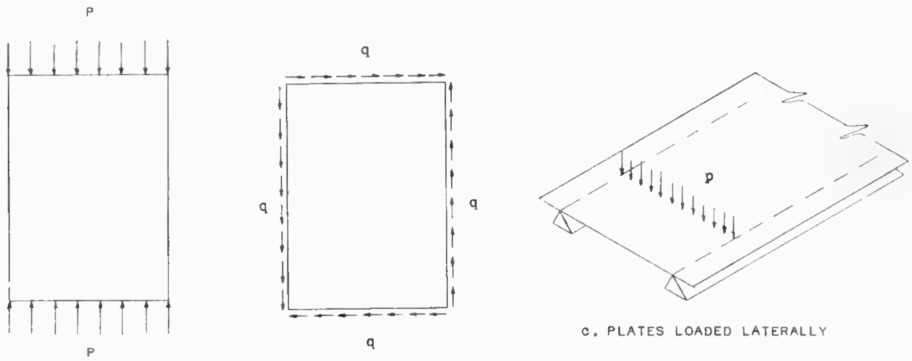
Plates can be subjected to many different combinations of loads, boundary conditions, aspect ratio, etc. There are however, three basic configurations from which most of the analysis begin; these are as illustrated in Fig. 6-43:

A. Plates loaded in edgewise compression.

B. Plates loaded in uniform shear.

C. Plates loaded laterally.

D. Plates loaded in any combinations of the above.



a. PLATES LOADED IN EDGEWISE COMPRESSION

b. PLATES LOADED IN UNIFORM SHEAR

c. PLATES LOADED LATERALLY

Fig. 6-43. Loads on Flat Plates

Groups A, B, C and D can be further subdivided according to boundary conditions, that is, free edges, clamped edges, or a combination of free and clamped edges.

The designer, when analyzing plates, is usually interested in the critical buckling load, bending stress and deflection. Formulas, methods, etc. have been established by which these variables can be obtained for plywood (5, 13, 15-20).

A. Plates Loaded in Edgewise Compression

Mathematical procedures are available by which the critical buckling load for plates under various edge conditions can be obtained (13, 15). The discussion presented here is for loads applied parallel to or at 90 degrees to the warp direction, Fig. 6-44.

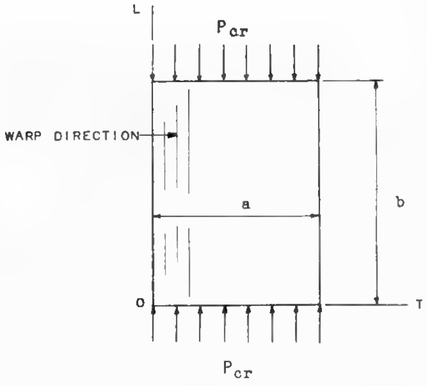


Fig. 6-44. Flat Plate in Compression - Load Parallel to Warp

The following terminology will apply to plate analysis for edgewise compression:

a = width of plate; $\leq b$

b = length of plate

h = thickness of plate

n = number of half-waves into which the panel buckles

E_T = Young's flexural modulus in a direction parallel to the T-axis

E_L = Young's flexural modulus in a direction parallel to the L-axis

G_{TL} = Modulus of rigidity associated with a shearing strain corresponding to the axes of T and L

σ_{TL} = Poisson's ratio associated with a contraction parallel to the T-axis and a tensile stress parallel to the L-axis

σ_{LT} = Poisson's ratio associated with a contraction parallel to the L-axis and a tensile stress parallel to the T-axis

$\lambda = 1 - \sigma_{TL}\,\sigma_{LT}$

Z = Coordinate measured perpendicular to the middle plane of the panel

w = Lateral deflection (namely in the Z direction) of points on the middle plane of the panel

P = Load per in. of edge of panel

P_{cr} = Buckling load per in. of edge of panel

K_{cr} = Coefficient in buckling formula

For an isotropic material $D_1 = D_2$, $E_T = E_L$, $\sigma_{TL} = \sigma_{LT} = \sigma$ and

$\lambda = 1 - \sigma^2$

Constants:

$$D_1 = \int_{-\frac{h}{2}}^{\frac{h}{2}} \frac{E_T}{\lambda}\, z^2 dz = \frac{E_T h^3}{12\lambda} \tag{6.44}$$

$$D_2 = \int_{-\frac{h}{2}}^{\frac{h}{2}} \frac{E_L}{\lambda}\, z^2 dz = \frac{E_L h^3}{12\lambda} \tag{6.44a}$$

$$A = E_T\,\sigma_{LT} + 2\lambda\, G_{TL} \tag{6.45}$$

$$K = \int_{-\frac{h}{2}}^{\frac{h}{2}} \frac{A}{\lambda}\, z^2 dz \tag{6.46}$$

$$\kappa = \frac{K}{\left[D_1 D_2\right]^{\frac{1}{2}}} \tag{6.47}$$

$$r = \frac{b}{a}\left[\frac{D_1}{D_2}\right]^{\frac{1}{4}} \tag{6.48}$$

$$E_1 = \int_{-\frac{h}{2}}^{\frac{h}{2}} E_T z^2 dz \div \left[\int_{-\frac{h}{2}}^{\frac{h}{2}} z^2 dz\right] = \frac{12}{h^3} \times \int_{-\frac{h}{2}}^{\frac{h}{2}} E_T z^2 dz \tag{6.49}$$

$$E_2 = \frac{12}{h^3} \times \int_{-\frac{h}{2}}^{\frac{h}{2}} E_L z^2 dz \tag{6.49a}$$

Case 1. All Edges Simply Supported

The critical buckling load, P_{cr}, per in. of width can be determined from the equation:

$$P_{cr} = k_{cr} \frac{12\sqrt{D_1 D_2}}{a^2} \qquad (6.50)$$

$$\text{where } k_{cr} = \frac{\pi^2}{12}\left[\frac{r^2}{n^2} + \frac{n^2}{r^2} + 2\kappa\right] \qquad (6.51)$$

and the panel will buckle in

one half wave if $r < \sqrt{2}$

two half waves if $\sqrt{2} < r < \sqrt{6}$

n half waves if $\sqrt{n(n-1)} < r < \sqrt{n(n+1)}$ (6.52)

Case 2. Loaded Edges Simply Supported - Remaining Edges Clamped

The critical load is

$$P_{cr} = k_{cr} \frac{12\sqrt{D_1 D_2}}{a^2} \qquad (6.50)$$

$$\text{where } k_{cr} = \frac{4\pi^2}{9}\left[\frac{r^2}{n^2} + \frac{3n^2}{16r^2} + \frac{\kappa}{2}\right] \qquad (6.51a)$$

The plate will buckle in n half waves when

$$\frac{1}{2}\sqrt{n(n-1)\sqrt{3}} < r < \frac{1}{2}\sqrt{n(n+1)\sqrt{3}} \qquad (6.52a)$$

Case 3. Loaded Edges Clamped - Remaining Edges Simply Supported

When the loaded edges are clamped and the remaining edges simply supported the critical buckling load, P_{cr}, becomes a function of the method in which the surface buckles. Consequently for each mode of buckling, there exists a critical load. The critical load then becomes

$$P_{cr} = \frac{k_{cr}\, 12\sqrt{D_1 D_2}}{a^2} \qquad (6.50)$$

where a different value of k_{cr} will exist for each mode of buckling as follows:

a. buckling in one half wave

$$k_{cr} = \frac{\pi^2}{48}\left[3r^2 + \frac{16}{r^2} + 8\kappa\right] \qquad (6.51b)$$

b. buckling in two half waves

$$k_{cr} = \frac{\pi^2}{60}\left[r^2 + \frac{41}{r^2} + 10\kappa\right] \qquad (6.51c)$$

c. buckling in three half waves

$$k_{cr} = \frac{\pi^2}{120}\left[r^2 + \frac{136}{r^2} + 20\kappa\right] \qquad (6.51d)$$

d. buckling in four half waves

$$k_{cr} = \frac{\pi^2}{204}\left[r^2 + \frac{353}{r^2} + 34\kappa\right] \qquad (6.51e)$$

Case 4. All Edges Clamped

When all edges are clamped, the buckling load is again dependent upon the form assumed by the buckled surface. The basic formula

$$P_{cr} = k_{cr}\frac{12\sqrt{D_1D_2}}{a^2} \text{ has the following} \qquad (6.50)$$

values for k_{cr}

a. buckling in one half wave

$$k_{cr} = \frac{\pi^2}{9}\left[3r^2 + \frac{3}{r^2} + 2\kappa\right] \qquad (6.51f)$$

b. buckling in two half waves

$$k_{cr} = \frac{\pi^2}{180}\left[16r^2 + \frac{123}{r^2} + 40\kappa\right] \qquad (6.51g)$$

c. buckling in three half waves

$$k_{cr} = \frac{\pi^2}{115}\left[2r^2 + \frac{51}{r^2} + 10\kappa\right] \qquad (6.51h)$$

d. buckling in four half waves

$$k_{cr} = \frac{\pi^2}{512}\left[16r^2 + \frac{1059}{r^2} + 136\kappa\right] \qquad (6.51i)$$

In Cases 3 and 4, the least value of P_{cr} will be the critical value for the plate.

In order to expedite the work of the designer, Tables 6-4 through 6-15 for mat, woven roving and cloth laminates have been prepared using an electronic digital computer. In setting up the above equations for the computer solution the following assumptions were made:

The values of E_L and E_T, modulus of elasticity, in the L and T direction respectively, were assumed to be constant throughout the range of the stress-strain curve. For the laminates tested this assumption appears valid since the stress-strain curves are almost straight lines.

Since fiberglass laminates do not exhibit a true proportional limit, the values used were ultimate values obtained by testing.

The panels were considered loaded along the "a" dimension with the warp fibers running parallel to the "b" dimension.

For the development of Tables 6-4 through 6-15, the following low average values from the tables in Chapter 5 were used:

Ultimate Flexural Stress (Table 5-9)

2 Oz. Mat : $F_{bL} = F_{bT} = 20{,}500$ psi

25-27 Oz. Woven Roving : $F_{bL} = F_{bT} = 28{,}200$ psi

10 Oz. Cloth : $F_{bL} = F_{bT} = 31{,}100$ psi

Flexural Modulus of Elasticity (Table 5-10)

2 Oz. Mat : $E_L = 0.86 \times 10^6$ psi $E_T = 0.86 \times 10^6$ psi

25-27 Oz. Woven Roving : $E_L = 1.81 \times 10^6$ psi $E_T = 1.54 \times 10^6$ psi

10 Oz. Cloth : $E_L = 1.96 \times 10^6$ psi $E_T = 1.70 \times 10^6$ psi

Ultimate Compressive Stress (Table 5-11)

2 Oz. Mat : $F_{cL} = F_{cT} = 19{,}200$ psi

25-27 Oz. Woven Roving : $F_{cL} = F_{cT} = 19{,}200$ psi

10 Oz. Cloth : $F_{cL} = F_{cT} = 18{,}900$ psi

Ultimate Shear Stress, Parallel (Table 5-14)

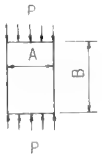
2 Oz. Mat : $F_{sL} = F_{sT} = 10{,}100$ psi

25-27 Oz. Woven Roving : $F_{sL} = F_{sT} = 9{,}500$ psi

10 Oz. Cloth : $F_{sL} = F_{sT} = 10{,}500$ psi

	Shear Modulus (Table 5-14)	Poisson's Ratio (Tables 5-8 and 5-13)
2 Oz. Mat	: $G_{LT} = 0.40 \times 10^6$ psi	$\sigma_{LT} = \sigma_{TL} = 0.37$
25-27 Oz. Woven Roving	: $G_{LT} = 0.45 \times 10^6$ psi	$\sigma_{LT} = \sigma_{TL} = 0.19$
10 Oz. Cloth	: $G_{LT} = 0.52 \times 10^6$ psi	$\sigma_{LT} = \sigma_{TL} = 0.20$

TABLE 6-4. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED



PHYSICAL CONSTANTS:

$E_X = E_Y = 0.86 \times 10^6$ PSI

$G_{XY} = 0.40 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.37$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	24	15	11	9	8	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
8	26	14	9	7	6	5	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	8
10	25	14	9	6	5	4	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	10
12	24	15	9	6	5	4	3	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	12
14	25	14	10	6	4	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	14
16	24	14	9	7	5	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	16
18	24	14	9	7	5	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	18
20	24	14	9	6	5	4	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	20
22	24	14	9	6	5	4	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	0	22
24	24	14	9	6	5	4	3	2	2	2	1	1	1	1	1	1	1	1	1	0	0	0	0	24
26	24	14	9	6	4	4	3	2	2	2	1	1	1	1	1	1	1	1	0	0	0	0	0	26
28	24	14	9	6	4	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	28
30	24	14	9	6	4	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	30
32	24	14	9	6	5	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	32
34	24	14	9	6	5	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	34
36	24	14	9	6	5	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	36
38	24	14	9	6	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	0	0	38
40	24	14	9	6	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	0	0	40
42	24	14	9	6	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	0	0	42
44	24	14	9	6	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	0	0	44
46	24	14	9	6	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	0	0	46
48	24	14	9	6	5	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	193	117	88	73	65	60	57	54	52	51	50	49	49	48	48	47	47	46	46	46	45	45	45	6
8	208	109	73	56	47	41	38	35	33	32	31	30	29	29	28	28	27	27	26	26	26	26	26	8
10	199	114	70	50	39	33	29	26	24	23	22	21	20	20	19	19	18	18	17	17	17	17	17	10
12	193	117	72	48	36	29	25	22	20	18	17	16	16	15	15	14	13	13	12	12	12	12	12	12
14	197	110	77	49	35	28	23	20	17	16	14	13	13	12	12	11	10	10	9	9	9	9	9	14
16	196	109	73	52	36	27	22	18	16	14	13	12	11	10	10	9	9	8	8	7	7	7	7	16
18	193	110	70	52	38	28	21	18	15	13	12	11	10	9	9	8	7	7	6	6	6	6	6	18
20	195	112	70	50	39	28	22	17	14	12	11	10	9	8	8	7	6	6	5	5	5	5	5	20
22	195	109	70	49	37	30	22	18	14	12	11	9	8	8	7	7	6	5	5	4	4	4	4	22
24	193	109	72	48	36	29	23	18	14	12	10	9	8	7	7	6	5	5	4	4	4	4	3	24
26	194	109	71	49	36	28	24	19	15	12	10	9	8	7	6	6	5	4	4	3	3	3	3	26
28	194	110	70	49	35	28	23	19	15	12	10	9	8	7	6	6	5	4	3	3	3	3	3	28
30	193	109	70	50	36	27	22	19	16	13	10	9	8	7	6	6	4	4	3	3	3	3	2	30
32	194	109	70	49	36	27	22	18	16	13	11	9	8	7	6	5	4	4	3	3	3	2	2	32
34	194	109	71	48	37	27	22	18	15	13	11	9	8	7	6	5	4	3	3	3	2	2	2	34
36	193	110	70	48	36	28	21	18	15	13	11	9	8	7	6	5	4	3	3	2	2	2	2	36
38	194	109	70	48	36	28	22	17	15	13	11	10	8	7	6	5	4	3	3	2	2	2	2	38
40	194	109	70	49	36	28	22	17	14	12	11	10	8	7	6	5	4	3	3	2	2	2	2	40
42	193	109	70	49	35	28	22	17	14	12	11	10	9	7	6	5	4	3	3	2	2	2	2	42
44	194	109	70	49	36	27	22	18	14	12	11	9	8	7	6	6	4	3	2	2	2	2	2	44
46	194	109	70	48	36	27	22	18	14	12	10	9	8	7	7	6	4	3	2	2	2	2	1	46
48	193	109	70	48	36	27	22	18	14	12	10	9	8	7	7	6	4	3	2	2	2	2	1	48

TABLE 6-4. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	652	396	296	247	220	203	191	183	177	173	169	167	164	163	161	160	157	156	154	154	153	153	152	6
8	703	367	246	189	158	139	127	118	112	107	104	101	99	97	96	94	92	90	89	88	87	87	86	8
10	672	384	235	168	133	112	98	89	83	78	74	71	69	67	65	64	61	60	58	58	57	56	56	10
12	652	396	242	163	122	99	84	74	67	62	58	55	53	51	49	48	45	43	42	41	40	40	40	12
14	667	373	260	167	120	93	77	66	58	53	49	45	43	41	39	38	35	33	32	31	31	30	30	14
16	660	367	246	176	122	92	73	61	53	47	43	40	37	35	33	32	29	27	26	25	24	24	23	16
18	652	372	237	176	127	93	72	59	50	44	39	36	33	31	29	27	24	23	21	20	20	19	19	18
20	659	378	235	168	133	96	73	59	49	42	37	33	30	28	26	25	21	19	18	17	17	16	16	20
22	657	369	237	164	126	101	75	59	49	41	36	32	28	26	24	22	19	17	16	15	14	14	13	22
24	652	367	242	163	122	99	78	61	49	41	35	31	27	25	23	21	18	15	14	13	12	12	12	24
26	656	369	239	164	120	95	80	62	50	41	35	30	27	24	22	20	16	14	13	12	11	11	10	26
28	655	373	236	167	120	93	77	65	51	42	35	30	26	23	21	19	15	13	12	11	10	9	9	28
30	652	368	235	168	120	92	75	63	53	43	35	30	26	23	21	19	15	12	11	10	9	9	8	30
32	655	367	236	165	122	92	73	61	53	44	36	30	26	23	20	18	14	12	10	9	8	8	8	32
34	654	368	238	164	124	92	73	60	52	45	37	31	26	23	20	18	14	11	10	9	8	7	7	34
36	652	371	237	163	122	93	72	59	50	44	38	32	27	23	20	18	14	11	9	8	7	7	6	36
38	654	368	235	163	121	94	73	59	49	43	38	33	27	24	21	18	13	11	9	8	7	6	6	38
40	654	367	235	165	120	95	73	59	49	42	37	33	28	24	21	18	13	11	9	8	7	6	6	40
42	652	368	235	166	120	93	74	59	49	41	36	32	29	25	21	19	13	10	9	7	6	6	5	42
44	653	369	237	164	120	92	75	59	49	41	36	32	28	25	22	19	13	10	8	7	6	6	5	44
46	653	367	236	163	121	92	74	60	49	41	35	31	28	25	22	19	13	10	8	7	6	5	5	46
48	652	367	235	163	122	92	73	61	49	41	35	31	27	25	23	20	14	10	8	7	6	5	5	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	1546	938	702	587	521	480	453	434	420	409	401	395	390	385	382	379	373	369	366	364	363	362	361	6
8	1667	870	582	448	375	330	301	280	266	255	246	240	234	230	227	224	217	213	211	209	207	206	205	8
10	1594	910	556	398	315	265	233	211	196	184	175	168	163	159	155	152	145	141	138	136	135	134	133	10
12	1546	938	574	386	290	234	199	176	159	147	137	130	125	120	116	113	107	102	99	97	96	95	94	12
14	1580	884	617	395	284	221	182	156	138	125	115	108	102	97	93	90	83	79	76	74	72	71	70	14
16	1566	870	582	417	289	217	174	146	126	112	102	94	87	82	78	75	68	64	61	59	57	56	55	16
18	1546	881	562	417	301	220	172	141	119	104	93	85	78	73	69	65	58	53	50	48	47	45	45	18
20	1562	896	556	398	315	228	174	139	116	100	88	79	72	66	62	58	51	46	43	41	39	38	37	20
22	1556	876	561	389	299	238	178	140	115	97	84	75	67	62	57	53	45	41	37	35	34	32	32	22
24	1546	870	574	386	290	234	185	143	116	97	83	73	65	59	54	50	42	37	33	31	30	28	27	24
26	1555	875	567	389	285	226	189	148	118	97	82	71	63	57	51	47	39	34	30	28	26	25	24	26
28	1553	884	559	395	284	221	182	154	121	99	83	71	62	55	50	45	37	31	28	25	24	22	22	28
30	1546	873	556	398	285	218	177	150	125	101	84	71	62	55	49	44	35	29	26	23	22	20	19	30
32	1552	870	559	391	289	217	174	146	126	104	86	72	62	54	48	43	34	28	24	22	20	19	18	32
34	1550	872	565	388	294	218	172	143	122	108	88	73	63	55	48	43	33	27	23	21	19	17	16	34
36	1546	878	562	386	290	220	172	141	119	104	91	75	64	55	48	43	32	26	22	20	18	16	15	36
38	1550	872	558	387	287	223	172	139	117	102	90	77	65	56	49	43	32	25	21	19	17	15	14	38
40	1549	870	556	390	285	224	174	139	116	100	88	79	67	57	49	43	32	25	21	18	16	15	13	40
42	1546	871	558	393	284	221	176	139	115	98	86	77	69	58	50	44	32	25	20	17	15	14	13	42
44	1549	876	561	389	284	219	178	140	115	97	84	75	67	60	51	45	32	24	20	17	15	13	12	44
46	1548	871	560	387	286	218	176	142	115	97	83	74	66	60	52	45	32	24	20	16	14	13	12	46
48	1546	870	557	386	289	217	174	143	116	97	83	73	65	59	54	46	32	24	19	16	14	12	11	48

TABLE 6-4. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	3019	1831	1371	1146	1017	938	885	847	820	799	783	771	761	753	746	740	728	720	715	711	708	707	705	6
8	3256	1698	1138	875	732	644	587	547	519	498	481	468	458	450	443	437	424	416	411	407	404	402	400	8
10	3112	1777	1087	778	615	517	455	412	382	359	342	329	318	310	303	297	284	276	270	266	264	261	260	10
12	3019	1831	1121	755	567	458	389	343	310	286	268	254	243	234	227	221	208	200	194	190	187	185	184	12
14	3086	1726	1205	771	555	432	355	305	270	244	225	210	199	190	182	176	162	154	148	144	141	139	137	14
16	3058	1698	1138	814	564	425	340	284	246	219	198	183	171	161	153	147	133	124	119	114	112	109	108	16
18	3019	1720	1098	814	587	430	335	275	233	203	182	165	152	142	134	127	113	104	98	94	91	89	87	18
20	3050	1751	1087	778	615	444	339	272	226	195	171	154	140	129	121	114	99	90	84	80	77	74	72	20
22	3040	1710	1096	760	585	466	348	274	225	190	165	146	132	121	111	104	89	79	73	69	66	63	62	22
24	3019	1698	1121	755	567	458	362	280	226	189	162	142	126	114	105	97	81	72	65	61	58	55	53	24
26	3037	1708	1108	759	557	442	369	289	230	190	161	139	123	110	100	92	76	66	59	55	51	49	47	26
28	3032	1726	1092	771	555	432	355	301	237	193	162	139	121	108	97	89	71	61	54	50	46	44	42	28
30	3019	1705	1087	778	557	426	346	293	245	197	164	139	121	107	95	86	68	57	51	46	42	40	38	30
32	3031	1698	1091	764	564	425	340	284	246	203	167	141	121	106	94	85	66	55	48	43	39	37	35	32
34	3028	1704	1103	757	574	426	336	278	239	210	172	144	123	107	94	84	64	53	45	40	37	34	32	34
36	3019	1716	1098	755	567	430	335	275	233	203	177	147	125	108	94	84	63	51	43	38	34	32	30	36
38	3027	1702	1090	757	560	436	336	272	229	198	176	151	127	109	95	84	62	50	42	36	33	30	28	38
40	3026	1698	1087	763	556	438	339	272	226	195	171	154	130	111	96	85	62	49	40	35	31	28	26	40
42	3019	1702	1089	767	555	432	343	272	225	192	168	149	134	114	98	86	62	48	39	34	30	27	25	42
44	3025	1710	1096	760	556	428	348	274	225	190	165	146	132	116	100	87	62	48	39	33	29	26	24	44
46	3024	1701	1094	756	559	425	343	277	225	189	163	144	129	117	102	89	62	47	38	32	28	25	23	46
48	3019	1698	1089	755	564	425	340	280	226	189	162	142	126	114	105	90	63	47	38	32	27	24	22	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	5217	3164	2370	1980	1758	1620	1528	1464	1417	1381	1354	1332	1315	1301	1289	1279	1258	1245	1236	1229	1224	1221	1218	6
8	5625	2935	1966	1513	1265	1113	1015	946	897	860	831	809	791	777	765	755	733	720	711	704	699	695	692	8
10	5378	3071	1878	1345	1062	894	786	713	660	621	592	569	550	535	523	513	491	477	467	461	456	452	449	10
12	5217	3164	1936	1304	979	791	672	592	536	495	464	440	420	405	393	382	360	345	336	329	324	320	317	12
14	5332	2983	2081	1333	958	746	614	527	466	422	389	364	344	328	314	304	281	266	256	249	244	240	237	14
16	5284	2935	1966	1406	974	734	587	491	426	378	343	316	295	278	265	254	230	215	205	198	193	189	186	16
18	5217	2972	1897	1406	1015	743	580	474	403	352	314	285	263	246	232	220	195	180	170	163	157	153	150	18
20	5271	3025	1878	1345	1062	768	586	470	391	336	296	265	242	224	209	197	171	155	145	138	132	128	125	20
22	5253	2955	1894	1313	1011	804	601	473	388	328	285	253	228	208	193	180	153	137	127	119	114	110	106	22
24	5217	2935	1936	1304	979	791	625	484	391	326	279	245	218	198	181	168	141	124	113	105	100	96	92	24
26	5248	2952	1914	1312	963	763	638	500	398	328	278	241	213	191	173	160	131	113	102	94	89	85	81	26
28	5240	2983	1886	1333	958	746	614	520	409	333	279	240	210	186	168	154	123	106	94	86	80	76	73	28
30	5217	2946	1878	1345	962	736	598	506	424	341	283	241	209	184	165	149	118	99	87	79	73	69	66	30
32	5237	2935	1835	1321	974	734	587	491	426	352	289	244	209	183	163	147	114	95	82	74	68	63	60	32
34	5233	2944	1905	1308	992	736	581	481	412	363	297	248	212	184	162	145	111	91	78	69	63	59	55	34
36	5217	2965	1897	1304	979	743	580	474	403	352	306	254	215	186	163	145	109	88	75	66	60	55	52	36
38	5231	2942	1883	1308	967	754	581	471	396	343	304	261	220	188	164	145	107	86	72	63	56	52	48	38
40	5228	2935	1878	1318	960	756	586	470	391	336	296	265	225	192	166	146	107	84	70	61	54	49	46	40
42	5217	2941	1882	1326	958	746	592	471	389	331	290	258	231	196	169	148	106	83	68	59	52	47	43	42
44	5227	2955	1894	1313	960	739	601	473	388	328	285	253	228	201	173	150	107	82	67	57	50	45	41	44
46	5226	2939	1890	1306	966	735	593	478	389	327	282	248	223	203	177	153	107	82	66	56	49	43	40	46
48	5217	2935	1881	1304	974	734	587	484	391	326	279	245	218	198	181	156	108	82	65	55	47	42	38	48

TABLE 6-4. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7740	5025	3763	3143	2792	2573	2427	2324	2250	2193	2149	2115	2088	2066	2047	2031	1997	1977	1962	1951	1944	1939	1934	6
8	7740	4660	3121	2402	2008	1768	1611	1502	1424	1365	1320	1285	1256	1234	1215	1199	1165	1143	1129	1118	1110	1104	1098	8
10	7740	4877	2982	2135	1686	1420	1248	1132	1048	986	940	903	874	850	831	814	780	758	742	731	724	717	713	10
12	7740	5025	3075	2071	1555	1256	1068	941	851	786	736	698	668	643	623	607	571	548	533	522	514	508	504	12
14	7740	4737	3305	2117	1522	1184	975	837	740	670	618	577	546	520	499	482	446	422	407	396	388	382	377	14
16	7740	4660	3121	2233	1547	1165	932	780	676	601	545	502	469	442	420	403	365	341	325	314	306	300	295	16
18	7740	4720	3013	2233	1612	1180	921	753	639	558	499	453	418	390	368	349	310	286	270	258	250	244	239	18
20	7740	4804	2982	2135	1686	1219	930	746	621	534	470	422	384	355	331	312	272	247	230	218	210	204	199	20
22	7740	4693	3007	2086	1605	1277	955	752	616	521	453	401	362	331	306	286	244	218	201	189	181	174	169	22
24	7740	4660	3075	2071	1555	1256	993	769	621	518	444	389	347	314	288	267	223	196	179	167	158	152	147	24
26	7740	4687	3039	2083	1529	1212	1013	794	632	521	441	382	338	303	276	253	208	180	162	150	141	134	129	26
28	7740	4737	2995	2117	1522	1184	975	826	650	529	443	380	333	296	267	244	196	168	149	136	127	121	115	28
30	7740	4678	2982	2135	1528	1169	949	804	673	542	450	382	331	292	262	237	187	158	139	126	116	110	104	30
32	7740	4660	2994	2098	1547	1165	932	780	676	558	459	387	333	291	259	233	181	150	130	117	108	101	95	32
34	7740	4676	3026	2077	1575	1169	923	764	655	577	471	394	336	292	258	231	176	144	124	110	100	93	88	34
36	7740	4708	3013	2071	1555	1180	921	753	639	558	486	403	342	295	259	230	173	140	119	105	95	87	82	36
38	7740	4671	2990	2077	1536	1197	923	747	628	544	482	414	349	299	261	231	171	136	114	100	90	82	77	38
40	7740	4660	2982	2092	1525	1201	930	746	621	534	470	422	357	305	264	232	169	133	111	96	86	78	72	40
42	7740	4670	2989	2105	1522	1184	941	747	617	526	460	410	367	312	269	235	169	132	108	93	82	74	69	42
44	7740	4693	3007	2085	1525	1173	955	752	616	521	453	401	362	319	274	239	169	130	106	90	79	71	65	44
46	7740	4668	3002	2075	1533	1167	942	759	617	519	447	394	353	322	280	243	170	130	105	88	77	69	63	46
48	7740	4660	2987	2071	1547	1165	932	769	621	518	444	389	347	314	287	248	172	129	104	87	75	67	61	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9600	7501	5617	4692	4167	3341	3623	3469	3358	3274	3208	3158	3117	3084	3055	3032	2981	2951	2929	2913	2902	2894	2887	6
8	9600	6956	4659	3586	2997	2639	2405	2242	2125	2038	1970	1918	1875	1842	1813	1790	1739	1706	1685	1669	1656	1648	1639	8
10	9600	7280	4452	3187	2517	2119	1864	1689	1565	1472	1402	1348	1304	1269	1240	1216	1164	1131	1108	1092	1080	1071	1064	10
12	9600	7501	4590	3092	2321	1875	1594	1404	1271	1173	1099	1042	997	960	930	906	852	818	796	779	767	758	752	12
14	9600	7071	4934	3160	2271	1768	1456	1249	1105	1000	922	862	814	776	745	720	665	631	607	591	579	570	563	14
16	9600	6956	4659	3334	2309	1739	1392	1165	1009	896	813	749	700	660	628	601	545	509	486	469	457	448	440	16
18	9600	7045	4498	3334	2406	1761	1374	1124	954	833	744	677	624	582	549	521	463	427	403	385	373	364	356	18
20	9600	7171	4452	3187	2517	1820	1388	1113	928	797	701	629	574	530	495	466	405	368	343	326	313	304	297	20
22	9600	7005	4489	3113	2395	1907	1426	1122	920	778	676	599	540	494	457	427	364	325	300	282	269	260	252	22
24	9600	6956	4590	3092	2321	1875	1482	1147	926	773	662	580	518	469	430	398	333	293	267	249	236	226	219	24
26	9600	6997	4536	3110	2283	1809	1513	1185	944	777	659	571	504	452	411	378	310	269	242	224	210	200	193	26
28	9600	7071	4471	3160	2271	1768	1456	1233	970	790	662	568	497	442	399	364	293	250	223	204	190	180	172	28
30	9600	6983	4452	3187	2281	1746	1416	1200	1004	809	671	570	495	436	391	354	280	235	207	188	174	164	156	30
32	9600	6956	4469	3131	2309	1739	1392	1165	1009	833	685	577	497	435	386	348	270	224	195	175	161	150	142	32
34	9600	6980	4516	3101	2351	1745	1378	1140	977	861	703	588	502	436	385	345	263	215	185	164	150	139	131	34
36	9600	7027	4498	3092	2321	1761	1374	1124	954	833	725	602	510	440	386	344	258	208	177	156	141	130	122	36
38	9600	6973	4463	3100	2292	1787	1378	1116	938	812	720	618	521	447	390	344	255	203	171	149	134	123	114	38
40	9600	6956	4452	3123	2276	1793	1388	1113	928	797	701	629	533	455	395	347	253	199	166	143	128	116	108	40
42	9600	6971	4462	3143	2271	1768	1404	1115	922	786	687	612	548	465	401	351	252	196	162	139	123	111	102	42
44	9600	7005	4489	3113	2276	1751	1426	1122	920	778	676	599	540	477	409	356	253	195	159	135	119	107	98	44
46	9600	6967	4480	3097	2289	1742	1407	1133	921	774	668	588	528	480	418	363	254	194	156	132	115	103	94	46
48	9600	6956	4459	3092	2309	1739	1392	1147	926	773	662	580	518	469	429	370	257	193	155	129	112	100	90	48

TABLE 6-4. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

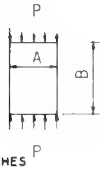
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10800	10680	7998	6681	5933	5468	5159	4940	4782	4662	4568	4496	4438	4391	4350	4317	4245	4201	4170	4147	4131	4121	4111	6
8	10800	9904	6634	5105	4268	3758	3424	3193	3026	2902	2806	2731	2670	2622	2582	2549	2475	2428	2399	2376	2359	2346	2334	8
10	10800	10366	6339	4538	3584	3018	2653	2405	2228	2096	1997	1919	1857	1807	1766	1731	1657	1610	1577	1554	1538	1525	1515	10
12	10800	10680	6535	4402	3305	2670	2269	2000	1809	1670	1565	1483	1419	1367	1325	1290	1214	1165	1133	1110	1093	1079	1070	12
14	10800	10068	7025	4499	3234	2517	2073	1778	1573	1424	1313	1227	1160	1106	1061	1025	948	898	865	842	824	812	801	14
16	10800	9904	6634	4747	3287	2476	1981	1659	1436	1276	1158	1067	996	940	894	856	776	725	691	668	650	637	627	16
18	10800	10031	6404	4747	3426	2508	1956	1601	1359	1187	1060	963	889	829	782	742	659	608	573	549	531	518	508	18
20	10800	10211	6339	4538	3584	2592	1976	1585	1321	1135	998	896	817	754	704	663	577	524	489	464	446	433	422	20
22	10800	9973	6392	4433	3411	2715	2030	1598	1310	1108	962	853	769	703	650	607	518	463	427	402	384	370	359	22
24	10800	9904	6535	4402	3305	2670	2110	1634	1319	1100	943	826	737	667	612	567	474	418	380	355	336	322	312	24
26	10800	9962	6459	4428	3250	2576	2154	1687	1344	1107	938	813	718	644	586	538	441	383	345	318	300	285	275	26
28	10800	10068	6366	4499	3234	2517	2073	1756	1381	1125	942	809	707	629	568	518	417	356	317	290	271	256	245	28
30	10800	9942	6339	4538	3248	2486	2017	1709	1429	1152	956	812	704	621	556	504	398	335	295	267	248	233	222	30
32	10800	9904	6363	4458	3287	2476	1981	1659	1436	1187	975	822	707	619	550	495	384	319	277	249	229	214	203	32
34	10800	9938	6431	4415	3348	2484	1962	1624	1391	1226	1001	837	715	621	548	491	374	306	263	234	214	198	187	34
36	10800	10006	6404	4402	3305	2508	1956	1601	1359	1187	1032	857	726	627	550	489	367	297	252	222	201	186	174	36
38	10800	9929	6354	4414	3264	2544	1962	1589	1336	1157	1025	880	741	636	555	490	363	289	243	212	191	175	163	38
40	10800	9904	6339	4447	3241	2553	1976	1585	1321	1134	998	896	759	648	562	494	360	284	236	204	182	166	154	40
42	10800	9926	6353	4475	3234	2517	2000	1588	1312	1119	978	872	781	662	571	500	359	280	230	198	175	158	146	42
44	10800	9973	6392	4432	3241	2493	2030	1598	1310	1108	962	853	769	679	583	507	360	277	226	192	169	152	139	44
46	10800	9920	6379	4409	3259	2480	2003	1613	1312	1102	951	838	751	683	596	517	362	276	223	188	164	146	134	46
48	10800	9904	6348	4402	3287	2476	1981	1634	1319	1100	943	826	737	667	611	527	365	275	220	184	160	142	129	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	12000	12000	10971	9165	8139	7501	7076	6776	6559	6394	6266	6167	6088	6023	5967	5922	5823	5763	5721	5689	5667	5653	5639	6
8	12000	12000	9101	7003	5854	5155	4697	4380	4151	3980	3849	3746	3663	3597	3542	3497	3396	3331	3291	3259	3235	3218	3202	8
10	12000	12000	8695	6225	4916	4140	3640	3299	3056	2876	2739	2632	2547	2478	2422	2375	2273	2209	2164	2132	2110	2092	2079	10
12	12000	12000	8964	6038	4534	3662	3112	2743	2482	2291	2147	2035	1947	1875	1817	1769	1665	1599	1554	1522	1499	1481	1468	12
14	12000	12000	9636	6171	4436	3453	2843	2439	2158	1954	1801	1683	1591	1517	1456	1406	1300	1232	1186	1155	1131	1113	1099	14
16	12000	12000	9101	6511	4510	3397	2718	2275	1970	1751	1588	1464	1366	1289	1226	1174	1064	995	949	916	892	874	860	16
18	12000	12000	8784	6511	4700	3440	2684	2196	1864	1628	1454	1322	1219	1138	1072	1018	904	833	786	753	729	710	696	18
20	12000	12000	8695	6225	4916	3555	2711	2174	1812	1556	1370	1229	1120	1035	966	910	792	719	670	637	612	594	580	20
22	12000	12000	8768	6080	4678	3724	2784	2192	1797	1520	1320	1170	1054	964	892	833	711	635	586	551	526	507	493	22
24	12000	12000	8964	6038	4534	3662	2894	2241	1809	1510	1294	1134	1011	916	840	778	650	573	522	487	461	442	428	24
26	12000	12000	8860	6074	4459	3533	2955	2315	1843	1518	1286	1115	984	883	803	739	606	525	473	437	411	392	377	26
28	12000	12000	8733	6171	4436	3453	2843	2409	1895	1543	1293	1109	970	863	779	711	572	488	435	398	371	352	337	28
30	12000	12000	8695	6225	4456	3409	2767	2344	1961	1580	1311	1114	966	852	763	692	546	460	404	367	340	320	304	30
32	12000	12000	8728	6116	4509	3397	2718	2275	1970	1628	1338	1127	970	849	755	680	527	438	380	342	314	294	278	32
34	12000	12000	8821	6056	4592	3408	2692	2227	1909	1681	1374	1148	980	852	752	673	513	420	361	321	293	272	256	34
36	12000	12000	8784	6038	4534	3440	2684	2196	1864	1628	1416	1175	996	860	754	671	504	407	346	305	276	255	239	36
38	12000	12000	8716	6054	4477	3490	2691	2179	1832	1587	1407	1207	1017	872	761	673	497	397	333	291	262	240	223	38
40	12000	12000	8695	6100	4446	3502	2711	2174	1812	1556	1370	1229	1042	889	771	678	494	389	324	280	250	227	211	40
42	12000	12000	8714	6138	4436	3453	2743	2179	1800	1534	1341	1196	1071	908	784	686	493	384	316	271	240	217	200	42
44	12000	12000	8768	6080	4445	3420	2784	2192	1797	1520	1320	1170	1054	931	799	696	494	380	310	264	232	208	191	44
46	12000	12000	8751	6048	4470	3402	2748	2213	1800	1512	1304	1149	1030	938	817	709	497	378	305	258	225	201	183	46
48	12000	12000	8708	6038	4509	3397	2718	2241	1809	1510	1294	1134	1011	916	838	723	501	377	302	253	219	195	176	48

TABLE 6-5. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED



PHYSICAL CONSTANTS:

$E_X = E_Y = 0.86 \times 10^6$ PSI

$G_{XY} = 0.40 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.37$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	47	25	16	12	10	9	8	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6
8	43	26	16	11	8	7	6	5	5	4	4	4	4	4	4	4	3	3	3	3	3	3	3	8
10	45	24	17	11	8	6	5	4	4	3	3	3	3	3	3	3	2	2	2	2	2	2	2	10
12	43	25	16	12	9	6	5	4	3	3	3	2	2	2	2	2	2	2	2	2	2	2	1	12
14	44	25	16	11	9	7	5	4	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	14
16	43	24	16	11	8	7	5	4	3	3	2	2	2	2	2	1	1	1	1	1	1	1	1	16
18	43	25	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	18
20	43	24	15	11	8	6	5	4	4	3	2	2	2	2	1	1	1	1	1	1	1	1	1	20
22	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	22
24	43	24	16	11	8	6	5	4	3	3	3	2	2	2	1	1	1	1	1	1	1	0	0	24
26	43	24	15	11	8	6	5	4	3	3	3	2	2	2	1	1	1	1	1	1	0	0	0	26
28	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	28
30	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	30
32	43	24	16	11	8	6	5	4	3	3	2	2	2	2	2	1	1	1	1	0	0	0	0	32
34	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	34
36	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	36
38	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	38
40	43	24	15	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	40
42	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	42
44	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	44
46	43	24	15	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	46
48	43	24	16	11	8	6	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	376	198	125	94	78	69	63	59	56	54	53	51	50	50	49	48	47	47	46	46	46	45	45	6
8	344	212	130	86	65	53	46	41	38	35	34	32	31	30	30	29	28	27	27	26	26	26	26	8
10	356	194	135	92	64	49	40	34	30	27	25	24	23	22	21	20	19	18	18	17	17	17	17	10
12	344	198	125	94	69	49	36	31	27	24	21	19	18	17	16	16	14	14	13	13	12	12	12	12
14	350	197	125	88	69	53	40	31	26	22	19	17	16	15	14	13	12	11	10	10	9	9	9	14
16	344	194	130	86	65	53	43	32	26	22	18	16	15	13	12	11	10	9	8	8	8	7	7	16
18	348	198	125	88	63	50	42	35	27	22	18	16	14	12	11	10	9	8	7	7	6	6	6	18
20	344	194	124	89	64	49	40	34	29	23	19	16	14	12	11	10	8	7	6	6	5	5	5	20
22	347	194	126	87	66	49	39	32	28	24	20	16	14	12	11	10	7	6	6	5	5	4	4	22
24	344	196	125	86	65	49	38	31	27	24	21	17	14	12	11	10	7	6	5	5	4	4	4	24
26	346	194	124	87	64	51	39	31	26	23	20	18	15	13	11	10	7	6	5	4	4	4	3	26
28	344	195	125	88	63	49	40	31	26	22	19	17	16	13	11	10	7	5	5	4	4	3	3	28
30	345	194	125	86	64	49	40	32	26	22	19	17	15	14	12	10	7	5	4	4	3	3	3	30
32	344	194	124	86	65	48	39	32	26	22	18	16	15	13	12	11	7	5	4	4	3	3	3	32
34	345	195	124	87	64	49	38	32	26	22	18	16	14	13	12	11	7	5	4	4	3	3	2	34
36	344	194	125	87	63	49	38	31	27	22	18	16	14	12	11	10	8	5	4	3	3	3	2	36
38	345	194	124	86	63	49	38	31	26	22	19	16	14	12	11	10	8	6	4	3	3	3	2	38
40	344	194	124	86	64	49	39	31	26	22	19	16	14	12	11	10	8	6	4	3	3	2	2	40
42	345	194	125	86	64	48	39	31	26	22	19	16	14	12	11	10	8	6	4	3	3	2	2	42
44	344	194	124	87	63	49	39	31	26	22	19	16	14	12	11	10	7	6	4	3	3	2	2	44
46	345	194	124	86	63	49	38	32	26	22	19	16	14	12	11	10	7	6	5	4	3	2	2	46
48	344	194	124	86	63	49	36	31	26	22	18	16	14	12	11	10	7	6	5	4	3	2	2	48

TABLE 6-5. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	1270	667	423	317	263	232	212	199	189	183	177	173	170	168	165	164	160	158	156	155	154	153	153	6
8	1163	714	436	291	219	179	154	138	127	119	113	109	105	103	100	99	95	92	90	89	88	88	87	8
10	1202	656	457	310	215	164	134	114	101	92	85	80	76	73	71	69	65	62	60	59	58	57	57	10
12	1163	667	423	317	232	167	129	106	90	79	72	66	61	58	55	53	48	46	44	43	42	41	40	12
14	1183	665	420	296	233	180	134	105	87	74	65	58	53	49	46	44	39	36	34	33	32	31	30	14
16	1163	654	438	291	219	179	144	109	87	73	62	55	49	45	41	39	33	30	28	26	25	25	24	16
18	1174	667	423	297	214	168	141	117	91	74	62	53	47	42	38	35	29	26	24	22	21	20	20	18
20	1163	656	419	301	215	164	134	114	98	78	64	54	47	41	37	33	27	23	21	19	18	17	17	20
22	1170	655	424	292	222	164	130	109	94	83	67	55	47	41	36	32	25	21	19	17	16	15	14	22
24	1163	661	423	291	219	167	129	106	90	79	71	58	49	42	36	32	24	20	17	15	14	13	13	24
26	1168	654	419	294	214	171	130	105	88	76	68	61	51	43	37	33	24	19	16	14	13	12	11	26
28	1163	657	420	296	214	166	134	105	87	74	65	58	53	45	38	33	24	18	15	13	12	11	10	28
30	1166	656	423	292	215	164	134	107	87	73	63	56	51	47	40	34	24	18	15	13	11	10	9	30
32	1163	654	419	291	219	163	131	109	87	73	62	55	49	45	41	36	24	18	15	12	11	10	9	32
34	1165	658	419	292	215	165	129	107	89	73	62	54	48	43	40	37	25	18	14	12	10	9	8	34
36	1163	654	423	294	214	167	129	106	90	74	62	53	47	42	38	35	26	19	14	12	10	9	8	36
38	1164	655	419	291	214	166	130	105	88	76	63	53	47	41	37	34	27	19	14	12	10	9	8	38
40	1163	656	419	291	215	164	131	105	87	75	64	54	47	41	37	33	27	19	15	12	10	8	7	40
42	1164	654	420	292	216	163	131	105	87	74	65	54	47	41	36	33	26	20	15	12	10	8	7	42
44	1163	655	419	292	214	164	130	106	86	73	64	55	47	41	36	32	25	21	15	12	10	8	7	44
46	1164	654	418	291	214	165	129	107	87	73	63	56	48	41	36	32	25	20	16	12	10	8	7	46
48	1163	654	419	291	214	165	129	106	87	73	62	55	49	42	36	32	24	20	16	12	10	8	7	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	3009	1582	1002	752	624	550	503	471	449	433	420	411	403	397	392	388	379	374	370	367	365	364	363	6
8	2756	1693	1038	689	518	423	365	328	302	283	269	258	250	243	238	234	224	218	214	212	210	208	207	8
10	2850	1555	1083	735	510	389	317	271	240	218	202	190	181	174	168	163	153	147	143	140	138	136	135	10
12	2756	1582	1002	752	549	395	306	250	214	188	170	156	146	137	131	126	115	108	104	101	99	97	96	12
14	2803	1577	996	701	553	426	316	249	205	175	154	138	126	117	110	104	92	85	81	78	75	74	72	14
16	2756	1550	1038	689	518	423	340	259	207	172	148	130	116	106	98	91	78	71	66	62	60	58	57	16
18	2783	1582	1002	703	506	399	334	278	217	176	147	127	111	100	91	84	69	61	56	52	50	48	47	18
20	2756	1555	992	713	510	389	317	271	231	184	151	128	110	97	87	79	63	55	49	45	43	41	39	20
22	2773	1553	1006	693	525	388	308	258	224	196	158	131	112	97	86	77	60	50	44	40	37	35	34	22
24	2756	1566	1002	689	518	395	306	250	214	188	168	137	115	99	86	77	58	47	41	36	34	31	30	24
26	2767	1550	992	696	508	405	309	248	208	180	160	145	120	102	88	77	56	45	38	34	31	28	27	26
28	2756	1557	996	701	506	394	316	249	205	175	154	138	126	107	91	79	56	44	36	32	28	26	24	28
30	2764	1555	1002	691	510	389	317	253	205	173	150	133	120	111	95	82	57	43	35	30	27	24	22	30
32	2756	1550	993	689	518	388	310	259	207	172	148	130	116	106	98	85	58	43	34	29	25	23	21	32
34	2761	1560	993	693	510	390	307	255	211	173	147	127	113	102	94	87	59	43	34	28	24	22	20	34
36	2756	1551	1001	696	506	395	306	250	214	176	147	127	111	100	91	84	61	44	34	28	24	21	19	36
38	2760	1552	994	690	507	392	308	248	209	179	149	127	110	98	89	81	63	45	34	28	23	20	18	38
40	2756	1555	992	689	510	389	311	248	207	178	151	128	110	97	87	79	63	46	35	28	23	20	18	40
42	2759	1550	996	692	511	387	311	249	205	175	154	129	111	97	86	78	61	47	35	28	23	19	17	42
44	2756	1553	994	693	507	388	308	251	205	173	151	131	112	97	86	77	60	49	36	28	23	19	17	44
46	2758	1551	992	689	506	391	306	253	206	172	149	132	113	98	86	77	59	48	37	28	23	19	17	46
48	2756	1550	994	689	507	391	306	250	207	172	148	130	115	99	86	77	58	47	38	29	23	19	16	48

TABLE 6-5. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	5250	3089	1957	1469	1219	1073	982	920	877	845	821	802	788	776	766	758	740	730	722	717	713	711	708	6
8	5250	3306	2027	1346	1012	827	714	640	589	552	525	504	488	475	465	456	438	426	419	413	409	406	404	8
10	5250	3037	2116	1437	996	759	619	529	469	426	395	372	354	339	328	318	299	287	278	273	269	266	263	10
12	5250	3089	1957	1469	1073	772	598	489	417	367	331	305	284	268	256	245	224	211	203	197	193	189	187	12
14	5250	3080	1946	1369	1080	832	618	487	401	342	301	270	247	229	215	204	180	166	157	151	147	144	141	14
16	5250	3028	2027	1346	1012	827	664	507	405	336	288	253	227	207	191	178	153	138	129	122	117	114	111	16
18	5250	3089	1957	1373	989	779	653	543	423	343	287	247	217	195	177	163	135	119	109	102	97	94	91	18
20	5250	3037	1938	1392	996	759	619	529	452	359	295	249	215	190	170	155	124	107	96	88	83	80	77	20
22	5250	3034	1964	1354	1026	759	602	503	437	382	309	256	218	190	168	150	117	98	86	78	73	69	66	22
24	5250	3058	1957	1346	1012	772	598	489	417	367	327	268	225	193	169	150	112	92	79	71	65	61	58	24
26	5250	3028	1938	1359	993	791	604	484	406	352	313	283	235	199	172	151	110	88	74	66	60	55	52	26
28	5250	3041	1946	1369	989	770	618	487	401	342	301	270	247	208	178	155	110	86	71	62	55	51	48	28
30	5250	3037	1957	1350	996	759	619	494	401	337	293	260	235	216	185	160	111	84	69	59	52	47	44	30
32	5250	3028	1939	1346	1012	757	606	507	405	336	288	253	227	207	191	166	113	84	67	57	50	45	41	32
34	5250	3047	1940	1354	996	762	599	497	413	339	287	249	221	200	183	170	116	85	67	55	48	42	39	34
36	5250	3029	1956	1359	989	772	598	489	417	343	287	247	217	195	177	163	119	86	66	54	46	41	37	36
38	5250	3030	1941	1348	990	766	601	485	409	350	290	247	216	192	173	158	124	88	67	54	45	40	35	38
40	5250	3037	1938	1346	996	759	608	484	403	348	295	249	215	190	170	155	124	90	68	54	45	39	34	40
42	5250	3027	1946	1351	998	757	608	487	401	342	301	252	216	189	168	152	120	92	69	54	45	38	33	42
44	5250	3034	1942	1354	991	759	602	491	400	339	295	256	218	190	168	150	117	96	70	55	44	38	33	44
46	5250	3030	1937	1347	988	764	599	495	402	337	291	257	221	191	168	150	114	95	72	55	45	37	32	46
48	5250	3028	1941	1346	990	764	598	489	405	336	288	253	225	193	169	150	112	92	74	56	45	37	32	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	6640	5338	3382	2539	2106	1855	1697	1590	1515	1460	1418	1386	1361	1340	1323	1309	1279	1261	1248	1239	1232	1228	1224	6
8	6640	5713	3502	2325	1749	1428	1233	1105	1018	954	907	872	843	821	803	788	756	736	724	714	707	702	697	8
10	6640	5247	3656	2482	1722	1312	1069	914	810	736	683	642	611	586	566	550	516	495	481	471	464	459	455	10
12	6640	5338	3382	2539	1854	1334	1033	845	721	635	573	526	491	464	442	424	387	365	350	340	333	327	323	12
14	6640	5321	3363	2365	1866	1438	1068	841	693	591	519	466	426	396	371	352	312	288	272	262	254	248	244	14
16	6640	5232	3502	2325	1749	1428	1148	875	700	581	498	437	392	357	330	308	264	239	222	211	203	197	193	16
18	6640	5338	3382	2372	1709	1346	1129	938	731	593	497	427	376	337	306	282	234	206	189	177	168	162	158	18
20	6640	5247	3348	2405	1722	1312	1069	914	781	621	510	430	372	328	294	267	214	184	165	153	144	138	133	20
22	6640	5243	3394	2340	1773	1311	1040	869	755	660	533	443	377	328	290	260	202	169	149	135	126	119	114	22
24	6640	5284	3382	2325	1749	1334	1033	845	721	635	565	463	389	334	291	258	194	159	137	123	113	106	101	24
26	6640	5232	3348	2349	1716	1367	1044	837	701	608	541	490	406	345	297	261	191	152	129	113	103	96	90	26
28	6640	5254	3363	2365	1708	1330	1068	841	693	591	519	466	426	359	307	267	190	148	123	107	96	88	82	28
30	6640	5247	3382	2332	1722	1312	1069	854	693	583	506	449	406	374	320	276	191	146	119	102	90	82	76	30
32	6640	5232	3351	2325	1749	1308	1047	875	700	581	498	437	392	357	330	287	195	145	116	98	86	77	71	32
34	6640	5264	3352	2340	1721	1316	1036	859	713	585	495	430	382	345	316	293	200	146	115	95	82	73	67	34
36	6640	5234	3380	2348	1709	1334	1033	845	721	593	497	427	376	337	306	282	206	148	115	94	80	71	64	36
38	6640	5236	3353	2329	1710	1324	1039	838	706	605	502	427	373	331	299	274	214	151	115	93	78	68	61	38
40	6640	5247	3348	2325	1722	1312	1050	837	697	601	510	430	372	328	294	267	214	155	117	93	77	67	59	40
42	6640	5231	3363	2335	1725	1308	1051	841	693	591	519	436	374	327	291	263	207	160	119	93	77	66	58	42
44	6640	5243	3356	2340	1712	1311	1040	849	692	585	509	443	377	328	290	260	202	165	121	94	77	65	57	44
46	6640	5236	3348	2327	1708	1320	1034	855	694	582	502	444	382	330	290	259	197	163	124	96	77	65	56	46
48	6640	5232	3354	2325	1711	1321	1033	845	700	581	498	437	389	334	291	258	194	159	128	97	78	65	55	48

TABLE 6-5. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	7740	7740	5370	4032	3344	2946	2695	2525	2406	2319	2252	2201	2161	2128	2101	2079	2031	2002	1982	1967	1957	1950	1943	6
8	7740	7740	5561	3692	2777	2268	1958	1755	1616	1516	1441	1384	1339	1304	1275	1252	1201	1169	1149	1134	1123	1115	1107	8
10	7740	7740	5806	3942	2734	2083	1697	1452	1286	1169	1084	1020	970	931	899	874	820	787	764	748	738	729	723	10
12	7740	7740	5370	4032	2943	2119	1641	1343	1145	1008	909	836	780	736	702	674	615	580	556	540	529	520	514	12
14	7740	7740	5340	3756	2962	2283	1696	1335	1100	939	825	741	677	628	589	558	495	457	432	415	403	394	387	14
16	7740	7740	5561	3692	2777	2268	1823	1390	1111	923	791	694	622	567	524	490	420	379	353	335	322	313	306	16
18	7740	7740	5370	3767	2714	2138	1792	1490	1161	942	789	678	597	534	486	448	372	327	299	281	267	258	250	18
20	7740	7740	5317	3819	2734	2083	1697	1452	1240	985	809	683	591	521	467	424	340	292	262	243	229	218	211	20
22	7740	7740	5390	3715	2815	2081	1651	1380	1200	1048	847	704	599	520	460	413	320	268	236	215	200	190	182	22
24	7740	7740	5370	3692	2777	2119	1641	1343	1145	1008	898	736	618	530	463	410	309	252	218	195	180	168	160	24
26	7740	7740	5317	3730	2724	2171	1658	1329	1114	965	859	778	645	547	472	414	303	241	204	180	164	152	143	26
28	7740	7740	5340	3756	2713	2113	1696	1335	1100	939	825	741	677	571	482	424	301	235	195	169	152	140	131	28
30	7740	7740	5370	3703	2734	2083	1697	1356	1100	926	803	713	645	593	508	438	304	231	189	161	143	130	120	30
32	7740	7740	5321	3692	2777	2077	1662	1390	1111	923	791	694	622	567	524	456	309	231	185	156	136	122	112	32
34	7740	7740	5322	3715	2733	2090	1644	1365	1132	929	786	683	606	548	502	466	317	232	183	152	131	117	106	34
36	7740	7740	5367	3729	2714	2119	1641	1343	1145	942	789	678	597	534	486	448	327	235	182	149	127	112	101	36
38	7740	7740	5325	3698	2715	2103	1650	1331	1122	961	797	679	592	526	475	434	339	240	183	148	125	109	97	38
40	7740	7740	5317	3692	2734	2083	1668	1329	1107	955	809	683	591	521	467	424	340	246	185	148	123	106	94	40
42	7740	7740	5340	3708	2740	2077	1669	1335	1100	939	825	692	593	519	462	417	329	254	188	148	122	104	92	42
44	7740	7740	5329	3715	2719	2081	1651	1348	1099	929	809	704	599	520	460	413	320	262	192	150	122	103	90	44
46	7740	7740	5316	3695	2712	2096	1642	1358	1103	924	798	706	607	524	460	411	314	259	197	152	123	103	89	46
48	7740	7740	5327	3692	2718	2098	1641	1343	1111	923	791	694	618	530	463	410	309	252	203	154	123	103	88	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	9600	9600	8016	6019	4992	4397	4022	3769	3592	3461	3362	3286	3226	3177	3136	3103	3032	2988	2958	2936	2921	2910	2900	6
8	9600	9600	8301	5512	4145	3386	2923	2620	2412	2262	2151	2066	1999	1947	1904	1869	1793	1746	1716	1693	1676	1664	1653	8
10	9600	9600	8667	5884	4081	3109	2534	2167	1920	1745	1618	1522	1448	1389	1343	1304	1224	1174	1141	1117	1101	1088	1079	10
12	9600	9600	8016	6019	4394	3163	2450	2004	1709	1505	1358	1248	1164	1099	1047	1006	918	865	831	806	789	776	767	12
14	9600	9600	7971	5606	4422	3408	2532	1993	1642	1402	1231	1106	1011	938	883	834	739	682	645	620	602	589	578	14
16	9600	9600	8301	5512	4145	3386	2721	2075	1659	1378	1180	1036	929	846	782	731	627	566	526	500	481	467	457	16
18	9600	9600	8016	5624	4051	3191	2675	2223	1734	1406	1177	1013	891	798	726	669	555	489	447	419	399	385	374	18
20	9600	9600	7937	5700	4081	3109	2534	2167	1851	1471	1208	1020	882	777	697	633	508	436	392	362	341	326	315	20
22	9600	9600	8046	5546	4202	3107	2465	2061	1791	1565	1264	1050	894	777	687	616	478	401	353	321	299	283	271	22
24	9600	9600	8016	5512	4145	3163	2450	2004	1709	1505	1340	1098	922	791	690	612	461	376	325	291	268	251	239	24
26	9600	9600	7937	5567	4067	3241	2475	1984	1662	1441	1282	1161	964	817	705	619	452	360	305	269	245	227	214	26
28	9600	9600	7971	5606	4049	3153	2532	1993	1642	1402	1231	1106	1011	852	728	633	450	350	291	253	227	208	195	28
30	9600	9600	8016	5528	4081	3109	2533	2024	1642	1382	1198	1064	963	885	759	654	453	345	282	241	213	194	180	30
32	9600	9600	7943	5511	4145	3100	2481	2075	1659	1378	1180	1036	929	846	782	680	461	344	276	232	203	183	168	32
34	9600	9600	7945	5546	4080	3120	2455	2037	1690	1387	1174	1020	905	818	750	696	473	347	273	226	195	174	158	34
36	9600	9600	8012	5567	4051	3163	2450	2004	1709	1406	1177	1013	891	798	726	669	488	351	272	223	190	167	151	36
38	9600	9600	7949	5520	4053	3139	2462	1987	1674	1434	1189	1013	883	785	708	648	506	359	274	221	186	162	145	38
40	9600	9600	7937	5512	4081	3109	2490	1984	1653	1425	1208	1020	882	777	697	633	508	368	277	220	184	158	140	40
42	9600	9600	7971	5536	4090	3100	2492	1993	1642	1402	1231	1033	886	775	690	623	491	379	281	221	182	156	137	42
44	9600	9600	7955	5546	4058	3107	2465	2011	1640	1387	1207	1050	894	777	687	616	478	391	287	223	182	154	134	44
46	9600	9600	7935	5516	4049	3128	2452	2027	1646	1379	1191	1053	906	782	687	613	468	387	294	227	183	153	132	46
48	9600	9600	7951	5512	4057	3131	2449	2004	1659	1378	1180	1036	922	791	690	612	461	376	302	231	184	153	131	48

TABLE 6-5. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES SIMPLY SUPPORTED REMAINING EDGES CLAMPED (Cont'd)

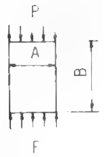
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10800	10800	10800	8570	7107	6261	5727	5367	5114	4928	4786	4678	4593	4524	4466	4419	4317	4255	4212	4180	4159	4144	4130	6
8	10800	10800	10800	7848	5902	4821	4162	3731	3434	3221	3063	2942	2847	2772	2711	2661	2553	2485	2443	2411	2387	2369	2354	8
10	10800	10800	10800	8378	5810	4427	3607	3085	2733	2485	2304	2167	2062	1978	1912	1857	1742	1672	1624	1591	1568	1549	1536	10
12	10800	10800	10800	8570	6256	4504	3488	2853	2433	2142	1933	1777	1658	1565	1491	1432	1308	1232	1183	1148	1124	1105	1091	12
14	10800	10800	10800	7982	6296	4852	3605	2837	2337	1996	1753	1574	1439	1335	1253	1187	1052	971	918	883	857	838	823	14
16	10800	10800	10800	7848	5902	4821	3875	2955	2362	1962	1680	1476	1323	1205	1113	1040	892	805	750	712	685	665	650	16
18	10800	10800	10800	8007	5768	4544	3809	3166	2469	2002	1677	1442	1268	1136	1033	952	790	696	636	596	568	548	532	18
20	10800	10800	10800	8116	5810	4427	3607	3085	2635	2094	1720	1453	1256	1107	992	902	723	621	558	515	486	464	448	20
22	10800	10800	10800	7897	5983	4424	3510	2934	2550	2228	1800	1496	1273	1106	978	877	681	570	502	457	426	403	386	22
24	10800	10800	10800	7848	5902	4504	3488	2853	2434	2142	1909	1564	1313	1126	983	872	656	536	462	415	382	358	340	24
26	10800	10800	10800	7927	5790	4615	3523	2825	2367	2051	1826	1653	1372	1163	1004	881	643	513	434	383	348	323	305	26
28	10800	10800	10800	7982	5766	4490	3605	2837	2337	1996	1753	1574	1439	1213	1037	901	641	499	414	360	323	297	277	28
30	10800	10800	10800	7871	5810	4427	3607	2883	2338	1968	1706	1515	1371	1261	1081	931	646	492	401	343	304	276	256	30
32	10800	10800	10800	7847	5902	4414	3533	2955	2362	1962	1680	1476	1322	1205	1113	969	657	490	393	331	289	260	239	32
34	10800	10800	10800	7897	5809	4442	3495	2900	2407	1974	1671	1452	1289	1165	1068	991	674	494	388	322	278	248	225	34
36	10800	10800	10800	7926	5768	4504	3488	2853	2433	2002	1677	1442	1268	1136	1033	952	695	500	388	317	270	238	215	36
38	10800	10800	10800	7859	5771	4469	3506	2829	2384	2042	1693	1443	1258	1117	1009	923	721	511	390	314	265	231	206	38
40	10800	10800	10800	7848	5810	4427	3545	2825	2353	2029	1720	1453	1256	1107	992	902	723	524	394	314	261	225	200	40
42	10800	10800	10800	7882	5823	4413	3548	2837	2337	1996	1753	1471	1261	1103	982	887	700	539	401	315	260	222	195	42
44	10800	10800	10800	7897	5778	4424	3510	2864	2335	1974	1719	1496	1273	1106	978	877	681	557	409	318	259	219	191	44
46	10800	10800	10800	7854	5764	4454	3491	2886	2343	1964	1695	1500	1291	1114	978	873	667	551	419	323	260	218	188	46
48	10800	10800	10800	7848	5776	4458	3488	2853	2362	1962	1680	1476	1313	1126	983	872	656	536	431	328	262	218	187	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	12000	12000	12000	11756	9749	8588	7856	7362	7016	6760	6566	6417	6300	6205	6126	6061	5921	5837	5778	5734	5704	5684	5665	6
8	12000	12000	12000	10765	8096	6613	5709	5117	4711	4419	4201	4036	3905	3802	3718	3650	3502	3409	3351	3307	3274	3250	3229	8
10	12000	12000	12000	11492	7970	6073	4948	4232	3750	3408	3160	2973	2828	2714	2622	2547	2390	2293	2228	2182	2150	2125	2107	10
12	12000	12000	12000	11756	8581	6178	4784	3914	3338	2939	2651	2437	2274	2147	2046	1964	1794	1690	1622	1575	1541	1515	1497	12
14	12000	12000	12000	10949	8637	6656	4944	3892	3206	2737	2404	2159	1974	1831	1718	1628	1443	1332	1260	1211	1176	1150	1129	14
16	12000	12000	12000	10765	8096	6613	5315	4053	3240	2691	2305	2024	1814	1653	1527	1427	1224	1105	1028	976	940	913	892	16
18	12000	12000	12000	10984	7912	6233	5225	4343	3386	2746	2300	1978	1740	1558	1418	1306	1083	954	873	818	780	751	730	18
20	12000	12000	12000	11133	7970	6073	4948	4232	3615	2873	2360	1993	1722	1518	1361	1237	992	852	765	707	666	637	615	20
22	12000	12000	12000	10832	8207	6068	4814	4025	3498	3056	2469	2052	1746	1517	1341	1204	934	782	689	627	584	553	530	22
24	12000	12000	12000	10765	8096	6178	4784	3914	3338	2939	2618	2145	1801	1545	1349	1196	900	735	634	569	523	491	467	24
26	12000	12000	12000	10874	7943	6330	4833	3875	3247	2814	2504	2268	1882	1595	1377	1208	883	703	595	525	478	444	418	26
28	12000	12000	12000	10949	7909	6159	4944	3892	3206	2737	2404	2159	1974	1664	1423	1236	879	684	568	494	443	407	381	28
30	12000	12000	12000	10797	7970	6073	4948	3954	3207	2699	2340	2078	1881	1729	1482	1277	886	675	550	470	417	379	351	30
32	12000	12000	12000	10764	8096	6055	4846	4053	3240	2691	2305	2024	1814	1653	1527	1329	901	673	538	454	397	357	328	32
34	12000	12000	12000	10832	7968	6093	4794	3978	3302	2708	2293	1992	1768	1597	1464	1359	924	677	533	442	382	340	309	34
36	12000	12000	12000	10872	7912	6178	4784	3914	3338	2746	2300	1978	1740	1558	1418	1306	953	686	532	435	371	327	295	36
38	12000	12000	12000	10781	7916	6130	4809	3881	3270	2801	2323	1979	1725	1533	1384	1266	989	700	534	431	363	317	283	38
40	12000	12000	12000	10765	7970	6073	4863	3875	3228	2783	2360	1993	1722	1518	1361	1237	992	718	540	431	359	309	274	40
42	12000	12000	12000	10812	7988	6054	4866	3892	3206	2737	2404	2017	1730	1514	1347	1217	960	740	549	432	356	304	267	42
44	12000	12000	12000	10832	7926	6068	4814	3929	3203	2708	2358	2052	1746	1517	1341	1204	934	764	561	437	356	301	262	44
46	12000	12000	12000	10773	7907	6110	4788	3959	3214	2693	2325	2057	1770	1527	1342	1197	914	756	575	443	357	299	258	46
48	12000	12000	12000	10765	7923	6116	4784	3914	3240	2691	2305	2024	1801	1545	1349	1196	900	735	591	450	360	299	256	48

TABLE 6-6. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED



PHYSICAL CONSTANTS:

$E_X = E_Y = 0.86 \times 10^6$ PSI

$G_{XY} = 0.40 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.37$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	39	31	27	26	25	24	24	23	23	23	23	23	23	23	23	23	22	22	22	22	22	22	22	6
8	33	22	18	16	15	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13	13	13	13	8
10	33	19	14	12	11	10	10	9	9	9	9	9	9	8	8	8	8	8	8	8	8	8	8	10
12	29	18	12	10	9	8	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	12
14	27	18	12	9	7	6	6	5	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	14
16	27	16	12	8	7	6	5	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	16
18	26	16	11	8	6	5	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	18
20	26	15	10	8	6	5	4	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	20
22	26	15	10	8	6	5	4	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	22
24	25	15	10	7	6	5	4	3	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	24
26	25	15	10	7	6	5	4	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	26
28	25	15	10	7	5	4	4	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	28
30	26	15	10	7	5	4	4	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	30
32	26	14	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	32
34	27	14	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	34
36	28	14	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	36
38	29	14	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	38
40	30	15	9	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	40
42	31	15	9	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	42
44	33	15	9	7	5	4	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	0	44
46	34	15	9	6	5	4	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	0	0	46
48	36	16	9	6	5	4	3	2	2	2	2	1	1	1	1	1	1	1	1	1	0	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	315	247	220	206	198	193	190	187	186	184	183	183	182	182	181	181	180	179	179	179	179	179	179	6
8	264	177	145	130	121	116	112	110	108	107	106	105	104	104	103	103	102	102	101	101	101	101	101	8
10	260	152	114	96	86	81	77	74	72	71	70	69	68	68	67	67	66	66	65	65	65	65	65	10
12	231	145	99	79	68	62	58	55	53	51	50	50	49	48	48	47	47	46	46	46	45	45	45	12
14	220	141	94	70	58	51	46	44	41	40	39	38	37	37	36	36	35	34	34	34	34	33	33	14
16	219	130	93	66	52	44	40	36	34	32	31	30	30	29	28	28	27	27	26	26	26	26	26	16
18	211	124	88	65	49	40	35	32	29	27	26	25	24	24	23	23	22	21	21	21	21	20	20	18
20	208	123	83	65	48	38	32	28	26	24	23	22	21	20	20	19	18	18	17	17	17	17	17	20
22	208	123	80	61	48	37	30	26	23	21	20	19	18	17	17	16	16	15	15	14	14	14	14	22
24	204	119	79	58	47	36	29	25	22	20	18	17	16	15	15	14	13	13	12	12	12	12	12	24
26	203	117	79	56	44	37	29	24	21	18	17	16	15	14	13	13	12	11	11	11	10	10	10	26
28	204	117	78	55	42	35	29	23	20	18	16	14	13	13	12	12	11	10	10	9	9	9	9	28
30	207	116	76	55	41	34	29	23	19	17	15	14	13	12	11	11	10	9	9	8	8	8	8	30
32	211	115	75	55	41	32	28	23	19	16	14	13	12	11	10	10	9	8	8	7	7	7	7	32
34	217	114	75	54	40	32	26	23	19	16	14	13	11	11	10	9	8	7	7	7	6	6	6	34
36	224	114	75	53	40	31	26	22	19	16	14	12	11	10	9	9	8	7	6	6	6	6	6	36
38	232	115	74	52	40	31	25	21	19	16	14	12	11	10	9	8	7	6	6	6	5	5	5	38
40	241	116	73	52	39	31	25	21	18	16	14	12	11	9	9	8	7	6	6	5	5	5	5	40
42	251	118	73	52	39	31	24	20	18	16	14	12	10	9	8	8	6	6	5	5	5	4	4	42
44	262	120	73	52	38	31	24	20	17	15	14	12	10	9	8	8	6	5	5	5	4	4	4	44
46	274	123	73	51	38	30	24	20	17	15	13	12	10	9	8	7	6	5	5	4	4	4	4	46
48	286	126	74	51	38	30	24	20	17	14	13	12	10	9	8	7	6	5	4	4	4	4	3	48

TABLE 6-6. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	1065	834	742	695	669	652	641	633	627	623	619	617	615	613	611	610	607	606	605	604	603	603	603	6
8	890	599	490	438	409	391	379	371	365	360	357	354	352	350	349	348	345	343	342	341	341	340	339	8
10	878	513	383	324	291	272	259	250	244	239	236	233	231	229	227	226	223	222	220	220	219	219	218	10
12	780	491	335	266	230	208	195	185	179	174	170	167	165	163	161	160	157	156	155	154	153	152	152	12
14	741	476	316	237	196	172	157	147	140	135	131	128	125	123	122	120	118	116	115	114	113	113	112	14
16	736	439	315	222	176	150	133	123	115	110	105	102	100	98	96	95	92	90	89	88	87	87	87	16
18	714	420	298	218	166	136	118	107	98	93	88	85	82	80	79	77	74	72	71	70	70	69	69	18
20	702	414	281	220	161	128	109	96	87	81	76	73	70	68	66	65	62	60	59	58	57	57	56	20
22	702	414	271	205	160	124	102	89	79	73	68	64	61	59	57	56	52	51	49	48	48	47	47	22
24	688	402	266	195	158	123	99	84	74	67	61	57	54	52	50	49	45	43	42	41	41	40	40	24
26	684	396	265	189	149	123	97	81	70	62	57	53	49	47	45	43	40	38	37	36	35	35	34	26
28	687	395	263	185	143	119	97	79	67	59	53	49	46	43	41	39	36	34	32	31	31	30	30	28
30	697	392	257	184	139	114	98	78	66	57	51	46	43	40	38	36	32	30	29	28	27	27	26	30
32	713	387	254	185	137	110	93	79	65	56	49	44	40	37	35	33	30	27	26	25	24	24	23	32
34	732	385	253	182	135	107	89	78	65	55	48	42	39	36	33	31	27	25	24	23	22	21	21	34
36	756	385	253	178	135	105	87	75	65	55	47	41	37	34	32	30	26	23	22	21	20	19	19	36
38	784	388	250	177	136	104	85	72	64	55	47	41	36	33	30	28	24	22	20	19	18	18	17	38
40	814	392	248	176	133	104	83	70	61	55	46	40	36	32	29	27	23	20	19	18	17	16	16	40
42	848	398	246	176	131	104	82	69	59	53	47	40	35	31	29	26	22	19	17	16	16	15	15	42
44	885	406	246	176	130	103	82	68	58	51	46	40	35	31	28	26	21	18	16	15	14	14	13	44
46	924	415	247	173	129	102	82	67	57	50	45	40	35	31	28	25	20	17	16	14	14	13	13	46
48	966	425	249	172	129	100	82	66	56	49	43	39	35	31	27	25	20	17	15	14	13	12	12	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	2524	1976	1758	1648	1585	1545	1519	1500	1486	1476	1468	1462	1457	1452	1449	1446	1439	1435	1434	1431	1430	1429	1429	6
8	2109	1420	1162	1038	970	927	899	879	865	854	846	840	834	830	827	824	817	813	811	809	807	806	804	8
10	2082	1216	909	767	690	644	614	593	578	567	559	552	547	542	539	536	530	526	523	520	519	518	517	10
12	1848	1163	794	631	545	494	462	439	424	412	403	396	391	386	383	380	373	369	366	364	363	361	361	12
14	1757	1128	750	561	464	407	372	348	331	319	310	303	297	292	289	286	279	275	272	270	268	267	266	14
16	1750	1040	746	527	417	355	316	291	273	260	250	242	237	232	228	225	218	214	211	209	207	206	205	16
18	1692	996	707	517	392	323	280	253	233	220	209	201	195	190	186	183	176	172	169	167	165	164	163	18
20	1665	982	665	520	381	304	257	227	207	192	181	173	166	161	157	153	146	142	139	137	135	134	133	20
22	1665	980	641	485	380	294	243	210	188	172	160	152	145	140	135	132	124	120	117	115	113	112	111	22
24	1631	952	630	462	374	291	234	199	175	158	145	136	129	124	119	115	108	103	100	98	96	95	94	24
26	1621	938	629	447	354	292	230	191	166	147	134	125	117	111	107	103	95	90	87	85	83	82	81	26
28	1629	937	623	439	339	282	230	187	160	140	126	116	108	102	97	93	85	80	77	74	73	71	70	28
30	1653	930	609	436	330	269	231	186	156	135	120	109	101	94	89	85	77	72	68	66	64	63	62	30
32	1689	917	602	438	324	260	220	187	154	132	116	104	96	89	83	79	70	65	61	59	57	56	55	32
34	1736	912	599	431	321	253	212	184	154	130	113	101	91	84	79	74	65	59	56	54	52	51	50	34
36	1793	913	601	423	321	249	205	177	155	129	111	98	88	81	75	70	61	55	51	49	47	46	45	36
38	1858	919	593	418	322	246	201	171	151	129	110	96	86	78	72	67	57	51	47	45	43	42	41	38
40	1930	930	587	416	315	245	197	166	145	130	110	95	84	76	69	64	54	48	44	42	40	38	37	40
42	2010	944	584	416	311	246	195	163	141	125	111	95	83	75	68	62	52	45	41	39	37	35	34	42
44	2097	963	584	416	308	245	194	160	137	121	110	95	83	74	66	61	49	43	39	36	34	33	32	44
46	2190	984	525	411	306	241	194	159	135	118	106	96	83	73	65	59	48	41	37	34	32	31	30	46
48	2289	1008	589	408	306	238	194	158	133	116	103	93	83	73	65	59	46	39	35	32	30	29	28	48

TABLE 6-6. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4930	3860	3433	3219	3095	3018	2967	2930	2903	2883	2866	2855	2845	2837	2829	2823	2811	2804	2800	2795	2794	2792	2792	6
8	4119	2773	2270	2028	1894	1811	1756	1717	1690	1669	1652	1640	1629	1622	1615	1610	1596	1588	1585	1580	1577	1575	1571	8
10	4066	2375	1775	1498	1349	1258	1199	1159	1130	1108	1091	1079	1068	1059	1053	1047	1034	1027	1021	1016	1014	1012	1010	10
12	3610	2271	1551	1232	1064	965	901	858	827	805	788	774	763	755	748	742	729	721	715	711	708	706	705	12
14	3432	2202	1465	1095	905	796	726	680	647	623	605	591	580	571	564	558	545	536	531	527	524	522	520	14
16	3419	2030	1458	1030	815	693	618	567	532	507	488	473	462	453	445	439	425	417	411	407	405	402	401	16
18	3305	1945	1382	1009	766	631	548	493	456	429	409	393	381	372	364	358	344	335	330	326	323	320	318	18
20	3252	1918	1299	1017	745	594	503	444	403	375	353	337	325	315	306	300	286	277	271	267	264	262	260	20
22	3252	1915	1252	948	742	574	474	410	367	336	313	296	283	273	264	257	243	234	228	224	221	218	217	22
24	3185	1859	1231	902	730	568	458	388	341	308	284	266	252	241	233	225	210	201	195	191	188	185	184	24
26	3165	1833	1228	874	691	571	450	374	323	288	263	243	229	217	208	201	185	176	170	165	162	160	158	26
28	3182	1829	1217	858	663	551	449	366	312	274	247	226	211	199	189	182	166	156	149	145	142	139	138	28
30	3228	1817	1190	852	644	526	452	363	304	264	235	213	197	185	175	166	150	140	133	129	126	123	121	30
32	3299	1792	1175	855	633	508	430	364	301	257	227	204	187	173	163	154	137	127	120	115	112	110	108	32
34	3391	1781	1170	841	627	495	414	360	300	254	221	197	178	165	154	145	127	116	109	104	101	99	97	34
36	3502	1783	1173	826	626	486	401	345	302	252	217	192	172	158	146	137	118	107	100	95	92	89	88	36
38	3628	1795	1159	817	629	481	392	334	294	253	215	188	168	152	140	131	111	100	93	88	84	82	80	38
40	3770	1816	1147	813	616	479	385	325	284	254	215	186	165	148	136	126	105	94	86	81	78	75	73	40
42	3926	1845	1141	813	607	480	381	318	275	245	216	185	163	146	132	122	101	88	81	76	72	69	67	42
44	4096	1880	1140	813	601	479	379	313	268	237	214	186	162	144	130	119	97	84	76	71	67	64	62	44
46	4277	1922	1143	803	598	471	379	310	263	231	207	187	161	142	128	116	93	80	72	67	63	60	58	46
48	4470	1970	1151	796	597	465	380	308	259	226	201	183	162	142	127	114	91	77	69	63	59	56	54	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	6640	6640	5932	5562	5349	5215	5127	5063	5017	4981	4953	4933	4916	4901	4889	4879	4857	4844	4839	4830	4828	4824	4824	6
8	6640	4791	3922	3505	3272	3129	3034	2967	2920	2884	2855	2834	2815	2802	2790	2781	2758	2744	2738	2731	2725	2722	2715	8
10	6640	4104	3067	2589	2330	2174	2072	2002	1952	1914	1886	1864	1846	1831	1819	1809	1787	1774	1763	1756	1753	1748	1745	10
12	6237	3924	2681	2130	1839	1668	1558	1483	1430	1391	1361	1337	1319	1304	1292	1282	1260	1245	1236	1229	1224	1220	1218	12
14	5931	3806	2531	1892	1565	1375	1255	1175	1118	1077	1046	1022	1002	987	974	964	942	927	917	911	906	902	899	14
16	5908	3508	2519	1779	1408	1198	1067	981	920	876	843	818	798	782	769	759	735	721	711	704	699	695	692	16
18	5710	3361	2388	1744	1324	1090	946	853	788	741	706	680	659	643	629	618	594	579	570	563	557	553	550	18
20	5619	3314	2245	1757	1287	1026	869	767	697	647	611	583	561	544	530	518	494	479	468	461	456	452	449	20
22	5619	3309	2164	1638	1283	993	819	709	634	580	541	512	489	471	457	445	420	404	394	386	381	377	374	22
24	5504	3212	2127	1559	1262	981	791	670	589	532	491	460	436	417	402	389	364	348	337	330	324	320	317	24
26	5469	3167	2122	1510	1194	986	777	646	559	498	454	421	395	376	360	347	320	304	293	286	280	276	273	26
28	5498	3161	2102	1483	1146	951	775	633	538	473	426	391	365	344	327	314	286	269	258	251	245	241	238	28
30	5578	3140	2056	1473	1113	908	781	628	526	456	406	369	341	319	302	288	259	242	230	222	217	213	210	30
32	5701	3096	2030	1477	1094	877	743	630	520	445	391	352	322	299	281	267	237	219	207	200	194	190	186	32
34	5860	3078	2022	1453	1084	855	715	622	519	438	381	340	308	284	265	250	219	201	189	181	175	171	167	34
36	6051	3081	2027	1428	1082	840	693	597	522	436	375	331	298	272	253	237	204	185	173	165	159	155	151	36
38	6270	3102	2002	1412	1087	832	677	577	508	437	372	325	290	263	242	226	192	173	160	151	145	141	138	38
40	6515	3138	1981	1405	1065	829	666	561	490	439	371	322	285	256	235	217	182	162	149	140	134	130	126	40
42	6640	3187	1971	1405	1049	830	659	550	475	423	373	320	281	252	228	210	174	153	139	131	124	120	116	42
44	6640	3249	1969	1405	1039	827	655	541	464	409	370	321	279	248	224	205	167	145	131	122	116	111	108	44
46	6640	3321	1976	1388	1033	813	655	535	455	399	357	323	279	246	221	201	161	139	125	115	109	104	100	46
48	6640	3403	1989	1376	1032	803	656	532	448	390	347	316	280	245	219	198	156	133	119	109	102	97	94	48

TABLE 6-6. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7713	7693	7684	7670	7666	7661	7661	6
8	7740	7609	6228	5565	5197	4968	4818	4712	4637	4579	4534	4500	4471	4449	4430	4416	4380	4358	4348	4336	4327	4322	4311	8
10	7740	6517	4870	4111	3700	3452	3290	3180	3100	3040	2995	2959	2931	2907	2889	2872	2838	2817	2800	2789	2783	2776	2771	10
12	7740	6231	4257	3382	2921	2648	2474	2355	2270	2208	2161	2123	2094	2070	2052	2035	2000	1978	1963	1952	1944	1937	1934	12
14	7740	6043	4019	3005	2484	2183	1993	1866	1776	1711	1661	1622	1592	1567	1547	1531	1495	1472	1456	1446	1438	1433	1427	14
16	7740	5571	4000	2826	2237	1902	1695	1557	1461	1391	1339	1299	1268	1242	1221	1205	1168	1145	1129	1118	1110	1104	1099	16
18	7740	5338	3791	2769	2103	1731	1503	1354	1251	1177	1122	1080	1047	1020	999	981	944	920	905	893	885	879	874	18
20	7740	5263	3566	2789	2043	1629	1379	1217	1107	1028	969	925	890	863	841	823	784	760	744	733	724	718	713	20
22	7740	5255	3437	2601	2037	1576	1301	1125	1006	922	860	813	777	748	725	706	666	642	625	614	606	599	594	22
24	7740	5101	3377	2476	2004	1558	1256	1064	936	845	780	730	692	662	638	618	577	552	535	524	515	509	504	24
26	7740	5029	3370	2398	1895	1566	1234	1026	887	790	720	668	628	596	571	551	509	482	465	454	445	438	434	26
28	7740	5019	3338	2355	1819	1511	1231	1005	855	751	677	621	579	546	520	498	454	428	410	398	389	383	378	28
30	7740	4986	3264	2339	1768	1443	1240	997	835	724	645	586	541	506	479	457	411	384	366	353	344	338	333	30
32	7740	4916	3224	2345	1737	1393	1180	1000	826	706	622	559	512	476	447	424	376	348	329	317	308	301	296	32
34	7740	4887	3210	2308	1721	1358	1135	988	824	696	606	540	490	451	421	397	348	319	300	287	278	271	266	34
36	7740	4892	3219	2267	1719	1334	1100	948	829	692	596	526	473	433	401	376	325	294	275	262	252	245	240	36
38	7740	4925	3180	2242	1726	1321	1075	916	807	694	591	516	461	418	385	359	305	274	254	241	231	224	219	38
40	7740	4983	3146	2231	1690	1316	1058	891	778	697	590	511	452	407	372	345	289	257	236	223	213	206	200	40
42	7740	5062	3130	2231	1666	1317	1046	873	755	671	592	509	447	399	363	334	276	243	221	207	197	190	185	42
44	7740	5159	3127	2231	1649	1314	1041	859	737	650	587	509	444	394	356	325	265	230	209	194	184	177	171	44
46	7740	5274	3137	2203	1640	1291	1039	850	723	633	568	512	443	391	350	319	256	220	198	183	172	165	159	46
48	7740	5405	3158	2185	1638	1275	1042	844	712	619	552	501	444	389	347	314	249	211	188	173	162	155	149	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	6
8	9600	9600	9297	8308	7757	7416	7192	7034	6921	6836	6768	6718	6674	6642	6613	6592	6539	6505	6491	6472	6459	6452	6436	8
10	9600	9600	7269	6137	5523	5153	4912	4746	4628	4537	4470	4418	4375	4339	4312	4287	4236	4205	4180	4163	4154	4144	4136	10
12	9600	9301	6355	5048	4360	3953	3692	3515	3389	3296	3226	3170	3126	3091	3062	3038	2986	2952	2930	2913	2902	2891	2888	12
14	9600	9021	5999	4485	3709	3259	2976	2785	2651	2553	2479	2422	2376	2340	2309	2285	2232	2197	2174	2159	2147	2139	2130	14
16	9600	8316	5970	4218	3339	2839	2530	2324	2181	2077	1999	1939	1892	1854	1823	1798	1743	1709	1685	1668	1657	1648	1641	16
18	9600	7968	5659	4134	3139	2583	2243	2021	1867	1757	1675	1612	1562	1523	1491	1465	1409	1374	1350	1333	1321	1312	1304	18
20	9600	7855	5322	4164	3050	2432	2059	1817	1652	1534	1447	1381	1329	1288	1255	1228	1170	1134	1110	1094	1081	1072	1065	20
22	9600	7844	5130	3883	3041	2353	1942	1680	1502	1376	1283	1214	1160	1117	1082	1054	995	958	933	916	904	894	887	22
24	9600	7614	5041	3696	2992	2325	1875	1589	1397	1262	1164	1090	1033	988	952	923	862	824	799	782	769	760	752	24
26	9600	7506	5031	3579	2829	2337	1843	1532	1324	1180	1075	997	937	890	853	823	759	720	695	677	664	654	647	26
28	9600	7492	4983	3515	2716	2255	1838	1500	1276	1121	1010	927	864	815	776	744	678	638	612	594	581	571	564	28
30	9600	7442	4873	3491	2639	2153	1851	1488	1247	1081	962	874	808	756	715	682	614	573	546	527	514	504	497	30
32	9600	7338	4813	3501	2592	2079	1762	1493	1232	1054	928	835	764	710	667	632	562	519	492	473	460	450	442	32
34	9600	7295	4792	3445	2569	2027	1694	1475	1230	1039	904	805	731	674	629	593	519	476	447	428	414	404	396	34
36	9600	7303	4806	3384	2565	1992	1643	1415	1238	1033	890	785	706	646	599	561	484	439	410	391	377	366	358	36
38	9600	7352	4746	3347	2576	1972	1605	1367	1204	1035	882	771	688	624	575	535	456	409	379	359	345	334	326	38
40	9600	7438	4697	3330	2523	1964	1579	1331	1161	1041	881	763	675	608	556	515	432	384	353	332	318	307	299	40
42	9600	7556	4672	3330	2486	1966	1562	1303	1127	1002	884	759	667	596	542	498	412	362	331	309	295	284	275	42
44	9600	7702	4668	3330	2462	1961	1553	1283	1100	971	876	760	662	588	531	486	396	344	312	290	275	264	255	44
46	9600	7873	4683	3289	2449	1928	1552	1269	1079	945	847	765	661	583	523	476	382	329	295	273	257	246	238	46
48	9600	8067	4715	3262	2445	1903	1556	1260	1063	924	823	748	663	581	518	469	371	315	281	258	242	231	222	48

TABLE 6-6. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

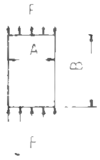
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	6
8	10800	10800	10800	10800	10800	10559	10241	10015	9855	9733	9637	9565	9502	9457	9416	9387	9310	9262	9242	9216	9196	9186	9163	8
10	10800	10800	10350	8738	7864	7338	6994	6758	6589	6460	6365	6290	6229	6179	6139	6104	6032	5987	5952	5928	5915	5901	5890	10
12	10800	10800	9048	7187	6208	5628	5257	5005	4825	4693	4593	4513	4451	4401	4360	4326	4251	4203	4172	4148	4132	4116	4111	12
14	10800	10800	8542	6387	5280	4640	4237	3966	3775	3636	3529	3448	3383	3331	3288	3253	3178	3128	3095	3074	3057	3045	3033	14
16	10800	10800	8501	6006	4754	4043	3602	3309	3105	2957	2846	2761	2694	2640	2596	2560	2481	2433	2400	2376	2359	2347	2336	16
18	10800	10800	8058	5886	4469	3678	3194	2878	2659	2502	2384	2295	2225	2169	2123	2086	2006	1956	1923	1898	1881	1868	1857	18
20	10800	10800	7578	5929	4343	3463	2931	2587	2352	2185	2061	1966	1893	1834	1787	1748	1667	1615	1581	1557	1540	1526	1516	20
22	10800	10800	7304	5528	4329	3350	2766	2392	2138	1959	1827	1728	1651	1590	1541	1501	1416	1364	1329	1304	1287	1273	1263	22
24	10800	10800	7178	5263	4259	3311	2669	2262	1989	1797	1657	1552	1471	1407	1356	1314	1227	1173	1138	1113	1095	1081	1071	24
26	10800	10687	7163	5096	4028	3328	2623	2181	1886	1680	1531	1420	1334	1268	1214	1171	1081	1025	989	964	946	932	921	26
28	10800	10668	7095	5004	3866	3211	2617	2136	1817	1597	1438	1320	1230	1160	1104	1059	966	909	872	846	827	813	803	28
30	10800	10596	6938	4971	3758	3066	2635	2119	1775	1539	1370	1245	1150	1076	1018	971	874	815	777	751	732	718	707	30
32	10800	10449	6852	4985	3691	2960	2509	2125	1755	1501	1321	1188	1088	1011	950	900	800	739	700	674	654	640	629	32
34	10800	10387	6823	4905	3658	2886	2412	2101	1751	1480	1288	1147	1041	959	895	844	739	677	637	609	590	575	564	34
36	10800	10398	6842	4818	3653	2836	2339	2014	1762	1471	1267	1117	1005	919	852	799	690	625	584	556	536	521	510	36
38	10800	10468	6758	4765	3668	2808	2286	1947	1715	1474	1256	1097	979	889	818	762	649	582	540	511	491	476	465	38
40	10800	10591	6687	4741	3593	2796	2248	1895	1654	1482	1254	1086	961	866	792	733	615	546	503	473	452	437	426	40
42	10800	10758	6652	4741	3540	2800	2224	1855	1605	1427	1259	1081	949	849	771	710	587	516	471	441	419	404	392	42
44	10800	10800	6647	4741	3505	2792	2212	1826	1566	1382	1247	1082	943	837	756	691	563	490	444	413	391	375	363	44
46	10800	10800	6668	4683	3486	2745	2209	1806	1536	1345	1206	1089	942	831	745	678	544	468	420	389	366	350	338	46
48	10800	10800	6713	4644	3481	2710	2215	1795	1513	1316	1172	1065	945	828	738	667	528	449	400	368	345	329	316	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	6
8	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	8
10	12000	12000	12000	11986	10788	10065	9593	9270	9038	8862	8731	8628	8545	8475	8422	8373	8274	8212	8164	8131	8114	8094	8079	10
12	12000	12000	12000	9859	8515	7721	7212	6866	6619	6438	6300	6191	6106	6036	5981	5934	5832	5765	5723	5690	5668	5647	5640	12
14	12000	12000	11718	8761	7243	6365	5812	5440	5178	4987	4841	4730	4640	4569	4510	4463	4359	4291	4246	4217	4193	4177	4161	14
16	12000	12000	11661	8238	6521	5546	4941	4540	4260	4056	3904	3788	3695	3621	3561	3512	3404	3338	3292	3259	3236	3219	3205	16
18	12000	12000	11053	8074	6130	5045	4382	3947	3647	3431	3271	3148	3052	2975	2913	2861	2751	2683	2637	2604	2581	2562	2548	18
20	12000	12000	10395	8133	5958	4750	4021	3549	3227	2997	2827	2697	2596	2516	2452	2398	2286	2215	2168	2136	2112	2093	2080	20
22	12000	12000	10020	7583	5939	4595	3794	3281	2933	2687	2507	2370	2265	2181	2114	2059	1943	1871	1823	1789	1765	1746	1732	22
24	12000	12000	9847	7219	5843	4542	3661	3103	2728	2465	2273	2129	2018	1930	1860	1803	1683	1609	1561	1526	1502	1483	1469	24
26	12000	12000	9825	6991	5526	4565	3599	2991	2587	2305	2100	1947	1831	1739	1666	1607	1483	1407	1357	1322	1297	1278	1264	26
28	12000	12000	9733	6865	5304	4405	3590	2929	2493	2190	1973	1811	1688	1591	1515	1453	1325	1247	1196	1160	1135	1116	1101	28
30	12000	12000	9517	6819	5155	4206	3614	2907	2435	2111	1879	1708	1577	1476	1396	1332	1199	1118	1066	1030	1004	985	970	30
32	12000	12000	9399	6838	5063	4061	3441	2915	2407	2060	1812	1630	1493	1386	1302	1235	1097	1014	961	924	898	878	863	32
34	12000	12000	9360	6728	5018	3958	3308	2882	2402	2030	1766	1573	1428	1316	1228	1158	1014	929	874	836	809	789	774	34
36	12000	12000	9386	6609	5010	3891	3208	2763	2417	2019	1737	1533	1379	1261	1169	1095	946	858	801	763	735	715	700	36
38	12000	12000	9270	6537	5031	3851	3135	2671	2352	2022	1723	1505	1343	1219	1122	1045	890	799	741	701	673	653	637	38
40	12000	12000	9173	6504	4929	3836	3084	2599	2268	2033	1720	1489	1318	1188	1086	1005	843	749	689	649	621	600	584	40
42	12000	12000	9125	6504	4856	3840	3051	2545	2201	1958	1727	1483	1302	1164	1058	973	805	707	646	604	575	554	538	42
44	12000	12000	9118	6504	4808	3830	3034	2505	2148	1896	1711	1485	1294	1149	1037	948	773	672	609	566	536	515	498	44
46	12000	12000	9147	6424	4782	3765	3031	2478	2106	1845	1655	1493	1292	1139	1022	929	746	642	576	533	503	481	464	46
48	12000	12000	9208	6370	4776	3718	3039	2462	2075	1805	1608	1461	1296	1135	1012	915	725	616	549	504	473	451	434	48

TABLE 6-7. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
2 OZ. MAT - ALL EDGES CLAMPED



PHYSICAL CONSTANTS:

$E_X = E_Y = 0.86 \times 10^6$ PSI

$G_{XY} = 0.40 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.37$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	62	39	31	28	26	25	24	24	24	23	23	23	23	23	23	23	23	22	22	22	22	22	22	6
8	54	35	24	19	17	16	15	14	14	14	14	13	13	13	13	13	13	13	13	13	13	13	13	8
10	50	31	22	16	13	12	11	10	10	9	9	9	9	9	9	9	8	8	8	8	8	8	8	10
12	48	29	21	15	12	10	9	8	7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	12
14	47	28	19	15	11	9	8	7	6	6	5	5	5	5	5	5	4	4	4	4	4	4	4	14
16	46	27	18	13	11	9	7	6	5	5	4	4	4	4	4	4	4	3	3	3	3	3	3	16
18	46	27	18	13	10	9	7	6	5	4	4	4	3	3	3	3	3	3	3	3	3	3	3	18
20	47	26	17	13	10	8	7	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2	2	20
22	49	26	17	12	9	7	6	6	5	4	3	3	3	3	2	2	2	2	2	2	2	2	2	22
24	52	26	17	12	9	7	6	5	5	4	3	3	3	2	2	2	2	2	2	2	2	2	2	24
26	56	26	17	12	9	7	6	5	4	4	3	3	3	2	2	2	2	2	1	1	1	1	1	26
28	61	27	16	12	9	7	6	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1	28
30	66	28	17	12	9	7	6	5	4	3	3	3	2	2	2	2	1	1	1	1	1	1	1	30
32	71	30	17	11	9	7	6	5	4	3	3	3	2	2	2	2	1	1	1	1	1	1	1	32
34	77	31	17	11	9	7	5	5	4	3	3	3	2	2	2	2	1	1	1	1	1	1	1	34
36	83	33	18	11	9	7	5	5	4	3	3	3	2	2	2	2	1	1	1	1	1	1	1	36
38	90	35	18	12	8	7	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1	1	38
40	97	37	19	12	8	7	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1	1	40
42	105	39	20	12	8	6	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1	1	42
44	113	42	21	12	8	6	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1	1	44
46	122	44	21	13	9	6	5	4	4	3	3	2	2	2	2	2	1	1	1	1	1	1	1	46
48	131	47	23	13	9	6	5	4	4	3	3	2	2	2	2	1	1	1	1	1	1	1	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	495	312	251	224	209	201	196	192	189	187	186	185	184	183	182	182	181	180	180	180	179	179	179	6
8	428	278	191	155	136	126	119	115	112	110	108	107	106	105	105	104	103	102	102	101	101	101	101	8
10	402	251	178	130	106	93	86	81	77	75	73	71	70	70	69	68	67	66	66	65	65	65	65	10
12	385	229	166	124	94	78	69	63	59	56	54	52	51	50	49	49	48	47	46	46	46	45	45	12
14	379	227	150	118	91	71	60	53	48	45	43	41	40	39	38	37	36	35	35	34	34	34	34	14
16	368	217	145	107	88	70	56	48	42	39	36	34	33	31	31	30	28	27	27	27	26	26	26	16
18	367	213	145	102	80	69	55	45	39	35	32	30	28	27	26	25	23	22	22	21	21	21	21	18
20	377	210	139	101	76	63	55	45	37	32	29	27	25	23	22	21	20	19	18	18	17	17	17	20
22	395	206	136	100	74	59	50	45	37	31	27	25	23	21	20	19	17	16	15	15	15	14	14	22
24	420	207	137	96	74	57	48	41	37	31	27	23	21	20	18	17	15	14	13	13	12	12	12	24
26	450	210	133	95	73	57	46	39	35	31	26	23	20	18	17	16	14	12	12	11	11	11	10	26
28	485	217	132	95	71	57	45	38	33	29	27	23	20	18	16	15	13	11	10	10	10	9	9	28
30	525	225	132	93	70	55	45	37	31	28	25	23	20	17	16	14	12	10	10	9	9	8	8	30
32	568	236	134	92	70	54	45	36	31	27	24	22	20	17	15	14	11	10	9	8	8	7	7	32
34	616	249	137	92	69	53	44	36	30	26	23	21	19	17	15	14	11	9	8	7	7	7	7	34
36	667	263	141	92	68	53	43	36	30	25	22	20	18	17	15	14	10	9	8	7	7	6	6	36
38	722	278	146	93	67	53	42	35	30	25	22	19	18	16	15	14	10	8	7	7	6	6	6	38
40	780	295	151	94	67	53	42	35	30	25	22	19	17	16	15	14	10	8	7	6	6	5	5	40
42	841	313	157	96	67	52	42	34	29	25	21	19	17	15	14	13	10	8	7	6	5	5	5	42
44	906	333	164	99	68	52	42	34	29	25	21	19	16	15	14	13	10	8	6	6	5	5	4	44
46	975	353	172	102	69	51	41	34	28	24	22	18	16	15	13	12	10	8	6	5	5	4	4	46
48	1046	375	180	105	70	52	41	34	28	24	21	18	16	14	13	12	10	8	6	5	5	4	4	48

TABLE 6-7. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	1670	1054	847	755	707	678	660	647	639	632	627	623	620	617	615	613	610	608	606	605	604	604	604	6
8	1446	939	645	522	460	425	403	389	379	371	366	361	358	355	353	352	348	345	344	343	342	341	340	8
10	1357	848	601	438	359	315	289	272	260	252	246	241	238	235	232	230	226	224	222	221	220	219	219	10
12	1300	774	560	417	317	264	232	212	198	189	182	177	173	170	167	165	161	158	156	155	154	153	153	12
14	1280	766	508	398	307	241	203	179	163	152	144	139	134	131	128	126	121	118	117	115	114	114	113	14
16	1242	731	490	362	298	235	189	161	143	130	122	115	110	106	103	101	96	93	91	90	89	88	87	16
18	1239	719	489	344	272	231	186	153	131	117	107	100	94	90	87	84	79	75	73	72	71	70	70	18
20	1273	710	468	339	257	212	185	150	126	109	98	90	83	79	75	72	66	63	61	59	58	58	57	20
22	1334	696	460	336	250	200	170	151	124	106	93	83	76	71	67	64	58	54	52	50	49	48	48	22
24	1417	697	461	325	250	194	161	140	126	104	90	79	72	66	61	58	51	47	45	43	42	41	41	24
26	1519	710	449	320	246	191	155	132	117	105	89	77	69	62	58	54	46	42	39	38	37	36	35	26
28	1638	731	445	320	239	191	152	127	111	99	90	77	67	60	55	51	43	38	35	34	32	31	31	28
30	1771	761	446	316	235	187	151	124	106	94	86	77	67	59	53	49	40	35	32	30	29	28	27	30
32	1918	797	452	311	235	183	152	122	103	90	81	74	67	59	52	47	38	33	29	28	26	25	24	32
34	2078	839	462	309	234	180	147	122	102	88	78	71	65	59	52	47	36	31	27	25	24	23	22	34
36	2251	887	475	310	230	180	144	122	101	86	76	68	62	58	52	46	35	29	26	24	22	21	20	36
38	2435	939	491	313	228	180	143	119	101	85	74	66	60	55	52	47	35	28	24	22	20	19	19	38
40	2632	996	510	318	227	177	142	117	101	85	73	64	58	53	49	46	34	27	23	21	19	18	17	40
42	2840	1057	532	325	228	175	142	116	98	85	72	63	56	51	47	44	34	27	23	20	18	17	16	42
44	2980	1123	555	334	230	174	141	115	97	84	72	63	55	50	46	43	34	26	22	19	17	16	15	44
46	2980	1193	581	343	233	174	139	115	96	82	73	62	55	49	45	41	34	26	21	18	17	15	14	46
48	2980	1266	608	354	237	174	138	115	95	81	71	62	54	48	44	40	33	26	21	18	16	14	14	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	3958	2499	2008	1790	1675	1607	1564	1534	1514	1498	1486	1477	1470	1463	1458	1454	1445	1440	1437	1435	1433	1431	1431	6
8	3428	2226	1529	1236	1090	1007	955	921	897	880	867	857	849	843	837	833	824	818	815	812	810	809	808	8
10	3216	2009	1425	1037	850	747	685	644	617	597	583	572	563	556	551	546	537	531	526	523	522	520	519	10
12	3081	1835	1326	990	752	625	550	502	470	447	431	419	409	402	396	391	381	374	370	367	365	364	363	12
14	3034	1815	1204	943	727	571	481	424	387	361	343	329	318	310	303	298	287	281	276	273	271	270	268	14
16	2945	1733	1160	857	705	557	449	382	339	309	288	273	261	252	245	239	227	220	215	212	210	208	207	16
18	2937	1703	1159	816	644	548	440	362	312	278	254	236	223	213	205	199	186	179	174	170	168	166	165	18
20	3017	1683	1109	804	609	502	438	356	298	259	232	212	198	187	178	171	157	149	144	141	138	137	135	20
22	3162	1650	1091	797	593	474	404	358	294	250	219	197	181	169	159	151	136	128	122	119	116	114	113	22
24	3360	1652	1093	770	591	459	381	332	298	247	213	188	170	156	146	137	121	112	106	102	100	98	96	24
26	3601	1682	1065	758	582	453	367	313	277	250	211	183	163	148	136	127	110	100	94	90	87	85	83	26
28	3882	1734	1055	758	566	454	360	301	262	236	212	182	159	143	130	120	101	90	84	80	77	75	73	28
30	4198	1804	1057	748	558	444	357	294	252	223	203	183	158	140	126	115	94	83	76	72	69	66	65	30
32	4200	1890	1072	736	556	433	359	290	245	214	192	176	159	139	124	112	90	77	70	65	62	60	58	32
34	4200	1990	1095	732	555	428	349	290	241	208	185	168	155	140	123	110	86	73	65	60	57	54	52	34
36	4200	2102	1126	734	545	426	342	290	239	204	179	161	147	137	124	110	84	69	61	56	52	50	48	36
38	4200	2226	1165	742	539	428	338	282	240	202	175	156	142	131	122	110	82	67	58	52	49	46	44	38
40	4200	2361	1209	754	538	421	337	277	238	201	173	152	137	126	117	110	81	65	55	49	46	43	41	40
42	4200	2507	1260	771	540	415	337	274	233	202	171	150	134	122	112	105	81	63	53	47	43	40	38	42
44	4200	2662	1316	791	544	412	335	273	229	199	171	148	131	119	109	101	81	63	52	45	41	38	36	44
46	4200	2827	1376	814	551	412	330	273	227	195	172	148	130	116	106	98	82	62	51	44	39	36	34	46
48	4200	3001	1441	840	561	413	327	273	226	193	169	148	129	115	104	95	78	62	50	42	38	34	32	48

TABLE 6-7. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	5250	4880	3921	3496	3271	3139	3055	2997	2956	2926	2902	2884	2870	2858	2849	2840	2823	2813	2807	2803	2799	2796	2795	6
8	5250	4348	2986	2415	2129	1966	1866	1799	1752	1719	1693	1674	1658	1646	1635	1628	1609	1598	1592	1586	1582	1579	1576	8
10	5250	3924	2783	2026	1660	1459	1337	1258	1205	1166	1138	1117	1100	1086	1076	1067	1048	1037	1028	1022	1019	1016	1013	10
12	5250	3584	2591	1933	1469	1220	1073	980	918	874	842	818	799	785	773	764	744	731	723	718	714	710	709	12
14	5250	3545	2351	1842	1420	1115	939	829	756	705	669	642	621	605	593	582	561	548	539	534	529	526	524	14
16	5250	3385	2266	1674	1378	1087	876	746	662	604	563	532	509	492	478	466	443	430	421	414	410	407	404	16
18	5250	3327	2264	1593	1257	1070	859	707	609	542	495	461	436	416	401	388	363	349	339	333	328	325	322	18
20	5250	3287	2166	1571	1190	981	856	696	583	507	453	415	386	365	348	334	307	292	282	275	270	267	264	20
22	5250	3222	2131	1557	1159	926	788	700	575	488	428	385	353	329	311	296	267	250	239	232	227	224	221	22
24	5250	3227	2136	1504	1155	896	744	648	581	483	415	367	332	305	284	268	237	218	207	200	195	191	188	24
26	5250	3285	2081	1481	1137	884	717	612	542	488	412	358	318	289	266	249	214	195	183	175	170	166	163	26
28	5250	3386	2060	1481	1105	886	702	588	512	460	415	355	311	279	254	235	197	176	164	155	150	146	143	28
30	5250	3523	2065	1461	1090	867	698	573	492	436	396	357	309	273	246	225	184	162	149	140	134	130	126	30
32	5250	3691	2093	1438	1087	846	702	567	479	418	376	344	311	272	242	219	175	151	137	127	121	117	113	32
34	5250	3886	2138	1430	1084	835	683	566	471	406	361	327	302	273	241	216	168	142	127	117	111	106	103	34
36	5250	4106	2200	1434	1065	832	669	566	467	398	350	314	288	268	242	215	163	136	119	109	102	97	94	36
38	5250	4348	2275	1449	1054	835	660	551	468	394	342	304	276	255	239	216	160	130	113	102	95	90	86	38
40	5250	4612	2362	1473	1050	822	657	542	465	393	337	297	268	245	228	214	158	127	108	97	89	84	80	40
42	5250	4896	2461	1505	1054	811	658	535	455	394	335	293	261	238	219	205	158	124	104	92	84	78	74	42
44	5250	5199	2570	1544	1063	806	654	533	448	389	335	290	257	232	212	197	158	122	101	88	80	74	70	44
46	5250	5250	2688	1589	1077	804	645	533	443	382	336	289	254	227	207	191	159	121	99	85	76	70	66	46
48	5250	5250	2815	1640	1095	807	639	534	440	376	331	289	252	224	203	186	153	121	97	83	74	67	63	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	6640	6640	6640	6041	5653	5425	5279	5179	5108	5055	5014	4984	4960	4939	4922	4908	4878	4860	4851	4843	4836	4831	4830	6
8	6640	6640	5159	4173	3679	3398	3224	3108	3028	2970	2925	2892	2864	2844	2826	2813	2781	2761	2751	2741	2733	2729	2725	8
10	6640	6640	4809	3501	2868	2520	2310	2175	2082	2015	1967	1930	1900	1877	1859	1843	1811	1791	1777	1767	1761	1755	1751	10
12	6640	6194	4476	3340	2538	2108	1855	1694	1586	1510	1455	1413	1381	1356	1336	1320	1285	1264	1250	1240	1233	1227	1224	12
14	6640	6126	4063	3182	2454	1927	1622	1432	1306	1219	1156	1109	1074	1046	1024	1006	970	947	932	922	915	910	905	14
16	6640	5848	3916	2892	2381	1879	1514	1290	1143	1043	972	920	880	849	825	806	766	742	727	716	709	703	699	16
18	6640	5749	3912	2753	2172	1850	1484	1222	1052	937	856	797	753	719	692	671	628	603	587	575	568	562	557	18
20	6640	5679	3743	2714	2056	1695	1479	1202	1007	875	783	717	668	630	601	578	531	504	487	475	467	461	456	20
22	6640	5568	3682	2691	2003	1601	1362	1210	994	844	740	666	611	569	537	511	461	432	413	401	393	386	382	22
24	6640	5577	3691	2599	1996	1548	1285	1119	1004	835	718	635	573	527	492	464	409	378	358	345	336	330	325	24
26	6640	5677	3596	2559	1965	1528	1238	1057	937	843	711	618	550	499	460	430	370	336	316	302	293	286	281	26
28	6640	5852	3559	2560	1910	1531	1213	1016	886	796	717	613	538	482	439	405	341	305	283	268	259	252	246	28
30	6640	6088	3569	2524	1883	1498	1206	991	850	753	685	618	534	472	425	389	319	280	257	242	231	224	219	30
32	6640	6378	3616	2485	1878	1462	1213	979	827	723	649	595	538	470	418	378	302	261	236	220	209	202	196	32
34	6640	6640	3695	2471	1874	1443	1179	978	813	702	623	566	523	472	416	373	290	246	219	202	191	183	177	34
36	6640	6640	3801	2478	1839	1437	1155	978	808	688	604	543	497	462	418	371	282	234	206	188	176	168	162	36
38	6640	6640	3931	2504	1821	1443	1141	953	809	681	591	526	478	441	412	373	277	225	195	177	164	155	149	38
40	6640	6640	4082	2546	1815	1420	1136	936	804	678	583	514	463	424	394	370	274	219	187	167	154	144	138	40
42	6640	6640	4252	2601	1821	1402	1138	925	786	681	579	506	451	410	379	354	273	214	180	159	145	135	128	42
44	6640	6640	4440	2668	1836	1392	1131	920	773	673	578	501	443	400	367	340	273	211	175	153	138	128	121	44
46	6640	6640	4645	2746	1861	1390	1115	920	765	659	581	499	438	392	357	330	275	209	171	147	132	121	114	46
48	6640	6640	4865	2835	1892	1394	1104	923	761	650	571	499	435	387	350	321	265	209	168	143	127	116	108	48

TABLE 6-7. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7740	7718	7703	7691	7679	7672	7670	6
8	7740	7740	7740	6627	5842	5396	5120	4936	4809	4716	4645	4592	4548	4515	4487	4466	4415	4384	4368	4352	4340	4333	4326	8
10	7740	7740	7637	5559	4555	4002	3669	3453	3306	3200	3123	3064	3018	2981	2952	2927	2876	2844	2821	2806	2797	2787	2780	10
12	7740	7740	7108	5303	4030	3348	2945	2690	2518	2398	2311	2244	2194	2154	2122	2096	2041	2007	1985	1969	1958	1948	1944	12
14	7740	7740	6452	5053	3896	3060	2575	2273	2074	1935	1836	1762	1705	1661	1626	1598	1540	1503	1480	1465	1453	1445	1437	14
16	7740	7740	6219	4593	3781	2983	2404	2048	1816	1657	1544	1460	1398	1349	1311	1280	1216	1179	1154	1137	1125	1117	1110	16
18	7740	7740	6213	4371	3449	2937	2357	1940	1670	1488	1359	1266	1196	1142	1100	1066	997	957	931	914	901	892	885	18
20	7740	7740	5944	4309	3264	2692	2348	1909	1598	1390	1244	1139	1060	1001	954	917	843	800	773	754	741	732	725	20
22	7740	7740	5846	4273	3180	2542	2163	1921	1578	1340	1175	1057	970	903	852	812	732	685	656	637	624	613	606	22
24	7740	7740	5860	4128	3170	2459	2041	1777	1595	1326	1140	1008	910	837	781	736	649	600	569	548	534	524	516	24
26	7740	7740	5710	4064	3120	2426	1966	1678	1487	1338	1130	982	874	793	731	682	587	534	501	480	465	454	446	26
28	7740	7740	5652	4065	3033	2432	1927	1613	1406	1263	1139	974	854	765	697	644	541	484	449	426	411	400	391	28
30	7740	7740	5667	4008	2990	2378	1915	1574	1350	1196	1087	981	849	750	676	618	506	445	408	384	367	356	347	30
32	7740	7740	5743	3945	2982	2322	1926	1555	1313	1148	1031	945	854	746	664	601	480	414	375	349	332	320	311	32
34	7740	7740	5868	3923	2976	2291	1873	1552	1291	1114	989	898	830	750	661	592	461	390	348	322	303	291	281	34
36	7740	7740	6036	3936	2921	2282	1834	1553	1283	1093	959	862	790	734	664	589	448	372	327	299	280	266	257	36
38	7740	7740	6242	3977	2891	2291	1812	1513	1284	1081	939	835	759	700	655	592	439	358	310	280	260	246	236	38
40	7740	7740	6482	4042	2882	2255	1804	1486	1277	1077	926	816	735	673	625	587	434	347	297	265	244	229	219	40
42	7740	7740	6752	4130	2892	2226	1807	1469	1248	1081	919	803	717	652	601	561	433	340	286	253	230	215	204	42
44	7740	7740	7051	4237	2916	2210	1796	1462	1228	1068	918	795	704	635	582	541	434	335	278	242	219	203	191	44
46	7740	7740	7376	4361	2954	2207	1770	1462	1215	1047	922	792	696	623	568	524	437	332	272	234	210	193	181	46
48	7740	7740	7725	4501	3005	2214	1753	1465	1209	1032	907	792	691	615	556	510	420	331	267	228	202	184	172	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	6
8	9600	9600	9600	9600	8720	8054	7642	7367	7178	7039	6933	6855	6789	6740	6698	6667	6591	6544	6521	6496	6478	6468	6458	8
10	9600	9600	9600	8299	6799	5974	5476	5155	4935	4777	4661	4574	4505	4449	4406	4369	4292	4246	4211	4188	4174	4161	4150	10
12	9600	9600	9600	7916	6016	4997	4396	4015	3759	3560	3449	3350	3274	3215	3167	3128	3047	2996	2963	2939	2923	2908	2902	12
14	9600	9600	9600	7543	5816	4568	3844	3394	3095	2889	2740	2630	2545	2480	2427	2386	2298	2244	2209	2186	2169	2156	2145	14
16	9600	9600	9283	6855	5644	4453	3589	3057	2710	2473	2304	2180	2086	2014	1956	1911	1816	1760	1723	1697	1680	1667	1656	16
18	9600	9600	9274	6525	5149	4384	3518	2895	2493	2221	2029	1889	1785	1704	1641	1591	1489	1429	1390	1364	1345	1331	1321	18
20	9600	9600	8872	6433	4872	4018	3505	2850	2386	2075	1857	1700	1583	1494	1424	1369	1259	1194	1153	1126	1107	1092	1082	20
22	9600	9600	8727	6379	4747	3794	3228	2867	2355	2001	1755	1578	1447	1349	1272	1212	1092	1023	980	951	931	916	904	22
24	9600	9600	8748	6161	4731	3670	3047	2653	2381	1979	1702	1504	1359	1249	1165	1099	969	895	849	819	798	782	770	24
26	9600	9600	8523	6067	4657	3621	2935	2505	2220	1997	1686	1465	1304	1183	1091	1018	877	797	749	717	694	678	666	26
28	9600	9600	8437	6068	4527	3630	2876	2408	2099	1886	1700	1454	1275	1142	1040	961	807	722	670	636	613	596	584	28
30	9600	9600	8460	5983	4463	3550	2859	2349	2015	1786	1623	1464	1267	1120	1008	922	755	664	608	573	548	531	518	30
32	9600	9600	8572	5889	4451	3466	2875	2321	1960	1714	1539	1411	1274	1113	991	897	717	618	559	522	496	478	464	32
34	9600	9600	8759	5857	4442	3420	2796	2317	1928	1664	1477	1341	1239	1119	986	884	688	583	520	480	453	434	420	34
36	9600	9600	9010	5875	4360	3407	2738	2319	1915	1631	1432	1287	1179	1096	991	880	668	555	488	446	418	398	383	36
38	9600	9600	9318	5936	4316	3420	2705	2259	1917	1614	1401	1247	1132	1045	977	883	656	534	463	418	388	368	352	38
40	9600	9600	9600	6034	4303	3366	2692	2218	1906	1608	1382	1218	1097	1005	933	876	648	519	443	396	364	342	326	40
42	9600	9600	9600	6165	4316	3322	2697	2193	1863	1613	1372	1198	1070	973	898	838	646	508	427	377	344	321	304	42
44	9600	9600	9600	6324	4353	3300	2680	2182	1833	1595	1371	1187	1051	949	869	807	648	500	415	362	327	303	286	44
46	9600	9600	9600	6510	4410	3294	2642	2182	1814	1563	1377	1182	1038	930	847	782	653	496	405	350	313	288	270	46
48	9600	9600	9600	6719	4485	3305	2617	2187	1804	1540	1354	1183	1031	918	830	762	627	495	399	340	301	275	256	48

TABLE 6-7. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 2 OZ. MAT - ALL EDGES CLAMPED (Cont'd)

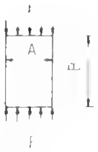
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	6
8	10800	10800	10800	10800	10800	10800	10800	10490	10220	10022	9872	9760	9667	9597	9537	9493	9384	9317	9284	9250	9224	9210	9196	8
10	10800	10800	10800	10800	9680	8506	7797	7339	7027	6801	6637	6512	6414	6335	6274	6220	6112	6045	5996	5963	5944	5924	5910	10
12	10800	10800	10800	10800	8566	7115	6260	5717	5352	5097	4911	4770	4662	4577	4510	4454	4338	4265	4219	4185	4162	4141	4132	12
14	10800	10800	10800	10740	8281	6504	5474	4832	4407	4114	3901	3745	3624	3531	3456	3397	3273	3195	3145	3113	3088	3070	3054	14
16	10800	10800	10800	9761	8036	6340	5110	4353	3859	3521	3281	3104	2971	2867	2785	2720	2585	2506	2453	2417	2392	2373	2358	16
18	10800	10800	10800	9290	7331	6243	5009	4123	3550	3162	2889	2690	2541	2426	2337	2265	2120	2034	1980	1942	1916	1896	1880	18
20	10800	10800	10800	9159	6937	5722	4991	4058	3397	2954	2644	2420	2253	2127	2028	1949	1792	1700	1642	1604	1576	1555	1540	20
22	10800	10800	10800	9082	6759	5402	4596	4082	3353	2848	2498	2247	2061	1920	1811	1726	1555	1457	1395	1354	1325	1304	1288	22
24	10800	10800	10800	8773	6737	5226	4338	3777	3390	2818	2423	2142	1935	1779	1659	1565	1380	1274	1209	1166	1136	1114	1097	24
26	10800	10800	10800	8638	6631	5156	4179	3567	3161	2844	2401	2087	1857	1685	1553	1450	1249	1135	1066	1020	989	966	949	26
28	10800	10800	10800	8639	6445	5169	4095	3428	2989	2685	2420	2070	1816	1626	1481	1368	1150	1028	954	906	873	849	831	28
30	10800	10800	10800	8519	6354	5054	4071	3345	2869	2543	2310	2084	1803	1594	1436	1313	1076	945	866	815	781	756	737	30
32	10800	10800	10800	8385	6338	4935	4094	3304	2791	2440	2191	2009	1814	1585	1411	1277	1020	880	796	743	706	680	661	32
34	10800	10800	10800	8339	6324	4870	3981	3299	2745	2369	2103	1909	1764	1593	1404	1258	980	830	740	683	645	618	598	34
36	10800	10800	10800	8365	6208	4851	3899	3301	2726	2323	2039	1833	1679	1561	1411	1252	952	791	696	635	595	566	546	36
38	10800	10800	10800	8452	6145	4870	3852	3216	2730	2297	1995	1776	1612	1488	1391	1258	933	761	660	596	553	523	502	38
40	10800	10800	10800	8592	6126	4792	3833	3158	2714	2290	1967	1734	1562	1430	1328	1248	923	738	631	563	519	487	465	40
42	10800	10800	10800	8778	6146	4731	3840	3123	2653	2297	1953	1706	1524	1385	1278	1193	920	723	608	537	490	457	433	42
44	10800	10800	10800	9005	6198	4698	3816	3106	2610	2271	1952	1690	1497	1351	1238	1149	923	712	591	515	466	431	407	44
46	10800	10800	10800	9269	6279	4691	3762	3107	2583	2226	1960	1683	1479	1325	1206	1113	930	706	577	498	445	410	384	46
48	10800	10800	10800	9567	6386	4705	3727	3114	2569	2193	1928	1684	1469	1306	1182	1085	893	704	568	484	429	391	365	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	6
8	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	8
10	12000	12000	12000	12000	12000	11669	10696	10068	9639	9329	9104	8933	8799	8690	8606	8533	8383	8292	8226	8180	8153	8127	8106	10
12	12000	12000	12000	12000	11751	9761	8586	7842	7342	6991	6737	6543	6395	6279	6186	6110	5950	5851	5787	5740	5709	5680	5668	12
14	12000	12000	12000	12000	11359	8921	7509	6628	6045	5643	5352	5137	4972	4844	4741	4659	4489	4383	4315	4270	4236	4212	4190	14
16	12000	12000	12000	12000	11023	8697	7009	5971	5294	4830	4500	4258	4075	3933	3821	3732	3546	3437	3365	3315	3281	3255	3235	16
18	12000	12000	12000	12000	10056	8563	6872	5655	4870	4338	3963	3690	3486	3328	3206	3107	2908	2790	2716	2664	2628	2600	2579	18
20	12000	12000	12000	12000	9516	7849	6846	5566	4660	4052	3627	3320	3091	2917	2782	2674	2458	2332	2253	2200	2162	2133	2112	20
22	12000	12000	12000	12000	9271	7410	6305	5600	4600	3907	3427	3082	2827	2634	2485	2367	2133	1998	1914	1857	1818	1788	1766	22
24	12000	12000	12000	12000	9241	7168	5951	5181	4650	3865	3324	2938	2654	2440	2276	2147	1892	1748	1659	1599	1558	1528	1505	24
26	12000	12000	12000	11849	9096	7073	5733	4893	4336	3901	3293	2862	2547	2311	2130	1989	1713	1557	1462	1400	1356	1325	1302	26
28	12000	12000	12000	11851	8841	7090	5618	4703	4100	3683	3320	2840	2491	2230	2032	1877	1577	1411	1309	1243	1198	1165	1140	28
30	12000	12000	12000	11686	8716	6933	5584	4588	3936	3488	3169	2859	2474	2187	1970	1801	1475	1297	1188	1119	1071	1037	1012	30
32	12000	12000	12000	11503	8694	6769	5615	4532	3828	3347	3006	2756	2489	2174	1936	1752	1400	1207	1093	1019	969	933	906	32
34	12000	12000	12000	11439	8675	6681	5460	4526	3765	3249	2885	2619	2419	2186	1926	1726	1344	1138	1016	937	885	848	820	34
36	12000	12000	12000	11474	8516	6654	5348	4528	3740	3186	2797	2514	2303	2141	1935	1718	1306	1085	954	871	816	777	749	36
38	12000	12000	12000	11594	8429	6680	5284	4412	3745	3151	2736	2436	2212	2041	1908	1725	1280	1044	905	817	759	718	688	38
40	12000	12000	12000	11785	8404	6573	5258	4332	3722	3141	2698	2379	2142	1962	1822	1712	1266	1013	865	773	711	668	638	40
42	12000	12000	12000	12000	8430	6489	5267	4283	3639	3151	2680	2341	2090	1900	1753	1637	1262	991	834	736	672	627	595	42
44	12000	12000	12000	12000	8502	6445	5235	4261	3580	3115	2677	2318	2053	1853	1698	1576	1266	977	810	707	639	592	558	44
46	12000	12000	12000	12000	8614	6435	5160	4262	3543	3053	2689	2308	2028	1817	1655	1527	1275	969	792	683	611	562	527	46
48	12000	12000	12000	12000	8760	6454	5112	4271	3523	3008	2645	2310	2014	1792	1621	1488	1225	966	779	663	588	537	500	48

TABLE 6-8. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED



PHYSICAL CONSTANTS:

$E_X - 1.81\times10^6$ PSI

$E_Y = 1.54\times10^6$ PSI

$G_{XY} = 0.45\times10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.19$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	33	20	15	13	12	11	11	10	10	10	10	10	9	9	9	9	9	9	9	9	9	9	9	6
8	38	19	12	10	8	7	7	6	6	6	6	6	6	6	5	5	5	5	5	5	5	5	5	8
10	34	20	12	9	7	6	5	5	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	10
12	33	20	13	8	6	5	4	4	4	3	3	3	3	3	3	3	3	2	2	2	2	2	2	12
14	35	19	13	9	6	5	4	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	14
16	34	19	12	9	6	5	4	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	16
18	33	19	12	9	7	5	4	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	18
20	34	19	12	9	7	5	4	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	20
22	33	19	12	8	6	5	4	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	22
24	33	19	12	8	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	24
26	34	19	12	8	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	26
28	33	19	12	9	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	1	1	1	0	28
30	33	19	12	9	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	1	0	0	0	30
32	34	19	12	8	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	32
34	33	19	12	8	6	5	4	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	0	34
36	33	19	12	8	6	5	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	36
38	33	19	12	8	6	5	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	38
40	33	19	12	9	6	5	4	3	2	2	2	2	2	1	1	1	1	1	0	0	0	0	0	40
42	33	19	12	8	6	5	4	3	2	2	2	2	1	1	1	1	1	1	0	0	0	0	0	42
44	33	19	12	8	6	5	4	3	2	2	2	2	1	1	1	1	1	1	0	0	0	0	0	44
46	33	19	12	8	6	5	4	3	2	2	2	2	1	1	1	1	1	1	0	0	0	0	0	46
48	33	19	12	8	6	5	4	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	267	161	123	105	95	89	85	82	80	79	77	77	76	75	75	74	74	73	73	72	72	72	72	6
8	301	150	100	77	66	59	54	51	49	48	46	46	45	44	44	43	42	42	42	41	41	41	41	8
10	273	162	96	68	54	46	41	38	35	34	32	31	31	30	29	29	28	27	27	27	27	26	26	10
12	267	161	102	67	50	40	34	31	28	26	25	24	23	22	22	21	20	20	19	19	19	19	18	12
14	279	152	108	70	49	38	31	27	24	22	20	19	18	18	17	17	16	15	15	14	14	14	14	14
16	269	150	100	75	51	38	30	25	22	19	18	16	15	15	14	14	13	12	12	11	11	11	11	16
18	267	154	96	72	54	39	30	24	20	18	16	15	14	13	12	12	11	10	9	9	9	9	9	18
20	273	154	96	68	54	41	30	24	20	17	15	14	12	12	11	10	9	8	8	8	7	7	7	20
22	267	150	98	67	51	43	32	25	20	17	14	13	12	11	10	9	8	7	7	7	6	6	6	22
24	267	150	100	67	50	40	33	25	20	17	14	12	11	10	9	9	7	7	6	6	5	5	5	24
26	270	153	97	68	49	39	33	27	21	17	14	12	11	10	9	8	7	6	5	5	5	5	5	26
28	267	152	96	70	49	38	31	27	22	17	14	12	11	9	9	8	6	5	5	5	4	4	4	28
30	267	150	96	68	50	38	30	26	23	18	15	12	11	9	8	8	6	5	5	4	4	4	4	30
32	269	150	97	67	51	38	30	25	22	19	15	13	11	9	8	7	6	5	4	4	4	3	3	32
34	267	152	98	67	51	38	30	24	21	19	16	13	11	9	8	7	6	5	4	4	3	3	3	34
36	267	151	96	67	50	39	30	24	20	18	16	13	11	10	8	7	6	4	4	3	3	3	3	36
38	268	150	96	67	49	39	30	24	20	17	15	14	12	10	9	7	5	4	4	3	3	3	3	38
40	267	150	96	68	49	38	30	24	20	17	15	14	12	10	9	8	5	4	4	3	3	3	2	40
42	267	151	97	67	49	38	31	24	20	17	15	13	12	10	9	8	5	4	3	3	3	2	2	42
44	267	150	97	67	49	38	31	25	20	17	14	13	12	11	9	8	5	4	3	3	3	2	2	44
46	267	150	96	67	50	38	30	25	20	17	14	13	11	10	9	8	6	4	3	3	2	2	2	46
46	267	150	96	67	50	38	30	25	20	17	14	12	11	10	9	8	6	4	3	3	2	2	2	48

TABLE 6-8. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	902	543	414	353	320	299	286	277	270	265	262	259	256	254	253	251	249	246	245	245	244	243	243	6
8	1017	507	337	261	222	199	184	173	166	161	157	154	151	149	148	146	143	141	140	139	139	138	138	8
10	921	548	325	230	183	155	138	127	119	113	109	106	103	101	99	98	95	93	91	91	90	89	89	10
12	902	543	343	226	168	136	116	103	95	88	84	80	77	75	73	72	68	66	65	64	63	63	62	12
14	940	512	363	235	166	128	105	91	81	74	69	65	62	59	57	56	53	50	49	48	47	47	46	14
16	907	507	337	254	171	127	101	84	73	65	60	55	52	50	48	46	42	40	39	38	37	37	36	16
18	902	521	326	241	182	130	100	81	69	60	54	49	46	43	41	39	36	33	32	31	30	29	29	18
20	921	518	325	230	183	137	103	81	67	58	51	46	42	39	36	35	31	28	27	26	25	24	24	20
22	903	508	331	226	173	144	107	83	67	56	49	43	39	36	33	31	27	25	23	22	21	21	20	22
24	902	507	337	226	168	136	113	86	68	56	48	42	37	34	31	29	25	22	20	19	18	18	17	24
26	911	515	326	229	166	131	110	90	70	57	48	41	36	33	30	27	23	20	18	17	16	16	15	26
28	901	512	324	235	166	128	105	91	73	59	49	41	36	32	29	26	21	18	17	15	15	14	14	28
30	902	507	325	230	168	127	102	87	76	61	50	42	36	32	28	26	20	17	15	14	13	13	12	30
32	907	507	328	227	171	127	101	84	73	64	51	43	36	32	28	25	20	16	14	13	12	11	11	32
34	901	512	330	225	171	128	100	82	71	63	53	44	37	32	28	25	19	16	14	12	11	11	10	34
36	902	509	326	226	168	130	100	81	69	60	54	46	38	33	28	25	19	15	13	11	11	10	9	36
38	904	506	324	227	166	132	101	81	68	59	52	47	39	33	29	25	18	15	12	11	10	9	9	38
40	900	507	325	230	165	130	103	81	67	58	51	46	41	34	29	26	18	14	12	10	9	9	8	40
42	902	511	327	227	166	128	104	82	67	57	50	44	40	35	30	26	18	14	12	10	9	8	8	42
44	903	508	327	226	167	127	103	83	67	56	49	43	39	36	31	27	19	14	11	10	9	8	7	44
46	900	506	325	225	169	127	102	84	68	56	48	43	38	35	32	27	19	14	11	10	8	8	7	46
48	902	507	324	226	168	127	101	84	68	56	48	42	37	34	31	28	19	14	11	9	8	7	7	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	2138	1287	980	837	758	710	678	656	641	629	620	613	608	603	599	596	589	584	581	580	578	576	576	6
8	2410	1203	798	620	526	471	435	411	394	382	372	365	359	354	350	347	340	335	332	330	328	327	326	8
10	2184	1299	770	546	433	368	328	301	282	269	258	250	244	239	235	232	224	220	217	215	213	212	211	10
12	2138	1287	813	535	398	322	275	245	224	209	198	189	183	177	173	170	162	157	154	152	150	149	148	12
14	2229	1212	860	557	393	303	250	215	192	175	163	154	146	141	136	133	125	120	116	114	112	111	110	14
16	2149	1203	798	602	406	301	239	200	173	155	142	131	124	118	113	109	101	95	92	90	88	87	86	16
18	2138	1235	772	572	432	309	238	193	163	143	128	117	109	102	97	93	84	79	75	73	71	70	69	18
20	2184	1229	770	546	433	325	243	192	159	137	120	108	99	92	86	82	73	67	64	61	59	58	57	20
22	2139	1203	765	535	410	340	253	196	159	134	116	103	93	85	79	74	64	59	55	52	50	49	48	22
24	2138	1203	798	535	398	322	268	203	162	134	114	99	89	80	74	69	58	52	48	46	44	42	41	24
26	2160	1221	778	542	392	310	260	213	167	136	114	98	86	77	71	65	54	47	43	41	39	37	36	26
28	2136	1212	769	557	393	303	250	215	174	139	115	98	85	76	68	62	51	44	39	37	35	33	32	28
30	2138	1201	770	546	397	300	243	206	181	144	118	99	86	75	67	61	48	41	36	33	31	30	29	30
32	2149	1203	778	537	406	301	239	200	173	151	122	101	86	75	66	60	46	39	34	31	29	27	26	32
34	2135	1215	782	534	405	304	237	195	168	148	127	104	88	76	67	59	45	37	32	29	27	25	24	34
36	2138	1206	772	535	398	309	238	193	163	143	128	108	90	77	67	59	44	36	31	27	25	23	22	36
38	2143	1200	768	539	394	313	240	192	161	139	124	112	93	79	68	60	44	35	29	26	23	22	20	38
40	2134	1203	770	546	392	307	243	192	159	137	120	108	96	81	70	61	44	34	28	25	22	21	19	40
42	2138	1211	775	539	393	303	248	194	159	135	118	105	96	84	71	62	44	34	28	24	21	19	18	42
44	2139	1203	775	535	395	301	245	196	159	134	116	103	93	85	74	63	44	33	27	23	20	19	17	44
46	2134	1200	770	533	400	300	241	199	160	133	115	101	90	83	76	65	44	33	27	23	20	18	16	46
48	2138	1203	768	535	398	301	239	200	162	134	114	99	89	80	74	67	45	33	27	22	19	17	16	48

TABLE 6-8. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4176	2514	1915	1634	1480	1386	1325	1282	1251	1229	1211	1197	1187	1178	1170	1164	1151	1141	1136	1132	1130	1125	1124	6
8	4707	2349	1559	1210	1027	919	850	803	770	745	726	712	701	691	683	677	663	655	649	645	641	639	637	8
10	4266	2538	1503	1066	846	719	641	588	551	525	505	489	477	467	459	453	438	429	423	419	416	413	411	10
12	4176	2514	1588	1044	777	628	538	479	438	408	387	370	357	347	338	331	316	307	301	297	293	291	289	12
14	4353	2368	1680	1088	767	592	487	420	374	342	318	300	286	275	266	259	243	234	227	223	220	217	215	14
16	4197	2349	1559	1177	793	587	466	390	339	303	276	257	242	230	220	212	196	186	180	175	172	169	167	16
18	4176	2413	1508	1117	843	603	464	377	319	279	251	229	213	200	190	182	164	154	147	142	139	137	135	18
20	4266	2399	1503	1066	846	634	475	376	311	267	235	211	194	180	169	160	142	131	124	119	116	113	111	20
22	4178	2350	1533	1045	802	665	495	383	311	261	226	200	181	166	155	145	126	115	107	102	99	96	94	22
24	4176	2349	1559	1044	777	628	523	397	316	261	222	194	173	157	145	134	114	102	94	89	86	83	81	24
26	4219	2384	1519	1060	766	605	508	416	326	265	222	192	169	151	138	127	105	93	85	79	75	73	71	26
28	4172	2368	1502	1088	767	592	487	420	339	272	225	192	167	148	133	122	99	85	77	72	68	65	63	28
30	4176	2346	1503	1066	776	586	474	402	354	282	231	194	167	147	131	118	94	80	71	65	61	58	56	30
32	4197	2349	1520	1049	793	587	466	390	338	294	238	198	169	147	130	117	90	76	66	60	56	53	51	32
34	4169	2372	1527	1042	792	593	463	382	327	289	247	204	172	148	130	116	88	72	63	56	52	49	47	34
36	4176	2356	1508	1044	777	603	464	377	319	279	251	211	176	151	131	116	86	70	60	53	49	45	43	36
38	4185	2345	1501	1053	769	612	468	375	314	272	242	219	182	154	133	117	85	68	57	51	46	42	40	38
40	4168	2349	1503	1066	766	600	475	376	311	267	235	211	188	159	136	119	85	67	56	48	44	40	37	40
42	4176	2366	1514	1052	767	592	484	379	310	263	230	205	187	164	140	121	85	66	54	47	42	38	35	42
44	4178	2350	1514	1045	772	588	478	383	311	261	226	200	181	166	144	124	86	65	53	45	40	36	34	44
46	4168	2344	1504	1042	781	586	471	389	313	260	224	197	177	161	148	127	87	65	52	44	39	35	32	46
48	4176	2349	1500	1044	777	587	466	390	316	261	222	194	173	157	145	131	88	65	52	43	38	34	31	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7200	4344	3308	2823	2558	2395	2289	2215	2162	2123	2092	2069	2050	2035	2022	2012	1989	1971	1962	1956	1952	1945	1943	6
8	7200	4059	2694	2091	1775	1588	1469	1388	1330	1288	1255	1230	1211	1194	1181	1170	1147	1131	1121	1114	1108	1104	1101	8
10	7200	4385	2598	1843	1461	1243	1107	1016	953	907	872	845	824	807	794	782	757	742	731	724	718	714	711	10
12	7200	4344	2744	1804	1343	1086	929	827	757	706	668	639	617	599	584	572	547	531	520	513	507	503	499	12
14	7200	4092	2903	1880	1325	1023	842	726	647	591	550	519	494	475	460	447	420	404	393	385	379	375	372	14
16	7200	4059	2694	2033	1370	1015	806	674	585	523	478	444	418	397	381	367	339	322	311	303	297	292	289	16
18	7200	4169	2605	1931	1457	1042	802	651	552	483	433	396	368	345	328	314	284	266	254	246	240	236	232	18
20	7200	4146	2598	1843	1461	1096	820	649	538	461	406	365	335	311	292	277	246	227	214	206	200	196	192	20
22	7200	4061	2648	1805	1385	1149	855	662	537	451	391	346	313	287	267	251	218	198	185	176	170	166	162	22
24	7200	4059	2694	1804	1343	1086	904	686	546	451	384	336	299	272	250	232	197	176	163	154	148	143	139	24
26	7200	4119	2624	1831	1324	1046	878	719	563	458	384	331	292	261	238	219	182	160	146	137	130	126	122	26
28	7200	4092	2595	1880	1325	1023	842	726	586	470	389	331	288	256	230	211	171	148	133	124	117	112	108	28
30	7200	4054	2598	1843	1341	1013	819	695	611	487	399	335	289	253	226	205	162	138	123	113	106	101	97	30
32	7200	4059	2626	1813	1370	1015	806	674	585	508	411	342	292	254	224	201	156	131	115	104	97	92	88	32
34	7200	4099	2638	1801	1368	1025	800	659	565	500	427	352	297	256	225	200	152	125	108	97	90	84	80	34
36	7200	4071	2605	1804	1343	1042	802	651	552	483	433	364	305	261	227	200	149	121	103	92	84	78	74	36
38	7200	4051	2593	1819	1328	1057	808	648	543	470	418	378	314	267	230	202	148	117	99	87	79	73	69	38
40	7200	4059	2598	1843	1323	1037	820	649	538	461	406	365	325	274	235	205	147	115	96	84	75	69	65	40
42	7200	4088	2617	1819	1325	1023	836	654	536	455	397	355	323	283	241	209	147	114	94	81	72	66	61	42
44	7200	4061	2616	1805	1334	1015	825	662	537	451	391	346	313	287	248	214	148	113	92	78	69	63	58	44
46	7200	4051	2598	1800	1349	1013	814	673	540	450	387	340	305	279	256	219	150	113	90	76	67	60	55	46
48	7200	4059	2593	1804	1343	1015	806	674	546	451	384	336	299	272	250	226	152	113	90	75	65	58	53	48

TABLE 6-8. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8400	6898	5254	4483	4062	3803	3635	3518	3434	3371	3322	3285	3256	3231	3211	3194	3158	3130	3116	3106	3100	3088	3085	6
8	8400	6445	4278	3321	2818	2522	2332	2204	2113	2045	1993	1954	1923	1896	1875	1858	1821	1797	1781	1769	1760	1753	1748	8
10	8400	6963	4125	2926	2320	1974	1758	1614	1513	1440	1385	1342	1309	1282	1260	1242	1203	1178	1161	1150	1140	1134	1129	10
12	8400	6898	4358	2865	2132	1725	1476	1313	1201	1121	1061	1015	979	951	928	909	868	843	826	814	805	799	793	12
14	8400	6498	4611	2986	2105	1624	1337	1153	1027	938	873	823	785	755	730	710	668	641	624	612	602	596	590	14
16	8400	6445	4278	3229	2175	1611	1280	1070	929	830	758	704	663	630	604	583	539	511	493	481	471	464	459	16
18	8400	6621	4137	3066	2314	1655	1273	1034	876	766	687	629	584	549	521	498	451	423	404	391	382	375	369	18
20	8400	6584	4125	2926	2320	1741	1302	1031	854	732	644	580	531	493	464	440	390	360	341	327	318	310	305	20
22	8400	6449	4206	2866	2200	1824	1358	1051	852	717	620	550	497	456	424	398	346	314	294	280	270	263	257	22
24	8400	6445	4278	2865	2132	1725	1435	1089	867	716	610	533	475	431	397	369	313	280	259	245	235	227	221	24
26	8400	6541	4167	2907	2103	1661	1394	1142	894	727	610	526	463	415	378	348	289	254	232	218	207	199	194	26
28	8400	6498	4121	2986	2105	1624	1337	1153	931	747	618	526	458	406	366	334	271	235	212	196	185	178	172	28
30	8400	6437	4125	2926	2130	1609	1301	1104	971	774	633	532	458	402	359	325	258	219	195	179	168	160	154	30
32	8400	6445	4170	2879	2175	1611	1280	1070	929	807	653	544	463	403	356	320	248	208	182	166	154	146	139	32
34	8400	6509	4189	2860	2172	1627	1271	1047	898	794	678	559	472	407	357	318	241	198	172	155	143	134	128	34
36	8400	6464	4137	2865	2132	1655	1273	1034	876	766	687	578	484	414	360	318	237	192	164	146	133	125	118	36
38	8400	6434	4118	2889	2109	1679	1284	1029	862	746	663	601	499	423	366	321	234	187	158	139	126	117	110	38
40	8400	6445	4125	2926	2101	1646	1302	1031	854	732	644	580	517	435	373	326	233	183	152	133	119	110	103	40
42	8400	6492	4155	2888	2105	1624	1327	1039	851	722	630	563	512	449	383	332	234	180	149	128	114	104	97	42
44	8400	6449	4153	2866	2119	1612	1311	1051	852	717	620	550	497	456	394	339	235	179	146	124	110	100	92	44
46	8400	6433	4126	2859	2143	1608	1292	1068	858	715	614	540	485	442	407	349	238	179	144	121	106	96	88	46
48	8400	6445	4117	2865	2132	1611	1280	1070	867	716	610	533	475	431	397	359	242	179	142	119	103	92	84	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9600	9600	7842	6692	6063	5677	5426	5251	5125	5032	4959	4904	4860	4823	4794	4768	4714	4673	4651	4637	4628	4609	4605	6
8	9600	9600	6386	4957	4206	3764	3481	3290	3154	3052	2975	2916	2870	2831	2799	2773	2718	2682	2658	2640	2627	2616	2609	8
10	9600	9600	6158	4368	3464	2946	2624	2409	2259	2150	2067	2003	1953	1913	1881	1854	1795	1759	1734	1717	1702	1693	1685	10
12	9600	9600	6505	4276	3183	2574	2203	1960	1793	1673	1584	1516	1462	1419	1385	1356	1296	1258	1232	1215	1202	1192	1184	12
14	9600	9600	6882	4457	3142	2425	1996	1721	1534	1401	1303	1229	1172	1127	1090	1060	997	957	931	913	899	889	881	14
16	9600	9600	6386	4820	3247	2405	1910	1597	1387	1239	1132	1052	990	941	902	870	804	763	736	718	704	693	685	16
18	9600	9600	6176	4576	3454	2471	1900	1544	1308	1144	1026	938	871	819	777	744	674	631	603	583	569	559	551	18
20	9600	9600	6158	4368	3464	2598	1944	1539	1274	1092	962	866	793	737	692	656	582	537	508	488	474	463	455	20
22	9600	9600	6278	4279	3284	2723	2027	1569	1272	1070	926	821	742	681	633	594	516	469	439	418	404	393	384	22
24	9600	9600	6386	4276	3183	2574	2142	1626	1294	1069	911	796	710	644	592	551	467	418	387	366	350	339	331	24
26	9600	9600	6221	4340	3140	2479	2080	1705	1334	1085	911	785	691	620	564	520	431	380	347	325	309	298	289	26
28	9600	9600	6151	4457	3142	2425	1996	1721	1390	1114	923	785	683	606	546	499	405	350	316	293	277	265	256	28
30	9600	9600	6158	4368	3179	2402	1941	1648	1449	1155	945	795	684	601	536	485	385	327	292	268	251	239	230	30
32	9600	9600	6224	4298	3247	2405	1910	1597	1386	1205	975	812	692	601	532	478	370	310	272	247	230	218	208	32
34	9600	9600	6253	4269	3243	2429	1897	1563	1340	1185	1013	835	705	607	533	474	360	296	257	231	213	200	191	34
36	9600	9600	6176	4276	3183	2471	1900	1544	1308	1144	1026	863	723	618	538	475	354	286	245	218	199	186	176	36
38	9600	9600	6146	4312	3149	2506	1916	1537	1286	1114	990	897	745	632	546	479	350	278	235	207	188	174	164	38
40	9600	9600	6158	4368	3136	2457	1944	1539	1274	1092	962	866	771	650	557	486	348	273	228	198	178	164	153	40
42	9600	9600	6203	4311	3142	2425	1981	1551	1270	1078	941	841	765	670	572	495	349	269	222	191	170	156	145	42
44	9600	9600	6200	4279	3163	2407	1957	1569	1272	1070	926	821	742	681	588	507	351	267	217	185	164	149	137	44
46	9600	9600	6159	4268	3199	2401	1929	1595	1280	1067	916	806	724	660	607	520	355	267	214	181	158	143	131	46
48	9600	9600	6145	4276	3183	2405	1910	1597	1294	1069	911	796	710	644	592	536	361	267	212	177	154	138	126	48

TABLE 6-8. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

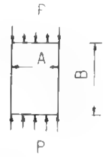
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10800	10800	10800	9529	8632	8084	7725	7477	7298	7165	7061	6983	6920	6867	6825	6789	6712	6653	6623	6602	6589	6563	6556	6
8	10800	10800	9093	7058	5989	5360	4957	4684	4490	4346	4236	4152	4086	4031	3986	3948	3869	3819	3785	3759	3740	3725	3715	8
10	10800	10800	8767	6219	4932	4195	3737	3430	3216	3061	2943	2852	2781	2724	2678	2639	2556	2504	2469	2444	2423	2411	2400	10
12	10800	10800	9261	6088	4532	3665	3157	2791	2553	2382	2255	2158	2082	2021	1972	1931	1845	1791	1755	1730	1711	1697	1685	12
14	10800	10800	9799	6347	4473	3453	2842	2450	2183	1994	1856	1750	1669	1604	1552	1509	1419	1363	1326	1300	1280	1266	1255	14
16	10800	10800	9093	6863	4623	3425	2720	2273	1974	1765	1612	1497	1409	1340	1284	1239	1145	1086	1048	1022	1002	987	976	16
18	10800	10800	8794	6516	4917	3518	2706	2198	1862	1629	1461	1336	1241	1166	1107	1059	959	898	858	831	811	796	785	18
20	10800	10800	8767	6219	4932	3700	2768	2192	1814	1555	1370	1233	1129	1049	985	934	829	765	724	695	675	660	648	20
22	10800	10800	8938	6092	4676	3878	2886	2235	1811	1523	1319	1169	1056	969	901	846	735	668	625	596	575	559	547	22
24	10800	10800	9093	6088	4532	3665	3050	2315	1842	1522	1297	1133	1010	916	843	784	665	596	551	520	499	483	471	24
26	10800	10800	8857	6179	4470	3530	2962	2427	1899	1545	1297	1118	984	882	803	740	614	541	494	463	440	424	411	26
28	10800	10800	8759	6347	4473	3453	2842	2450	1979	1587	1314	1118	973	863	778	711	576	499	450	417	394	377	365	28
30	10800	10800	8767	6219	4526	3420	2764	2346	2064	1644	1346	1132	974	855	763	691	548	466	415	381	357	340	327	30
32	10800	10800	8863	6119	4623	3425	2720	2273	1974	1716	1389	1156	985	856	757	680	527	441	388	352	328	310	296	32
34	10800	10800	8903	6079	4617	3459	2702	2226	1909	1688	1442	1189	1003	865	758	675	513	422	366	329	304	285	271	34
36	10800	10800	8793	6088	4531	3518	2706	2198	1862	1629	1461	1229	1029	880	765	676	504	407	349	310	284	265	251	36
38	10800	10800	8751	6139	4483	3568	2729	2188	1832	1586	1409	1277	1061	900	777	682	498	396	335	295	267	248	233	38
40	10800	10800	8767	6219	4465	3498	2768	2192	1814	1555	1370	1233	1098	925	794	692	496	389	324	282	254	234	219	40
42	10800	10800	8831	6138	4473	3453	2821	2208	1808	1534	1340	1197	1089	954	814	705	497	384	316	272	243	222	206	42
44	10800	10800	8827	6092	4503	3427	2786	2235	1811	1523	1319	1169	1056	969	837	722	500	381	310	264	233	212	196	44
46	10800	10800	8769	6076	4554	3418	2746	2271	1823	1519	1305	1148	1030	940	864	741	506	380	305	258	226	203	187	46
48	10800	10800	8750	6088	4532	3425	2720	2273	1842	1522	1297	1133	1010	916	843	763	514	381	302	253	219	196	179	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	12000	12000	12000	12000	11841	11088	10597	10256	10010	9829	9686	9579	9493	9420	9363	9313	9207	9127	9085	9057	9039	9003	8993	6
8	12000	12000	12000	9682	8215	7353	6799	6425	6159	5961	5811	5695	5606	5529	5467	5416	5308	5238	5192	5157	5131	5110	5096	8
10	12000	12000	12000	8531	6765	5755	5126	4706	4412	4199	4037	3912	3815	3737	3674	3621	3507	3435	3386	3353	3324	3308	3292	10
12	12000	12000	12000	8352	6216	5028	4303	3829	3503	3268	3094	2960	2856	2772	2705	2649	2531	2457	2407	2373	2347	2328	2312	12
14	12000	12000	12000	8706	6136	4736	3899	3361	2995	2736	2545	2401	2289	2200	2129	2070	1946	1870	1819	1783	1756	1736	1722	14
16	12000	12000	12000	9414	6341	4698	3731	3118	2708	2421	2211	2054	1933	1838	1762	1700	1571	1490	1438	1401	1374	1354	1339	16
18	12000	12000	12000	8938	6745	4826	3712	3016	2554	2235	2004	1833	1702	1599	1518	1452	1316	1232	1177	1140	1112	1092	1076	18
20	12000	12000	12000	8531	6765	5075	3797	3007	2489	2133	1879	1691	1549	1439	1351	1281	1137	1050	993	954	926	905	889	20
22	12000	12000	12000	8357	6414	5319	3959	3065	2485	2089	1809	1604	1449	1330	1236	1161	1008	916	857	817	788	767	751	22
24	12000	12000	12000	8352	6216	5028	4184	3176	2527	2088	1779	1554	1386	1257	1156	1076	913	817	755	714	684	662	646	24
26	12000	12000	12000	8476	6132	4842	4063	3329	2605	2119	1779	1533	1350	1211	1102	1016	843	742	678	634	604	581	564	26
28	12000	12000	12000	8706	6136	4736	3899	3360	2714	2176	1803	1534	1335	1184	1067	975	790	684	617	572	541	518	500	28
30	12000	12000	12000	8531	6209	4692	3792	3218	2831	2256	1846	1552	1336	1173	1047	948	752	639	570	523	490	467	449	30
32	12000	12000	12000	8394	6341	4698	3731	3118	2708	2353	1905	1585	1351	1174	1039	933	724	605	532	483	450	425	407	32
34	12000	12000	12000	8338	6333	4745	3706	3053	2618	2315	1978	1630	1376	1186	1040	926	704	579	502	451	416	391	372	34
36	12000	12000	12000	8352	6216	4826	3712	3016	2554	2235	2004	1686	1412	1206	1050	928	691	559	478	425	389	363	344	36
38	12000	12000	12000	8422	6150	4894	3743	3001	2513	2175	1933	1752	1455	1234	1066	936	683	544	459	404	367	340	320	38
40	12000	12000	12000	8531	6125	4799	3797	3007	2489	2133	1879	1691	1506	1269	1089	949	681	533	445	387	348	320	300	40
42	12000	12000	12000	8420	6136	4736	3869	3029	2480	2105	1838	1642	1494	1309	1116	967	682	526	433	373	333	304	283	42
44	12000	12000	12000	8357	6177	4701	3822	3065	2485	2089	1809	1604	1449	1330	1149	990	686	522	425	362	320	290	268	44
46	12000	12000	12000	8335	6247	4689	3767	3115	2501	2084	1790	1575	1414	1290	1185	1016	694	521	419	353	310	279	256	46
48	12000	12000	12000	8352	6216	4698	3731	3118	2527	2088	1779	1554	1386	1257	1156	1046	705	522	415	346	301	269	246	48

TABLE 6-9. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED



PHYSICAL CONSTANTS:

$E_X = 1.81\times10^6$ PSI

$E_Y = 1.54\times10^6$ PSI

$G_{XY} = 0.45\times10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.19$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	68	37	23	17	14	13	12	11	11	10	10	10	10	10	10	9	9	9	9	9	9	9	9	6
8	64	38	25	16	12	10	8	7	7	7	6	6	6	6	6	6	5	5	5	5	5	5	5	8
10	65	36	25	18	12	9	7	6	5	5	5	4	4	4	4	4	4	4	3	3	3	3	3	10
12	64	37	23	17	13	9	7	6	5	4	4	4	3	3	3	3	3	3	2	2	2	2	2	12
14	64	36	23	16	13	10	7	6	5	4	3	3	3	3	3	2	2	2	2	2	2	2	2	14
16	64	36	24	16	12	10	8	6	5	4	3	3	3	2	2	2	2	2	2	1	1	1	1	16
18	64	36	23	16	12	9	8	7	5	4	3	3	3	2	2	2	2	1	1	1	1	1	1	18
20	64	36	23	16	12	9	7	6	5	4	4	3	3	2	2	2	1	1	1	1	1	1	1	20
22	63	36	23	16	12	9	7	6	5	5	4	3	3	2	2	2	1	1	1	1	1	1	1	22
24	64	36	23	16	12	9	7	6	5	4	4	3	3	2	2	2	1	1	1	1	1	1	1	24
26	63	36	23	16	12	9	7	6	5	4	4	3	3	2	2	2	1	1	1	1	1	1	1	26
28	64	36	23	16	12	9	7	6	5	4	3	3	3	3	2	2	1	1	1	1	1	1	1	28
30	63	36	23	16	12	9	7	6	5	4	3	3	3	3	2	2	1	1	1	1	1	1	1	30
32	64	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	1	1	1	1	1	1	0	32
34	63	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	1	1	1	1	1	0	0	34
36	64	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	1	1	1	1	1	0	0	36
38	63	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	2	1	1	1	1	0	0	38
40	63	36	23	16	12	9	7	6	5	4	4	3	3	2	2	2	1	1	1	1	1	0	0	40
42	63	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	1	1	1	1	1	0	0	42
44	63	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	1	1	1	1	1	0	0	44
46	63	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	1	1	1	1	1	0	0	46
48	63	36	23	16	12	9	7	6	5	4	3	3	3	2	2	2	1	1	1	1	1	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	546	297	183	137	114	101	93	88	85	82	81	79	78	77	76	76	75	74	73	73	73	72	72	6
8	509	307	197	127	94	77	67	60	56	53	50	49	47	46	46	45	43	43	42	42	41	41	41	8
10	518	285	197	141	95	71	58	49	44	40	37	35	34	32	32	31	29	28	28	27	27	27	27	10
12	509	297	183	137	106	74	57	46	39	34	31	28	27	25	24	23	22	21	20	20	19	19	19	12
14	511	287	185	128	100	82	60	46	38	32	28	25	23	21	20	19	17	16	15	15	14	14	14	14
16	509	286	190	127	94	77	66	49	39	32	27	24	21	19	18	17	14	13	12	12	11	11	11	16
18	508	290	183	132	93	73	61	53	41	33	27	23	20	18	16	15	13	11	10	10	9	9	9	18
20	509	285	183	130	95	71	58	49	44	35	28	24	20	18	16	14	12	10	9	8	8	8	7	20
22	507	288	187	127	98	72	56	47	41	36	30	25	21	18	16	14	11	9	8	7	7	7	6	22
24	509	286	183	127	94	74	57	46	39	34	31	26	22	19	16	14	10	9	7	7	6	6	6	24
26	507	285	183	130	93	74	58	46	38	33	29	26	23	19	17	14	10	8	7	6	6	5	5	26
28	509	287	185	128	93	72	59	46	38	32	28	25	23	21	17	15	10	8	7	6	5	5	4	28
30	507	285	183	127	95	71	58	47	38	32	27	24	22	20	18	16	11	8	6	5	5	4	4	30
32	509	286	182	127	94	72	57	47	39	32	27	24	21	19	18	16	11	8	6	5	5	4	4	32
34	506	286	184	129	93	73	56	46	40	32	27	23	21	19	17	16	11	8	6	5	4	4	4	34
36	508	285	183	127	93	73	57	46	39	33	27	23	20	18	16	15	12	8	6	5	4	4	3	36
38	506	286	182	127	94	72	57	46	38	33	28	23	20	18	16	15	12	8	6	5	4	4	3	38
40	508	285	183	127	94	71	58	46	38	32	28	24	20	18	16	14	12	9	6	5	4	4	3	40
42	506	285	183	128	93	71	57	46	38	32	28	24	21	18	16	14	11	9	7	5	4	4	3	42
44	507	285	182	127	93	72	56	47	38	32	27	24	21	18	16	14	11	9	7	5	4	4	3	44
46	507	285	183	127	93	72	56	46	38	32	27	24	21	18	16	14	11	9	7	5	4	4	3	46
48	507	286	183	127	94	71	57	46	39	32	27	24	21	19	16	14	10	9	7	5	4	4	3	48

TABLE 6-9. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	1844	1002	618	461	384	341	315	298	286	278	272	267	263	260	258	256	252	249	247	246	245	244	244	6
8	1716	1037	665	429	318	259	225	202	188	177	170	164	160	156	154	151	147	144	142	141	140	139	138	8
10	1750	962	664	475	321	240	194	166	147	135	125	119	114	110	106	104	99	96	94	92	91	90	90	10
12	1716	1002	618	461	356	250	191	154	131	115	104	96	90	85	82	79	73	70	67	66	65	64	63	12
14	1725	970	624	431	339	278	202	156	127	108	94	85	78	72	68	65	58	54	52	50	49	48	47	14
16	1716	965	641	429	318	259	222	166	131	107	91	80	71	65	60	56	49	44	42	40	39	38	37	16
18	1716	980	618	445	314	245	205	180	139	111	92	79	69	61	56	51	43	38	35	33	32	31	30	18
20	1716	962	618	437	321	240	194	166	147	119	96	80	69	60	54	49	39	34	30	28	27	26	25	20
22	1712	971	632	428	330	243	190	158	137	123	102	84	71	61	53	48	37	31	27	25	23	22	22	22
24	1716	965	618	429	318	250	191	154	131	115	104	89	74	63	54	48	35	29	25	22	21	20	19	24
26	1711	963	616	438	314	249	195	154	128	110	98	89	78	66	56	49	35	28	23	21	19	18	17	26
28	1716	970	624	431	315	243	201	156	127	108	94	85	78	69	59	50	35	27	22	19	17	16	15	28
30	1710	962	618	427	321	240	194	160	128	107	92	82	74	68	62	53	36	27	22	18	16	15	14	30
32	1716	965	616	429	318	241	191	160	131	107	91	80	71	65	60	56	37	27	21	18	16	14	13	32
34	1709	964	620	435	315	245	190	156	134	109	91	79	70	63	57	53	38	27	21	17	15	13	12	34
36	1716	962	618	429	314	245	191	154	131	111	92	79	69	61	56	51	40	28	21	17	15	13	12	36
38	1710	967	615	427	316	242	193	154	129	112	94	79	68	60	54	50	41	29	21	17	14	12	11	38
40	1714	962	618	429	318	240	194	154	127	109	96	80	69	60	54	49	39	30	22	17	14	12	11	40
42	1710	964	618	431	315	241	192	156	127	108	94	82	69	60	53	48	38	31	22	17	14	12	10	42
44	1712	963	615	428	314	243	190	158	128	107	93	82	71	61	53	48	37	31	23	18	14	12	10	44
46	1710	962	617	427	315	243	190	156	129	107	92	81	72	62	54	47	36	30	24	18	14	12	10	46
48	1711	965	618	429	317	241	191	154	131	107	91	80	71	63	54	48	35	29	25	18	15	12	10	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	3950	2374	1464	1093	911	809	747	707	679	659	644	633	624	617	611	607	597	589	586	583	581	578	577	6
8	3950	2459	1575	1017	755	615	532	480	445	420	402	389	379	371	364	359	348	341	337	334	331	329	328	8
10	3950	2280	1574	1125	760	570	461	393	349	319	297	281	269	260	252	246	234	226	222	218	216	214	213	10
12	3950	2374	1464	1093	845	594	452	366	311	273	247	228	213	202	194	187	173	165	160	156	153	152	150	12
14	3950	2300	1480	1022	803	658	478	370	301	256	224	201	184	171	161	153	137	128	123	119	116	114	112	14
16	3950	2288	1519	1017	755	615	527	394	310	254	216	189	169	154	142	133	115	105	99	95	92	90	88	16
18	3950	2323	1464	1055	745	581	486	426	330	264	218	186	163	145	132	121	101	90	83	79	75	73	72	18
20	3950	2280	1465	1037	760	570	461	393	349	281	228	190	163	142	127	115	92	80	72	67	64	62	60	20
22	3950	2302	1499	1015	782	576	451	375	325	291	242	199	167	144	126	113	87	73	65	59	56	53	51	22
24	3950	2288	1464	1017	755	594	452	366	311	273	247	211	175	148	128	113	84	68	59	53	49	47	45	24
26	3950	2282	1460	1039	745	589	462	365	303	262	233	212	186	155	133	115	83	65	55	49	45	42	40	26
28	3950	2300	1480	1022	747	575	475	370	301	256	224	201	184	164	139	119	83	64	53	46	41	38	36	28
30	3950	2280	1464	1013	760	570	461	380	304	253	218	193	175	161	147	125	84	63	51	44	39	35	33	30
32	3950	2288	1459	1017	755	572	453	380	310	254	216	189	169	154	142	132	87	64	50	42	37	33	31	32
34	3950	2284	1470	1030	746	580	450	371	319	258	216	186	165	149	136	126	90	64	50	41	35	32	29	34
36	3950	2280	1464	1017	745	581	452	366	311	264	218	186	163	145	132	121	94	66	50	41	35	30	27	36
38	3950	2292	1459	1013	750	573	458	365	305	265	222	187	162	143	129	118	96	68	51	41	34	29	26	38
40	3950	2280	1465	1017	755	570	461	366	302	259	228	190	163	142	127	115	92	70	52	41	34	29	25	40
42	3950	2284	1464	1022	747	571	454	370	301	256	224	194	164	143	126	114	89	73	53	41	33	28	25	42
44	3950	2283	1459	1015	744	576	451	375	303	254	220	195	167	144	126	113	87	73	55	42	34	28	24	44
46	3950	2280	1462	1013	746	577	450	369	305	253	217	191	171	146	127	113	85	70	56	43	34	28	24	46
48	3950	2288	1464	1017	751	572	452	366	310	254	216	189	169	148	128	113	84	68	59	44	34	28	24	48

TABLE 6-9. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4940	4637	2860	2134	1779	1580	1460	1381	1326	1287	1258	1236	1219	1205	1194	1185	1165	1151	1144	1138	1135	1130	1128	6
8	4940	4803	3077	1987	1474	1201	1039	937	869	821	786	760	740	724	711	701	680	666	658	651	647	643	641	8
10	4940	4452	3074	2197	1485	1113	900	768	682	623	580	549	525	507	493	481	457	442	433	426	421	418	415	10
12	4940	4637	2860	2134	1650	1159	883	715	607	534	482	445	417	395	378	365	338	322	312	305	300	296	293	12
14	4940	4492	2891	1996	1568	1285	934	723	589	499	437	392	359	334	314	299	268	250	239	232	226	223	220	14
16	4940	4470	2966	1986	1474	1201	1029	769	605	497	422	369	330	300	278	260	225	205	193	185	179	175	172	16
18	4940	4537	2860	2061	1454	1134	949	833	645	515	426	364	318	284	257	237	198	176	162	153	147	143	140	18
20	4940	4452	2861	2025	1485	1113	900	768	682	549	445	371	318	278	248	225	180	156	141	131	125	120	117	20
22	4940	4496	2927	1982	1527	1124	881	732	635	569	474	388	326	281	247	220	170	142	126	116	109	104	100	22
24	4940	4469	2860	1986	1474	1159	883	715	607	534	482	413	342	290	251	221	164	133	115	104	97	91	87	24
26	4940	4456	2852	2029	1455	1151	902	713	592	511	455	414	363	304	259	225	162	128	108	96	88	82	78	26
28	4940	4492	2891	1996	1459	1123	929	723	589	499	437	392	359	321	271	233	162	125	103	90	81	75	70	28
30	4940	4452	2860	1979	1485	1113	900	742	593	495	426	378	342	314	287	244	165	124	100	85	76	69	64	30
32	4940	4470	2850	1986	1474	1117	885	742	605	497	422	369	330	300	278	257	170	124	98	82	72	65	60	32
34	4940	4462	2871	2012	1457	1133	879	724	623	504	422	364	322	290	266	247	176	126	98	80	69	62	56	34
36	4940	4454	2860	1986	1454	1134	883	715	607	515	426	364	318	284	257	237	183	129	98	79	67	59	54	36
38	4940	4477	2849	1979	1464	1119	894	712	596	518	434	366	317	280	252	230	188	133	99	79	66	58	51	38
40	4940	4452	2861	1986	1474	1113	900	715	590	506	445	371	318	278	248	225	180	137	101	79	66	56	50	40
42	4940	4461	2860	1996	1459	1115	887	723	589	499	437	379	321	279	247	222	174	143	104	80	65	55	49	42
44	4940	4459	2849	1982	1454	1124	881	732	591	495	429	382	326	281	247	220	170	142	107	82	66	55	48	44
46	4940	4453	2855	1979	1457	1127	880	721	597	495	424	374	333	285	248	220	166	137	110	83	66	55	47	46
48	4940	4469	2860	1986	1467	1117	883	715	605	497	422	369	330	290	251	221	164	133	114	85	67	55	47	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7200	7200	4942	3688	3074	2731	2522	2386	2292	2224	2174	2136	2106	2082	2063	2047	2013	1989	1976	1967	1961	1952	1949	6
8	7200	7200	5316	3433	2548	2075	1796	1620	1502	1419	1358	1313	1279	1251	1229	1211	1174	1151	1137	1126	1118	1112	1107	8
10	7200	7200	5311	3797	2565	1923	1555	1328	1179	1076	1003	949	908	876	851	831	789	764	748	737	728	723	718	10
12	7200	7200	4942	3688	2851	2003	1526	1236	1048	922	833	768	720	683	654	631	584	556	538	527	518	512	507	12
14	7200	7200	4995	3450	2710	2220	1613	1249	1017	862	755	677	620	577	543	516	463	433	413	401	391	385	380	14
16	7200	7200	5125	3433	2548	2075	1779	1329	1046	858	729	637	569	519	480	449	389	355	334	320	310	303	298	16
18	7200	7200	4942	3561	2513	1960	1639	1439	1115	890	737	628	549	490	445	410	342	303	280	265	255	247	242	18
20	7200	7200	4943	3499	2565	1923	1555	1328	1179	949	768	641	549	481	429	389	311	269	244	227	216	208	202	20
22	7200	7200	5052	3425	2638	1942	1522	1264	1097	983	818	671	564	486	426	381	293	246	218	200	188	179	173	22
24	7200	7200	4942	3433	2548	2003	1526	1236	1048	922	833	713	591	501	433	381	283	231	200	180	167	158	151	24
26	7200	7200	4928	3505	2513	1988	1558	1232	1024	884	786	715	626	524	448	389	279	221	187	166	151	141	134	26
28	7200	7200	4995	3450	2522	1940	1605	1249	1017	862	755	677	620	555	469	403	280	216	178	155	140	129	121	28
30	7200	7200	4942	3419	2565	1923	1555	1282	1025	855	737	652	590	543	495	422	285	214	173	148	131	120	111	30
32	7200	7200	4924	3433	2548	1931	1528	1281	1046	858	729	637	569	519	480	445	293	215	170	142	124	112	104	32
34	7200	7200	4961	3477	2518	1959	1519	1252	1076	870	729	629	556	501	459	427	304	218	169	139	120	107	97	34
36	7200	7200	4942	3432	2513	1960	1526	1236	1048	890	737	628	549	490	445	410	317	223	170	137	116	102	93	36
38	7200	7200	4923	3419	2530	1934	1544	1231	1030	894	750	632	547	483	435	397	325	229	172	137	114	99	89	38
40	7200	7200	4943	3433	2548	1923	1555	1236	1020	875	768	641	549	481	429	389	311	237	175	137	113	97	86	40
42	7200	7200	4942	3450	2521	1927	1533	1249	1017	862	755	654	555	482	426	383	301	247	179	139	113	96	84	42
44	7200	7200	4923	3424	2512	1942	1522	1264	1021	856	742	660	564	486	426	381	293	246	185	141	113	95	82	44
46	7200	7200	4934	3420	2517	1947	1520	1246	1031	855	733	646	576	492	429	380	287	237	191	144	115	95	81	46
48	7200	7200	4942	3433	2535	1931	1526	1236	1046	858	729	637	569	501	433	381	283	231	198	148	116	95	81	48

TABLE 6-9. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8400	8400	7848	5857	4881	4337	4005	3788	3639	3532	3452	3392	3345	3306	3276	3251	3197	3159	3138	3124	3114	3100	3095	6
8	8400	8400	8400	5451	4046	3294	2852	2572	2385	2253	2157	2085	2031	1987	1952	1923	1865	1828	1805	1788	1775	1765	1758	8
10	8400	8400	8400	6030	4074	3054	2470	2108	1872	1709	1593	1507	1442	1391	1352	1320	1253	1214	1188	1170	1156	1148	1140	10
12	8400	8400	7848	5857	4528	3181	2423	1962	1665	1464	1323	1220	1143	1084	1038	1001	927	883	855	836	822	813	805	12
14	8400	8400	7933	5478	4303	3526	2562	1983	1615	1370	1199	1076	985	916	862	820	736	687	657	636	621	611	603	14
16	8400	8400	8139	5451	4046	3294	2824	2111	1661	1363	1158	1011	904	824	762	713	618	563	530	508	492	481	472	16
18	8400	8400	7848	5655	3990	3112	2603	2285	1770	1414	1170	998	872	778	707	651	542	482	445	421	404	392	384	18
20	8400	8400	7849	5557	4074	3054	2470	2108	1872	1507	1220	1018	872	764	681	617	495	427	387	360	343	330	320	20
22	8400	8400	8032	5438	4189	3085	2417	2008	1743	1562	1299	1065	896	771	677	604	465	390	346	317	298	284	274	22
24	8400	8400	7848	5451	4046	3181	2423	1962	1665	1464	1323	1132	938	795	688	606	450	366	317	286	265	250	240	24
26	8400	8400	7826	5566	3991	3157	2474	1957	1626	1403	1248	1135	995	833	711	618	443	351	297	263	240	225	213	26
28	8400	8400	7933	5478	4005	3081	2548	1983	1615	1369	1199	1076	985	881	745	640	445	342	283	246	222	205	193	28
30	8400	8400	7848	5430	4074	3054	2470	2036	1628	1357	1170	1036	937	862	786	670	453	339	274	234	208	190	177	30
32	8400	8400	7819	5451	4046	3066	2427	2035	1660	1363	1158	1011	904	824	762	706	465	341	270	226	198	178	164	32
34	8400	8400	7877	5521	3998	3110	2413	1987	1708	1382	1158	999	883	796	730	678	482	346	268	221	190	169	155	34
36	8400	8400	7848	5450	3990	3112	2423	1962	1665	1414	1170	998	872	778	707	651	503	353	269	218	185	163	147	36
38	8400	8400	7818	5429	4017	3071	2452	1955	1635	1420	1191	1004	869	768	691	631	516	364	272	217	182	158	141	38
40	8400	8400	7849	5451	4046	3054	2470	1962	1619	1389	1220	1018	872	764	681	617	495	377	278	218	180	154	137	40
42	8400	8400	7848	5478	4004	3060	2435	1983	1615	1369	1199	1039	881	765	677	609	478	392	285	220	179	152	133	42
44	8400	8400	7817	5438	3988	3085	2417	2008	1622	1360	1178	1047	896	771	677	604	465	390	293	224	180	151	131	44
46	8400	8400	7835	5430	3997	3092	2413	1979	1637	1358	1164	1026	915	781	681	603	456	377	303	229	182	151	129	46
48	8400	8400	7848	5451	4026	3066	2423	1962	1660	1363	1158	1011	904	795	688	606	450	366	314	235	185	151	129	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9800	9600	9600	8743	7286	6473	5979	5655	5432	5273	5153	5063	4993	4936	4890	4852	4773	4716	4684	4663	4649	4627	4619	6
8	9600	9600	9600	8137	6039	4918	4257	3839	3560	3363	3220	3113	3032	2966	2914	2871	2784	2729	2694	2668	2649	2635	2624	8
10	9600	9600	9600	9001	6081	4559	3687	3147	2794	2551	2377	2249	2152	2077	2018	1970	1871	1812	1773	1747	1726	1713	1702	10
12	9600	9600	9600	8743	6759	4749	3617	2929	2485	2186	1975	1821	1706	1618	1550	1495	1384	1318	1276	1248	1228	1213	1201	12
14	9600	9600	9600	8177	6423	5263	3824	2961	2411	2044	1789	1606	1470	1367	1287	1224	1098	1026	980	950	927	912	900	14
16	9600	9600	9600	8137	6039	4918	4216	3150	2479	2034	1728	1510	1350	1229	1137	1064	922	841	791	758	735	718	705	16
18	9600	9600	9600	8442	5957	4646	3886	3410	2643	2110	1747	1489	1302	1161	1055	971	810	719	664	628	604	586	573	18
20	9600	9600	9600	8295	6081	4559	3686	3147	2794	2250	1821	1520	1302	1140	1017	922	738	638	577	538	511	492	478	20
22	9600	9600	9600	8117	6254	4604	3608	2997	2601	2331	1939	1590	1337	1151	1010	902	695	583	516	473	445	424	409	22
24	9600	9600	9600	8137	6039	4749	3616	2929	2485	2186	1975	1690	1400	1187	1027	904	671	546	473	427	396	374	358	24
26	9600	9600	9600	8309	5958	4713	3693	2921	2426	2095	1862	1694	1485	1243	1062	923	662	524	443	392	359	335	318	26
28	9600	9600	9600	8177	5978	4599	3803	2960	2411	2044	1789	1606	1470	1316	1111	956	664	511	423	367	331	306	288	28
30	9600	9600	9600	8105	6081	4559	3687	3039	2431	2026	1747	1546	1399	1287	1174	1000	676	507	410	350	310	283	264	30
32	9600	9600	9600	8137	6039	4577	3623	3037	2478	2034	1728	1510	1350	1229	1137	1054	695	509	403	337	295	266	245	32
34	9600	9600	9600	8241	5968	4643	3602	2967	2550	2063	1729	1492	1319	1189	1089	1011	720	516	400	330	284	253	231	34
36	9600	9600	9600	8135	5957	4646	3616	2929	2485	2110	1747	1489	1302	1161	1055	971	751	528	402	325	276	243	219	36
38	9600	9600	9600	8104	5996	4584	3661	2918	2441	2120	1778	1499	1297	1146	1031	942	770	543	407	324	271	236	211	38
40	9600	9600	9600	8137	6039	4559	3686	2929	2417	2074	1821	1520	1302	1140	1017	922	738	563	415	325	269	230	204	40
42	9600	9600	9600	8177	5977	4568	3634	2960	2411	2044	1789	1551	1316	1142	1010	909	714	585	425	329	268	227	199	42
44	9600	9600	9600	8117	5954	4604	3608	2997	2421	2029	1758	1563	1337	1151	1010	902	695	583	437	334	269	225	195	44
46	9600	9600	9600	8106	5967	4616	3602	2954	2444	2026	1738	1532	1366	1166	1016	901	681	563	452	341	272	225	193	46
48	9600	9600	9600	8137	6010	4576	3616	2929	2478	2034	1728	1510	1350	1187	1027	904	671	546	468	350	275	226	192	48

TABLE 6-9. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

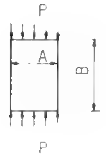
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10800	10800	10800	10800	10374	9217	8512	8051	7734	7507	7336	7209	7109	7028	6963	6909	6795	6714	6670	6639	6619	6583	6577	6
8	10800	10800	10800	10800	8599	7002	6062	5467	5069	4788	4585	4432	4317	4223	4148	4088	3963	3886	3836	3799	3772	3752	3737	8
10	10800	10800	10800	10800	8658	6492	5249	4481	3978	3633	3385	3202	3064	2957	2873	2805	2664	2580	2525	2487	2458	2439	2423	10
12	10800	10800	10800	10800	9623	6761	5149	4170	3539	3112	2812	2593	2430	2304	2206	2128	1970	1877	1817	1777	1748	1727	1710	12
14	10800	10800	10800	10800	9145	7494	5444	4215	3433	2911	2548	2286	2093	1946	1833	1743	1564	1460	1396	1352	1321	1298	1281	14
16	10800	10800	10800	10800	8599	7002	6003	4486	3529	2897	2460	2150	1922	1751	1619	1515	1312	1197	1126	1079	1046	1022	1004	16
18	10800	10800	10800	10800	8481	6615	5532	4856	3763	3005	2487	2120	1853	1654	1502	1383	1153	1024	946	895	859	834	815	18
20	10800	10800	10800	10800	8658	6491	5249	4481	3978	3204	2593	2164	1854	1623	1448	1312	1051	908	822	766	728	701	681	20
22	10800	10800	10800	10800	8904	6556	5137	4268	3704	3319	2762	2263	1904	1639	1439	1284	989	830	735	674	633	604	583	22
24	10800	10800	10800	10800	8598	6761	5149	4170	3539	3112	2812	2406	1994	1690	1462	1287	955	778	674	607	563	532	509	24
26	10800	10800	10800	10800	8483	6710	5258	4159	3455	2982	2652	2413	2114	1770	1512	1314	943	746	631	559	511	477	453	26
28	10800	10800	10800	10800	8511	6549	5415	4215	3433	2911	2548	2286	2093	1873	1583	1361	946	728	602	523	472	436	410	28
30	10800	10800	10800	10800	8658	6491	5249	4327	3461	2885	2487	2202	1992	1833	1671	1424	962	721	583	498	442	404	376	30
32	10800	10800	10800	10800	8598	6517	5159	4324	3529	2896	2460	2150	1922	1751	1619	1501	989	724	573	480	420	379	350	32
34	10800	10800	10800	10800	8497	6610	5128	4224	3631	2938	2462	2124	1877	1692	1551	1440	1025	734	570	469	404	360	329	34
36	10800	10800	10800	10800	8481	6615	5149	4170	3539	3005	2487	2120	1853	1654	1502	1383	1069	751	572	463	393	346	312	36
38	10800	10800	10800	10800	8538	6527	5212	4154	3475	3018	2531	2134	1846	1632	1468	1341	1096	774	579	462	386	335	300	38
40	10800	10800	10800	10800	8598	6491	5249	4171	3442	2953	2593	2164	1854	1623	1448	1312	1051	801	590	463	382	328	290	40
42	10800	10800	10800	10800	8510	6503	5174	4215	3433	2911	2548	2208	1873	1626	1438	1294	1016	833	605	468	381	323	283	42
44	10800	10800	10800	10800	8477	6556	5137	4268	3447	2889	2503	2226	1904	1639	1439	1284	989	830	623	476	383	321	278	44
46	10800	10800	10800	10800	8496	6572	5129	4206	3479	2885	2475	2181	1944	1661	1447	1282	969	801	644	486	387	321	275	46
48	10800	10800	10800	10800	8557	6516	5149	4170	3529	2896	2460	2150	1922	1690	1462	1287	955	778	667	498	392	322	273	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	12000	12000	12000	12000	12000	12000	11677	11044	10609	10298	10064	9889	9752	9640	9552	9477	9321	9210	9149	9107	9080	9037	9022	6
8	12000	12000	12000	12000	11796	9605	8315	7499	6953	6568	6289	6080	5921	5793	5691	5608	5437	5331	5262	5212	5175	5146	5126	8
10	12000	12000	12000	12000	11876	8905	7201	6147	5457	4983	4643	4393	4204	4057	3942	3848	3654	3539	3463	3412	3372	3346	3324	10
12	12000	12000	12000	12000	12000	9275	7064	5720	4854	4269	3857	3557	3333	3161	3026	2919	2702	2575	2492	2438	2398	2369	2346	12
14	12000	12000	12000	12000	12000	10280	7468	5782	4710	3993	3495	3136	2871	2670	2514	2391	2145	2003	1914	1855	1811	1781	1758	14
16	12000	12000	12000	12000	11796	9605	8234	6153	4841	3973	3375	2949	2636	2401	2220	2079	1800	1642	1544	1480	1435	1402	1377	16
18	12000	12000	12000	12000	11634	9074	7589	6661	5162	4122	3412	2908	2542	2268	2060	1897	1581	1405	1297	1227	1179	1144	1118	18
20	12000	12000	12000	12000	11876	8904	7200	6147	5457	4395	3558	2969	2543	2226	1986	1800	1442	1246	1128	1051	999	962	934	20
22	12000	12000	12000	12000	12000	8993	7046	5854	5080	4553	3788	3105	2612	2248	1973	1762	1357	1138	1008	925	869	829	800	22
24	12000	12000	12000	12000	11795	9275	7063	5720	4854	4269	3857	3300	2735	2319	2006	1766	1311	1067	924	833	773	730	699	24
26	12000	12000	12000	12000	11636	9204	7212	5705	4739	4091	3637	3310	2900	2428	2074	1803	1293	1023	865	766	701	655	622	26
28	12000	12000	12000	12000	11676	8983	7428	5782	4710	3993	3495	3136	2871	2570	2171	1867	1297	998	825	718	647	598	562	28
30	12000	12000	12000	12000	11876	8904	7200	5936	4748	3958	3411	3020	2732	2514	2293	1953	1320	989	800	683	606	554	516	30
32	12000	12000	12000	12000	11795	8939	7076	5932	4841	3973	3375	2949	2636	2401	2221	2059	1356	993	786	659	576	520	479	32
34	12000	12000	12000	12000	11656	9067	7034	5794	4981	4030	3377	2914	2575	2321	2127	1975	1406	1007	782	644	554	494	451	34
36	12000	12000	12000	12000	11634	9074	7063	5720	4854	4122	3411	2908	2542	2268	2060	1897	1467	1031	785	636	539	474	429	36
38	12000	12000	12000	12000	11712	8953	7150	5698	4767	4140	3472	2928	2533	2238	2014	1840	1503	1061	794	633	530	460	411	38
40	12000	12000	12000	12000	11795	8904	7200	5721	4721	4050	3558	2969	2543	2226	1986	1800	1442	1099	810	636	525	450	398	40
42	12000	12000	12000	12000	11674	8921	7098	5782	4709	3993	3495	3028	2570	2230	1973	1774	1394	1142	830	642	523	444	388	42
44	12000	12000	12000	12000	11628	8993	7046	5854	4728	3964	3433	3054	2612	2248	1973	1762	1357	1138	854	653	525	440	382	44
46	12000	12000	12000	12000	11654	9015	7036	5770	4773	3958	3395	2992	2667	2278	1984	1759	1330	1099	883	667	530	440	377	46
48	12000	12000	12000	12000	11738	8938	7063	5720	4841	3973	3375	2949	2636	2319	2006	1766	1311	1067	915	684	538	441	375	48

TABLE 6-10. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED



PHYSICAL CONSTANTS:

$E_X = 1.81x10^6$ PSI

$E_Y = 1.54x10^6$ PSI

$G_{XY} = 0.45x10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.19$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	57	45	42	40	38	38	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	37	6
8	49	33	26	24	23	23	23	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	8
10	47	28	21	17	16	16	14	14	14	14	14	14	14	14	14	14	14	14	12	12	12	12	12	10
12	40	26	17	14	12	12	10	10	10	10	10	10	9	9	9	9	9	9	9	9	9	9	9	12
14	38	24	17	12	10	9	9	9	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	14
16	38	23	17	12	9	9	7	7	7	7	5	5	5	5	5	5	5	5	5	5	5	5	5	16
18	37	23	16	12	9	7	7	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3	3	18
20	37	23	14	12	9	7	5	5	5	5	3	3	3	3	3	3	3	3	3	3	3	3	3	20
22	37	21	14	10	9	7	5	5	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	22
24	35	21	14	10	9	7	5	5	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	24
26	35	21	14	10	7	7	5	5	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	26
28	37	21	14	10	7	7	5	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	28
30	37	21	14	10	7	5	5	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	30
32	38	19	14	10	7	5	5	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	32
34	40	19	14	9	7	5	5	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	34
36	42	21	14	9	7	5	5	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	36
38	43	21	12	9	7	5	5	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	38
40	45	21	12	9	7	5	5	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	40
42	49	21	12	9	7	5	3	3	3	3	2	2	2	2	2	2	2	2	2	2	0	0	0	42
44	50	23	12	9	7	5	3	3	3	3	2	2	2	2	2	2	2	2	2	0	0	0	0	44
46	54	23	12	9	7	5	3	3	3	2	2	2	2	2	2	2	2	2	0	0	0	0	0	46
48	56	23	14	9	7	5	3	3	3	2	2	2	2	2	2	2	2	2	0	0	0	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	461	369	334	316	308	302	299	296	294	292	292	290	290	289	289	289	287	287	287	287	287	285	285	6
8	384	259	216	195	184	179	174	172	169	169	167	165	165	165	163	163	163	162	162	162	162	162	162	8
10	369	221	165	141	129	122	116	115	111	110	110	108	108	106	106	106	104	104	104	104	104	104	103	10
12	325	214	144	115	101	92	87	83	82	80	78	76	76	75	75	75	73	73	73	73	73	71	71	12
14	311	200	137	103	85	75	70	66	63	61	59	59	57	57	56	56	56	54	54	54	54	54	54	14
16	308	183	137	96	76	64	57	54	50	49	47	47	45	45	43	43	42	42	42	42	42	42	40	16
18	296	176	125	96	71	59	50	47	43	42	40	38	37	37	37	35	35	33	33	33	33	33	33	18
20	292	174	116	92	70	56	47	42	38	35	33	33	31	31	30	30	28	28	28	26	26	26	26	20
22	289	170	113	85	70	54	43	38	35	31	30	28	28	26	26	24	24	23	23	23	23	23	23	22
24	283	167	111	82	66	54	43	37	31	30	26	24	24	23	23	21	21	19	19	19	19	19	19	24
26	283	165	113	78	63	54	42	35	30	26	24	23	21	21	19	19	17	17	17	16	16	16	16	26
28	287	165	108	78	59	50	42	35	30	26	23	21	19	19	17	17	16	16	14	14	14	14	14	28
30	294	162	106	78	57	47	42	35	28	24	23	19	19	17	16	16	14	14	12	12	12	12	12	30
32	304	160	106	76	57	45	38	35	28	24	21	19	17	16	16	14	14	12	12	12	10	10	10	32
34	316	160	106	75	57	45	37	33	28	24	21	19	17	16	14	14	12	10	10	10	10	10	10	34
36	330	160	104	73	57	43	37	31	28	24	21	17	16	14	14	12	10	10	10	9	9	9	9	36
38	346	163	103	73	56	43	35	30	26	24	21	17	16	14	14	12	10	9	9	9	9	9	9	38
40	365	165	103	73	56	43	35	30	26	23	21	17	16	14	12	12	10	9	9	7	7	7	7	40
42	384	170	103	73	54	43	35	28	24	23	21	17	16	14	12	12	9	9	7	7	7	7	7	42
44	405	174	103	71	54	43	35	28	24	21	19	17	16	14	12	10	9	9	7	7	7	7	7	44
46	428	181	103	71	54	42	35	28	24	21	19	17	16	14	12	10	9	7	7	7	5	5	5	46
48	450	186	104	71	54	42	35	28	23	21	17	17	16	14	12	10	9	7	7	5	5	5	5	48

TABLE 6-10. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	1552	1243	1126	1071	1040	1020	1006	998	991	987	984	980	979	977	975	973	972	968	966	966	966	965	965	6
8	1297	874	727	659	624	601	588	579	572	567	563	560	558	555	553	553	549	548	546	546	544	544	544	8
10	1246	746	560	478	436	412	396	386	377	372	369	365	363	360	358	358	355	353	351	351	349	349	349	10
12	1099	721	487	388	339	311	294	282	273	268	262	259	257	256	254	252	249	247	245	245	243	243	243	12
14	1048	673	462	344	285	252	233	221	212	205	200	196	193	191	189	188	184	183	183	181	179	179	179	14
16	1040	617	466	325	256	219	196	181	172	165	160	156	153	151	148	148	144	141	141	139	139	137	137	16
18	996	593	421	322	242	198	172	156	146	137	132	129	125	123	120	118	115	113	111	111	110	110	110	18
20	987	589	395	311	236	186	158	139	129	120	113	110	106	103	101	99	96	94	92	90	90	89	89	20
22	973	577	382	289	238	181	149	129	115	106	99	96	92	89	87	83	80	78	76	76	75	75	75	22
24	958	561	377	275	224	181	144	122	108	97	90	85	80	78	75	73	70	66	66	64	64	63	63	24
26	958	555	379	266	210	179	143	118	101	90	83	76	73	70	66	64	61	57	57	56	54	54	54	26
28	970	556	367	262	202	169	143	116	97	85	78	71	66	63	61	59	54	50	50	49	47	47	47	28
30	994	544	358	262	196	160	139	115	96	83	73	68	63	59	56	54	49	45	43	43	42	42	42	30
32	1027	539	356	261	193	155	132	116	96	82	71	64	59	54	52	49	43	42	40	38	38	37	37	32
34	1069	537	356	254	193	151	125	110	96	80	70	63	56	52	49	45	40	38	37	35	33	33	33	34
36	1116	541	353	249	193	148	122	106	94	80	68	61	54	49	45	43	38	35	33	31	30	30	30	36
38	1170	549	348	247	189	148	120	101	90	82	68	59	52	49	43	42	35	31	30	28	28	28	26	38
40	1231	560	344	247	186	148	118	99	87	78	68	59	52	47	42	40	33	30	28	26	26	24	24	40
42	1295	574	344	247	183	148	116	97	83	75	68	59	52	45	42	38	31	28	26	24	24	23	23	42
44	1366	589	346	243	183	144	116	96	82	73	66	59	52	45	40	37	30	26	24	23	23	21	21	44
46	1441	607	348	240	181	143	116	94	80	70	63	57	52	45	40	37	30	26	23	21	21	19	19	46
48	1521	628	353	240	183	141	115	94	78	68	61	56	52	45	40	37	28	24	23	21	19	19	17	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	3682	2945	2670	2538	2463	2416	2387	2366	2350	2340	2331	2324	2319	2314	2310	2308	2302	2295	2291	2291	2291	2288	2284	6
8	3075	2070	1723	1563	1478	1427	1394	1372	1356	1342	1333	1326	1321	1316	1312	1309	1302	1299	1295	1293	1290	1288	1288	8
10	2953	1768	1325	1133	1033	975	939	913	895	883	873	866	859	855	850	847	840	836	833	831	829	827	827	10
12	2602	1710	1154	920	803	737	695	668	648	634	624	615	610	605	600	596	589	584	582	579	579	577	575	12
14	2486	1594	1097	815	676	600	553	521	501	485	475	466	459	454	450	447	438	433	431	428	426	426	424	14
16	2465	1464	1104	768	607	518	464	431	407	391	379	370	362	356	353	348	341	335	332	330	329	327	327	16
18	2362	1406	1000	761	570	469	409	370	346	327	315	304	297	290	285	282	273	268	266	262	261	261	259	18
20	2340	1398	937	739	558	442	374	332	302	283	269	259	250	243	238	235	226	221	217	216	214	212	210	20
22	2308	1366	904	685	563	429	353	306	275	252	236	226	216	210	203	200	191	186	183	179	177	176	176	22
24	2268	1328	893	650	530	428	342	289	254	229	214	200	191	184	179	174	163	158	155	153	151	149	148	24
26	2268	1316	899	631	499	424	337	278	240	214	196	183	172	165	158	153	144	137	134	132	130	129	127	26
28	2300	1319	869	622	478	398	339	275	231	203	184	169	158	149	143	137	127	122	118	115	113	111	111	28
30	2357	1290	850	621	464	379	329	275	228	196	174	158	148	139	132	125	115	108	104	101	99	97	97	30
32	2435	1276	843	615	457	367	311	276	226	193	169	151	139	129	122	116	104	97	94	90	89	87	85	32
34	2533	1274	843	600	455	356	299	261	228	189	165	146	132	122	115	108	96	89	85	82	80	78	76	34
36	2646	1283	836	591	457	351	289	250	223	189	162	143	129	116	110	103	89	82	76	75	71	71	70	36
38	2774	1300	824	586	448	349	283	242	214	191	162	141	125	113	104	97	83	76	71	68	66	64	63	38
40	2917	1326	817	586	440	349	278	235	205	184	162	139	123	111	101	94	78	71	66	63	61	59	57	40
42	3072	1358	815	588	435	349	276	229	198	177	162	139	122	108	99	90	75	66	61	57	56	54	52	42
44	3238	1396	819	577	431	342	276	226	193	170	155	141	122	108	97	89	71	63	57	54	52	50	49	44
46	3416	1439	826	570	429	335	276	224	189	167	149	137	122	106	96	87	70	61	54	50	49	47	45	46
48	3605	1488	834	567	431	332	275	223	188	163	146	132	123	108	96	85	68	57	52	49	45	43	42	48

TABLE 6-10. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4940	4940	4940	4940	4812	4721	4662	4620	4591	4568	4551	4539	4528	4520	4513	4507	4495	4481	4476	4474	4474	4467	4462	6
8	4940	4045	3364	3054	2887	2788	2722	2679	2647	2621	2604	2590	2580	2569	2562	2555	2543	2536	2529	2524	2521	2517	2515	8
10	4940	3452	2588	2213	2018	1903	1332	1783	1749	1724	1705	1690	1677	1669	1662	1655	1641	1632	1627	1622	1618	1617	1615	10
12	4940	3343	2255	1797	1568	1438	1358	1304	1265	1239	1219	1203	1191	1180	1172	1165	1151	1142	1135	1132	1128	1126	1125	12
14	4855	3115	2142	1591	1321	1170	1079	1020	979	949	927	911	897	887	878	871	857	847	841	836	833	831	829	14
16	4813	2860	2157	1502	1184	1012	907	841	796	763	741	721	707	697	688	681	666	655	650	645	641	640	638	16
18	4613	2747	1957	1486	1114	916	800	725	674	640	614	594	579	568	558	551	535	525	518	513	509	508	506	18
20	4570	2729	1830	1443	1092	864	730	647	591	553	525	504	488	476	466	459	442	431	424	419	415	414	412	20
22	4507	2670	1766	1337	1099	840	688	596	535	492	462	440	422	410	398	391	372	362	355	349	346	344	342	22
24	4431	2595	1745	1271	1034	836	668	563	495	450	417	393	374	360	348	339	322	309	302	297	294	292	289	24
26	4431	2571	1754	1232	973	831	659	544	469	419	382	356	337	322	309	301	282	269	262	257	254	250	249	26
28	4492	2578	1697	1213	933	779	664	535	454	398	358	330	309	292	280	269	249	236	229	224	221	217	216	28
30	4603	2521	1662	1213	907	741	641	535	445	384	341	311	287	269	257	245	224	212	203	198	195	191	189	30
32	4756	2493	1646	1203	893	714	608	539	442	375	329	296	271	252	238	228	203	191	183	177	174	170	169	32
34	4940	2489	1648	1173	890	697	582	511	443	372	322	285	259	240	224	212	188	174	165	160	155	153	149	34
36	4940	2505	1632	1154	893	687	565	488	436	372	318	278	250	229	212	200	174	160	151	144	141	137	136	36
38	4940	2540	1608	1144	876	681	553	471	415	374	316	275	243	221	203	189	163	148	139	132	129	125	123	38
40	4940	2588	1596	1142	859	681	544	457	400	360	318	273	240	216	196	183	155	139	129	122	118	115	113	40
42	4940	2653	1592	1146	848	683	539	448	388	346	316	273	238	212	193	177	146	130	120	113	110	106	103	42
44	4940	2726	1597	1126	841	668	539	442	379	334	302	275	238	210	189	172	141	123	113	106	101	97	96	44
46	4940	2811	1611	1114	840	657	541	438	370	325	292	268	238	209	186	169	136	116	106	99	94	90	89	46
48	4940	2906	1631	1107	841	648	535	436	365	318	283	259	240	209	186	167	132	113	101	94	89	85	82	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	6
8	7200	6988	5811	5277	4989	4817	4704	4627	4573	4532	4500	4476	4459	4441	4427	4417	4396	4381	4372	4361	4356	4351	4347	8
10	7200	5966	4473	3823	3487	3291	3167	3082	3023	2979	2946	2920	2899	2884	2872	2860	2835	2821	2811	2804	2795	2793	2790	10
12	7200	5776	3896	3106	2710	2486	2345	2253	2189	2140	2105	2079	2056	2039	2025	2015	1989	1973	1963	1956	1950	1947	1943	12
14	7200	5382	3701	2748	2282	2023	1865	1761	1690	1639	1603	1573	1551	1531	1518	1505	1479	1464	1453	1446	1439	1434	1432	14
16	7200	4940	3727	2594	2046	1747	1568	1453	1375	1319	1278	1246	1224	1205	1189	1177	1149	1133	1121	1114	1109	1104	1100	16
18	7200	4746	3372	2567	1926	1584	1380	1252	1165	1104	1060	1027	1001	980	965	951	923	906	895	887	881	878	874	18
20	7200	4714	3162	2491	1884	1491	1262	1118	1022	956	907	873	845	822	805	791	763	746	734	725	720	714	711	20
22	7200	4613	3052	2312	1898	1450	1191	1031	925	852	798	760	730	707	688	674	643	626	614	605	600	594	591	22
24	7200	4485	3014	2195	1787	1445	1152	973	857	777	720	678	645	621	601	586	555	535	523	515	508	504	501	24
26	7200	4441	3032	2129	1683	1434	1140	940	812	723	662	617	582	556	535	518	485	466	452	443	436	433	429	26
28	7200	4455	2931	2098	1613	1345	1146	925	784	687	619	570	534	506	483	466	431	410	396	388	381	377	372	28
30	7200	4354	2870	2095	1570	1281	1107	925	768	662	589	537	497	468	443	424	388	365	351	342	335	330	327	30
32	7200	4306	2844	2079	1545	1236	1050	932	763	648	568	511	469	436	412	393	353	330	315	306	299	294	290	32
34	7200	4301	2847	2027	1538	1205	1008	881	767	641	556	494	448	414	388	365	325	301	285	275	268	264	259	34
36	7200	4330	2821	1994	1544	1187	975	843	754	641	548	482	433	396	367	346	301	276	261	250	243	238	235	36
38	7200	4389	2778	1976	1516	1179	954	814	720	647	546	475	422	382	353	329	282	256	240	229	221	216	212	38
40	7200	4474	2755	1975	1485	1179	940	791	692	622	548	471	415	374	341	316	266	238	223	210	203	198	195	40
42	7200	4582	2752	1980	1464	1179	932	774	669	598	546	471	412	367	332	306	254	224	207	196	188	183	177	42
44	7200	4711	2760	1947	1453	1152	930	763	654	577	523	475	410	362	327	297	243	212	195	183	174	169	165	44
46	7200	4859	2785	1926	1450	1133	933	756	641	561	506	464	412	362	322	292	235	203	184	172	163	156	153	46
48	7200	5022	2818	1914	1453	1121	925	754	633	549	490	447	414	362	320	289	228	195	174	162	153	146	143	48

TABLE 6-10. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	6
8	8400	8400	8400	8380	7921	7649	7469	7348	7263	7195	7146	7108	7080	7052	7031	7012	6979	6957	6941	6927	6917	6908	6903	8
10	8400	8400	7103	6072	5538	5225	5029	4895	4799	4732	4678	4638	4605	4579	4560	4542	4504	4480	4462	4452	4440	4436	4429	10
12	8400	8400	6185	4932	4304	3946	3723	3577	3475	3400	3344	3301	3266	3238	3216	3198	3158	3134	3117	3106	3098	3092	3085	12
14	8400	8400	5877	4365	3624	3212	2960	2797	2684	2604	2543	2498	2461	2434	2409	2390	2350	2324	2308	2296	2286	2279	2274	14
16	8400	7847	5917	4120	3249	2774	2491	2307	2183	2095	2030	1980	1942	1912	1888	1867	1825	1799	1782	1770	1761	1754	1749	16
18	8400	7536	5354	4076	3059	2514	2192	1987	1850	1754	1683	1631	1591	1558	1531	1511	1467	1439	1422	1408	1399	1392	1387	18
20	8400	7487	5022	3956	2993	2369	2004	1775	1624	1518	1441	1384	1340	1305	1279	1257	1212	1184	1165	1151	1142	1135	1130	20
22	8400	7325	4848	3670	3014	2302	1891	1636	1467	1351	1269	1206	1159	1123	1095	1071	1022	994	973	961	951	946	939	22
24	8400	7122	4787	3487	2837	2293	1830	1545	1361	1232	1142	1076	1026	987	956	932	880	850	829	817	807	800	794	24
26	8400	7052	4815	3381	2674	2277	1810	1493	1288	1149	1050	979	925	883	850	824	770	739	718	704	694	687	681	26
28	8400	7075	4653	3331	2562	2136	1820	1469	1243	1092	984	906	848	803	768	741	685	650	629	615	605	598	591	28
30	8400	6915	4558	3327	2491	2034	1759	1467	1219	1053	937	852	789	742	704	674	615	581	558	544	534	525	520	30
32	8400	6838	4516	3303	2454	1961	1667	1479	1212	1029	904	812	744	694	654	622	560	523	501	485	475	468	461	32
34	8400	6828	4521	3218	2442	1912	1599	1401	1217	1019	883	784	711	657	614	581	515	476	454	438	426	419	412	34
36	8400	6875	4480	3165	2453	1884	1551	1338	1198	1019	871	765	687	629	584	548	478	438	414	398	386	377	372	36
38	8400	6969	4412	3139	2406	1870	1516	1292	1142	1027	867	753	669	607	560	521	448	407	381	363	351	344	337	38
40	8400	7104	4377	3136	2357	1872	1493	1255	1099	989	871	749	659	593	541	501	422	379	353	335	323	315	308	40
42	8400	7277	4368	3145	2326	1872	1481	1229	1064	949	867	749	654	582	527	485	403	356	329	311	299	289	283	42
44	8400	7482	4384	3092	2308	1830	1478	1212	1038	918	831	754	652	575	518	473	386	337	309	290	276	268	261	44
46	8400	7715	4420	3058	2303	1801	1483	1201	1017	892	803	737	654	574	511	464	372	322	292	271	259	249	242	46
48	8400	7975	4476	3039	2308	1780	1467	1198	1003	873	779	709	657	574	508	457	362	308	276	256	243	233	226	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	6
8	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	8
10	9600	9600	9600	9062	8266	7800	7506	7306	7165	7064	6983	6922	6873	6835	6805	6779	6722	6686	6661	6646	6626	6621	6612	10
12	9600	9600	9232	7363	6423	5891	5559	5340	5185	5074	4992	4926	4876	4834	4801	4773	4716	4678	4652	4638	4624	4615	4605	12
14	9600	9600	8773	6515	5410	4794	4420	4175	4007	3887	3796	3729	3675	3631	3598	3569	3508	3470	3445	3428	3412	3402	3395	14
16	9600	9600	8834	6148	4850	4141	3716	3444	3259	3127	3030	2957	2899	2854	2818	2788	2726	2686	2660	2642	2628	2618	2609	16
18	9600	9600	7993	6084	4567	3753	3271	2967	2762	2618	2514	2434	2373	2324	2286	2255	2190	2149	2121	2103	2089	2079	2072	18
20	9600	9600	7496	5907	4469	3536	2992	2651	2423	2265	2152	2067	2001	1950	1909	1877	1808	1766	1738	1719	1705	1695	1686	20
22	9600	9600	7235	5479	4500	3437	2823	2442	2190	2018	1893	1801	1731	1677	1634	1599	1526	1483	1455	1434	1420	1410	1401	22
24	9600	9600	7146	5206	4236	3423	2733	2308	2030	1841	1705	1606	1531	1472	1427	1391	1314	1269	1239	1219	1205	1194	1186	24
26	9600	9600	7186	5046	3989	3400	2701	2230	1924	1716	1568	1460	1380	1318	1269	1229	1151	1102	1073	1052	1036	1026	1017	26
28	9600	9600	6946	4972	3824	3190	2717	2194	1857	1629	1469	1352	1265	1199	1147	1106	1020	972	940	918	904	892	883	28
30	9600	9600	6804	4966	3720	3037	2625	2190	1820	1571	1398	1272	1179	1107	1052	1006	918	867	834	812	796	786	775	30
32	9600	9600	6743	4930	3663	2927	2489	2208	1808	1537	1349	1213	1113	1036	977	930	836	782	747	725	709	697	688	32
34	9600	9600	6748	4803	3645	2856	2388	2089	1817	1521	1318	1170	1062	980	918	867	768	713	676	654	636	624	615	34
36	9600	9600	6687	4725	3661	2813	2314	1997	1787	1521	1300	1142	1026	939	871	819	714	655	617	593	575	563	555	36
38	9600	9600	6586	4686	3591	2793	2262	1928	1705	1533	1295	1125	1000	907	834	779	669	607	568	542	525	513	502	38
40	9600	9600	6533	4680	3518	2793	2229	1874	1639	1476	1300	1118	984	883	808	747	631	567	527	501	482	469	459	40
42	9600	9600	6520	4693	3471	2795	2209	1836	1589	1417	1295	1118	975	869	787	723	601	532	492	464	445	431	422	42
44	9600	9600	6545	4617	3445	2734	2206	1810	1549	1370	1241	1125	972	859	772	706	575	504	461	433	414	400	389	44
46	9600	9600	6599	4565	3438	2689	2213	1794	1519	1332	1198	1099	975	855	763	692	556	480	435	407	386	372	362	46
48	9600	9600	6680	4537	3445	2658	2190	1787	1498	1302	1161	1059	982	855	758	683	539	461	414	382	362	348	337	48

TABLE 6-10. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

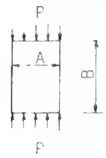
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	6
8	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	8
10	10800	10800	10800	10800	10800	10800	10689	10404	10202	10058	9943	9856	9787	9733	9691	9653	9571	9519	9486	9463	9435	9429	9415	10
12	10800	10800	10800	10484	9145	8387	7916	7602	7384	7224	7108	7016	6941	6882	6837	6797	6713	6661	6625	6604	6585	6571	6557	12
14	10800	10800	10800	9277	7702	6826	6294	5945	5705	5533	5406	5309	5232	5171	5123	5081	4994	4940	4905	4879	4857	4843	4834	14
16	10800	10800	10800	8754	6905	5896	5293	4904	4640	4452	4314	4208	4128	4064	4012	3969	3880	3823	3786	3762	3741	3727	3716	16
18	10800	10800	10800	8664	6503	5344	4659	4224	3932	3727	3577	3466	3379	3310	3256	3211	3119	3059	3021	2993	2974	2960	2950	18
20	10800	10800	10673	8410	6362	5034	4261	3774	3451	3226	3063	2943	2849	2776	2719	2672	2574	2514	2475	2448	2428	2413	2401	20
22	10800	10800	10303	7800	6407	4893	4019	3477	3119	2872	2696	2564	2465	2387	2326	2275	2173	2112	2070	2043	2022	2008	1996	22
24	10800	10800	10174	7412	6030	4872	3890	3285	2891	2621	2428	2286	2180	2096	2030	1978	1870	1806	1764	1735	1716	1698	1688	24
26	10800	10800	10232	7184	5681	4841	3847	3174	2740	2442	2234	2081	1964	1876	1806	1750	1637	1570	1526	1497	1476	1460	1448	26
28	10800	10800	9891	7080	5444	4540	3868	3124	2644	2319	2091	1926	1801	1707	1632	1573	1453	1384	1338	1307	1286	1271	1259	28
30	10800	10800	9688	7071	5297	4323	3737	3119	2592	2237	1990	1811	1677	1575	1497	1434	1307	1234	1187	1156	1133	1118	1106	30
32	10800	10800	9601	7019	5215	4168	3544	3145	2574	2189	1919	1726	1584	1474	1391	1323	1191	1113	1064	1033	1010	993	980	32
34	10800	10800	9608	6838	5191	4066	3400	2976	2587	2166	1876	1667	1512	1396	1305	1234	1095	1013	963	930	906	888	876	34
36	10800	10800	9522	6727	5211	4003	3294	2846	2545	2166	1851	1625	1460	1337	1239	1165	1017	932	880	845	820	803	789	36
38	10800	10800	9376	6672	5112	3977	3219	2745	2427	2183	1844	1601	1424	1292	1189	1109	953	864	808	774	747	730	716	38
40	10800	10800	9302	6665	5010	3977	3172	2668	2335	2103	1851	1591	1401	1259	1149	1066	899	807	749	713	687	668	654	40
42	10800	10800	9284	6684	4942	3981	3146	2613	2262	2018	1844	1591	1389	1236	1121	1031	855	758	699	661	634	615	601	42
44	10800	10800	9317	6573	4905	3892	3139	2576	2206	1950	1768	1601	1385	1224	1100	1005	820	718	657	617	589	568	555	44
46	10800	10800	9396	6500	4895	3828	3150	2554	2162	1896	1705	1564	1389	1217	1086	966	791	683	619	579	549	530	515	46
48	10800	10800	9512	6460	4905	3784	3120	2543	2133	1853	1653	1507	1398	1219	1079	973	767	655	588	544	516	495	480	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	6
8	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	8
10	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	10
12	12000	12000	12000	12000	12000	11504	10857	10428	10129	9910	9748	9623	9522	9441	9378	9323	9210	9138	9088	9058	9032	9015	8996	12
14	12000	12000	12000	12000	10565	9364	8632	8156	7826	7589	7416	7282	7176	7094	7026	6971	6851	6776	6729	6694	6663	6644	6630	14
16	12000	12000	12000	12000	9472	8088	7261	6727	6366	6108	5919	5773	5663	5575	5503	5444	5323	5244	5194	5161	5133	5111	5097	16
18	12000	12000	12000	11885	8921	7330	6392	5795	5394	5112	4909	4754	4634	4540	4466	4405	4276	4196	4144	4108	4080	4061	4045	18
20	12000	12000	12000	11537	8728	6906	5844	5177	4733	4426	4203	4036	3909	3809	3729	3666	3530	3449	3395	3357	3331	3310	3294	20
22	12000	12000	12000	10701	8789	6712	5512	4768	4278	3941	3697	3518	3381	3275	3190	3122	2981	2896	2840	2802	2774	2755	2738	22
24	12000	12000	12000	10167	8273	6686	5337	4507	3967	3595	3331	3136	2990	2877	2786	2715	2566	2477	2420	2380	2352	2331	2315	24
26	12000	12000	12000	9854	7793	6640	5277	4354	3756	3351	3063	2853	2694	2573	2479	2401	2246	2154	2095	2053	2023	2003	1987	26
28	12000	12000	12000	9712	7469	6228	5307	4285	3626	3181	2868	2640	2472	2341	2239	2159	1994	1898	1836	1794	1764	1742	1726	28
30	12000	12000	12000	9701	7264	5929	5128	4278	3555	3070	2729	2484	2302	2161	2053	1966	1794	1693	1629	1585	1556	1533	1516	30
32	12000	12000	12000	9628	7155	5719	4862	4313	3532	3002	2634	2368	2171	2022	1907	1815	1632	1526	1460	1415	1384	1361	1344	32
34	12000	12000	12000	9382	7120	5576	4664	4082	3548	2971	2573	2286	2074	1914	1790	1695	1502	1391	1321	1276	1243	1220	1203	34
36	12000	12000	12000	9229	7150	5493	4518	3902	3491	2971	2538	2230	2004	1832	1702	1597	1394	1278	1206	1159	1125	1100	1083	36
38	12000	12000	12000	9152	7014	5455	4417	3763	3329	2995	2529	2197	1954	1771	1631	1521	1305	1184	1109	1060	1026	1001	982	38
40	12000	12000	12000	9142	6871	5457	4351	3661	3202	2884	2538	2182	1921	1726	1577	1460	1234	1106	1029	977	942	916	897	40
42	12000	12000	12000	9168	6779	5460	4316	3584	3101	2769	2529	2183	1903	1697	1537	1413	1173	1041	960	906	869	843	824	42
44	12000	12000	12000	9017	6729	5338	4308	3532	3025	2675	2425	2197	1900	1677	1509	1378	1125	986	900	845	808	780	761	44
46	12000	12000	12000	8916	6713	5251	4321	3503	2967	2600	2340	2147	1905	1671	1491	1352	1085	939	850	793	754	727	706	46
48	12000	12000	12000	8860	6731	5191	4280	3489	2926	2541	2268	2069	1917	1671	1481	1335	1052	899	807	747	707	678	657	48

TABLE 6-11. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
25-27 OZ. WOVEN ROVING - ALL EDGES CLAMPED



PHYSICAL CONSTANTS:

$E_X = 1.81 \times 10^6$ PSI

$E_Y = 1.54 \times 10^6$ PSI

$G_{XY} = 0.45 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.19$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	96	59	47	43	40	38	38	38	37	37	37	37	37	37	37	37	37	37	37	37	30	37	37	6
8	80	54	37	30	26	24	23	23	23	21	21	21	21	21	21	21	21	21	21	21	21	21	21	8
10	76	47	35	24	21	17	16	16	16	14	14	14	14	14	14	14	14	14	14	12	12	12	12	10
12	71	43	31	24	17	16	14	12	10	10	10	10	10	10	10	9	9	9	9	9	9	9	9	12
14	71	42	28	23	17	14	12	10	9	9	9	9	7	7	7	7	7	7	7	7	7	7	7	14
16	68	40	28	19	16	14	10	9	9	7	7	7	7	5	5	5	5	5	5	5	5	5	5	16
18	70	40	26	19	16	12	10	9	7	7	5	5	5	5	5	5	5	3	3	3	3	3	3	18
20	71	38	26	19	14	12	10	9	7	7	5	5	5	5	3	3	3	3	3	3	3	3	3	20
22	76	38	26	19	14	10	9	9	7	5	5	5	3	3	3	3	3	3	3	3	3	3	3	22
24	83	38	24	17	14	10	9	7	7	5	5	5	3	3	3	3	3	3	2	2	2	2	2	24
26	90	40	24	17	14	10	9	7	7	5	5	5	3	3	3	3	2	2	2	2	2	2	2	26
28	99	42	24	17	14	10	9	7	7	5	5	5	3	3	3	3	2	2	2	2	2	2	2	28
30	108	43	24	17	12	10	9	7	5	5	5	5	3	3	3	3	2	2	2	2	2	2	2	30
32	118	47	26	17	14	10	9	7	5	5	5	3	3	3	3	3	2	2	2	2	2	2	2	32
34	130	50	26	17	12	10	9	7	5	5	3	3	3	3	3	3	2	2	2	2	2	2	2	34
36	143	54	28	17	12	10	9	7	5	5	3	3	3	3	3	3	2	2	2	2	2	2	2	36
38	155	57	28	17	12	10	9	7	5	5	3	3	3	3	3	3	2	2	2	2	2	2	2	38
40	169	61	30	17	12	10	9	7	5	5	3	3	3	3	3	2	2	2	2	2	2	2	2	40
42	183	66	31	19	12	10	9	7	5	5	3	3	3	3	2	2	2	2	2	2	2	2	2	42
44	198	70	33	19	12	9	7	7	5	5	3	3	3	3	2	2	2	2	2	2	2	2	0	44
46	216	75	35	19	14	10	7	7	5	5	3	3	3	3	2	2	2	2	2	2	2	0	0	46
48	231	80	37	21	14	10	7	7	5	5	3	3	3	3	2	2	2	2	2	2	2	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	770	475	382	344	323	313	306	301	297	296	294	292	292	290	290	290	289	287	287	287	231	287	285	6
8	638	433	292	235	209	193	184	179	176	172	170	169	167	167	165	165	163	163	162	162	162	162	162	8
10	608	374	276	198	162	143	130	123	118	116	113	111	110	110	108	108	106	106	104	104	104	104	104	10
12	570	344	247	193	144	118	104	96	90	85	83	82	80	78	76	76	75	75	73	73	73	73	73	12
14	565	339	224	176	141	110	92	80	73	70	66	63	61	59	59	57	56	56	54	54	54	54	54	14
16	544	322	219	160	130	108	87	73	64	59	56	52	50	49	47	47	43	43	42	42	42	42	42	16
18	551	320	214	153	120	103	85	70	59	52	49	45	42	40	40	38	37	35	35	33	33	33	33	18
20	575	309	205	151	113	94	82	70	57	50	43	40	38	35	35	33	30	30	28	28	28	26	26	20
22	614	306	203	148	111	89	75	66	57	49	42	38	35	31	30	30	26	24	24	23	23	23	23	22
24	662	309	202	143	113	85	71	61	56	49	42	37	33	30	28	26	23	21	21	19	19	19	19	24
26	721	320	196	141	108	85	68	57	52	47	42	35	31	28	26	24	21	19	17	17	17	17	16	26
28	789	334	196	141	104	85	68	56	49	43	40	35	31	28	24	23	19	17	16	16	16	14	14	28
30	866	351	198	137	104	82	68	56	47	42	38	35	31	28	24	23	17	16	14	14	14	12	12	30
32	949	372	203	136	104	80	66	54	45	40	37	33	31	28	24	21	17	14	14	12	12	12	10	32
34	1040	398	209	136	103	80	64	56	45	38	35	31	30	28	24	21	16	14	12	12	10	10	10	34
36	1137	424	217	137	101	80	63	54	45	38	33	30	28	26	24	21	16	14	12	10	10	9	9	36
38	1241	455	228	141	99	78	63	52	45	38	33	30	26	24	23	21	16	12	10	10	9	9	9	38
40	1351	487	238	144	101	78	63	52	43	38	33	28	26	23	21	21	16	12	10	9	9	9	9	40
42	1467	521	250	148	101	76	63	50	43	38	33	28	24	23	21	19	16	12	10	9	9	7	7	42
44	1591	560	264	153	103	76	61	50	42	37	33	28	24	23	21	19	16	12	10	9	7	7	7	44
46	1719	598	280	160	104	76	61	50	42	37	31	28	24	21	19	17	16	12	10	9	7	7	7	46
48	1740	640	296	165	108	78	61	50	42	37	31	28	24	21	19	17	14	12	10	9	7	7	7	48

TABLE 6-11. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	2599	1604	1292	1159	1093	1055	1033	1017	1006	998	993	987	986	982	980	979	973	970	968	968	779	966	965	6
8	2150	1462	984	793	702	652	622	603	589	581	574	568	565	561	560	556	553	549	548	548	546	544	544	8
10	2053	1259	935	669	546	480	442	417	402	391	382	375	372	369	365	363	358	355	353	353	351	349	349	10
12	1926	1159	831	650	487	402	353	323	302	290	280	273	268	264	261	257	252	250	247	247	245	245	243	12
14	1905	1146	756	591	478	370	309	273	249	233	221	214	207	202	198	196	189	186	184	183	181	181	181	14
16	1837	1083	737	537	443	365	290	245	217	198	184	176	169	163	158	155	149	146	143	141	141	139	139	16
18	1858	1078	721	515	403	344	289	235	202	179	163	151	144	137	132	129	122	116	115	113	111	111	110	18
20	1940	1045	694	513	384	315	275	235	193	167	149	136	127	120	115	110	103	97	96	92	92	90	90	20
22	2069	1033	688	497	375	297	252	224	193	163	141	127	116	108	103	97	89	83	80	78	76	76	75	22
24	2237	1045	678	482	379	290	238	209	188	162	139	122	110	101	94	89	78	73	70	68	66	64	64	24
26	2437	1078	664	478	363	289	231	196	174	158	139	120	106	96	87	82	71	64	61	59	57	56	56	26
28	2600	1125	662	476	355	287	228	189	165	148	136	120	104	92	83	76	64	57	54	52	50	49	49	28
30	2600	1186	669	464	351	276	228	186	158	139	127	118	104	90	82	75	61	54	49	47	45	43	42	30
32	2600	1259	685	459	353	271	224	184	155	134	120	111	103	92	80	73	57	50	45	42	40	38	38	32
34	2600	1340	706	461	344	269	217	186	153	130	116	104	97	90	82	71	56	47	42	38	37	35	35	34
36	2600	1434	734	464	339	269	214	181	153	129	113	101	92	85	82	73	54	45	40	37	33	33	31	36
38	2600	1535	768	473	337	266	212	176	153	129	111	97	89	82	76	73	54	43	37	33	31	30	28	38
40	2600	1644	805	485	339	261	212	174	148	129	110	96	85	78	73	70	52	42	35	31	30	28	26	40
42	2600	1761	847	501	341	259	212	172	146	127	110	94	83	76	70	66	54	42	35	30	28	26	24	42
44	2600	1886	893	518	346	259	209	172	143	123	110	94	83	75	68	63	54	40	33	30	26	24	23	44
46	2600	2018	942	537	353	259	205	172	143	122	108	94	82	73	66	61	50	40	33	28	24	23	21	46
48	2600	2159	996	560	362	261	203	170	143	120	106	94	82	73	66	59	49	40	33	28	24	23	21	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	3950	3803	3059	2748	2592	2501	2448	2411	2385	2366	2352	2343	2335	2328	2322	2317	2308	2300	2296	2295	1846	2289	2286	6
8	3950	3464	2331	1881	1664	1545	1474	1429	1399	1377	1359	1349	1338	1332	1325	1319	1311	1304	1300	1295	1293	1292	1290	8
10	3950	2985	2216	1585	1292	1137	1046	989	951	925	906	892	881	873	866	860	848	841	838	834	831	831	829	10
12	3950	2747	1971	1540	1152	951	836	765	718	687	664	648	634	626	617	612	600	591	586	584	581	579	577	12
14	3950	2713	1794	1401	1132	876	732	645	589	551	525	504	490	480	471	464	450	442	436	433	429	428	426	14
16	3950	2567	1747	1274	1048	866	688	582	515	469	438	415	400	386	377	369	353	344	339	335	332	330	329	16
18	3950	2554	1709	1220	956	815	685	556	476	422	386	360	341	325	315	306	289	278	271	268	264	262	261	18
20	3950	2479	1643	1217	909	746	652	555	459	396	353	323	301	283	271	261	242	231	224	221	217	216	214	20
22	3950	2448	1631	1177	892	706	600	534	459	386	335	301	275	256	242	231	209	196	189	186	183	179	177	22
24	3950	2477	1606	1142	897	687	567	492	445	384	329	289	259	238	221	209	184	172	163	158	155	153	151	24
26	3950	2554	1573	1132	859	683	548	466	412	375	329	283	250	226	207	193	167	153	144	139	136	132	130	26
28	3950	2667	1568	1130	838	678	541	448	389	351	323	283	247	219	198	183	153	137	129	123	118	116	113	28
30	3950	2811	1585	1102	831	655	541	440	375	332	301	280	247	216	193	176	144	127	116	110	106	103	101	30
32	3950	2981	1622	1090	836	641	532	436	367	318	285	262	245	217	191	172	136	118	106	99	96	92	90	32
34	3950	3178	1674	1090	817	636	516	440	362	309	275	249	229	216	191	170	132	111	99	92	87	83	82	34
36	3950	3397	1740	1100	805	638	508	428	362	306	266	240	219	203	193	170	129	106	92	85	80	76	73	36
38	3950	3637	1818	1121	800	631	504	417	362	304	262	231	210	195	183	172	127	103	89	80	75	70	68	38
40	3950	3897	1909	1149	801	619	504	410	351	304	259	228	203	186	174	163	125	99	83	75	70	66	63	40
42	3950	3950	2008	1186	808	614	502	409	344	301	259	224	200	181	167	156	125	97	82	71	66	61	59	42
44	3950	3950	2117	1226	822	612	492	407	339	294	259	223	196	177	162	149	127	96	80	70	63	57	54	44
46	3950	3950	2234	1272	838	614	487	409	337	289	256	223	195	174	158	146	122	96	78	66	59	54	52	46
48	3950	3950	2361	1325	859	619	485	402	337	285	250	224	195	172	155	141	116	96	76	64	57	52	49	48

TABLE 6-11. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
25-27 OZ. WOVEN ROVING - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4940	4940	4940	4940	4940	4886	4779	4707	4657	4622	4594	4575	4560	4546	4535	4527	4509	4490	4483	4480	3605	4471	4466	6
8	4940	4940	4554	3673	3249	3019	2880	2792	2733	2689	2656	2634	2616	2600	2588	2578	2559	2547	2538	2531	2526	2522	2519	8
10	4940	4940	4330	3098	2524	2220	2044	1933	1858	1808	1770	1742	1721	1704	1691	1681	1658	1644	1636	1629	1624	1622	1618	10
12	4940	4940	3849	3007	2249	1857	1632	1493	1405	1342	1299	1265	1241	1222	1206	1194	1170	1156	1146	1140	1135	1132	1128	12
14	4940	4940	3504	2738	2209	1710	1431	1260	1151	1076	1024	986	958	935	920	906	878	862	852	845	840	836	833	14
16	4940	4940	3412	2489	2049	1691	1345	1139	1006	918	857	812	780	754	735	720	690	673	661	654	648	645	641	16
18	4940	4940	3339	2385	1869	1592	1337	1086	930	826	753	702	664	636	614	596	563	542	530	523	518	513	511	18
20	4940	4839	3211	2376	1775	1457	1272	1083	897	774	690	631	588	555	530	511	473	452	438	429	424	421	417	20
22	4940	4782	3185	2298	1742	1378	1172	1041	895	753	655	588	537	501	473	450	409	386	370	362	355	351	348	22
24	4940	4839	3139	2229	1752	1342	1106	963	869	753	640	563	506	464	433	409	362	335	320	309	304	299	296	24
26	4940	4940	3073	2211	1677	1333	1069	909	805	735	641	553	488	442	405	377	327	297	282	271	262	259	254	26
28	4940	4940	3063	2206	1637	1325	1055	876	761	685	629	553	480	428	388	358	299	269	250	240	231	226	223	28
30	4940	4940	3098	2150	1624	1279	1055	859	732	648	589	546	482	422	377	344	280	247	228	216	207	202	196	30
32	4940	4940	3169	2128	1632	1253	1038	854	714	622	558	513	478	422	374	337	266	229	209	195	186	181	176	32
34	4940	4940	3271	2129	1594	1245	1008	859	706	605	535	487	450	422	375	334	257	216	193	179	170	163	158	34
36	4940	4940	3400	2150	1570	1246	991	834	706	596	521	468	428	398	375	334	250	207	181	165	156	149	144	36
38	4940	4940	3553	2190	1561	1231	984	815	706	593	511	454	410	379	355	335	247	198	172	155	144	137	132	38
40	4940	4940	3727	2246	1566	1210	984	803	687	594	506	443	398	365	339	318	245	193	165	148	136	127	122	40
42	4940	4940	3922	2314	1580	1199	980	796	673	589	504	438	389	353	325	304	245	189	158	141	129	120	113	42
44	4940	4940	4134	2395	1604	1196	963	796	664	574	508	436	384	344	315	292	249	188	155	134	122	113	106	44
46	4940	4940	4363	2486	1637	1199	951	800	659	565	499	436	381	339	308	283	236	188	151	130	116	106	101	46
48	4940	4940	4610	2588	1677	1210	946	784	657	558	488	438	379	335	302	276	228	188	149	127	111	103	96	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	7200	6230	7200	7200	6
8	7200	7200	7200	6347	5615	5217	4977	4824	4721	4645	4591	4549	4520	4492	4471	4454	4422	4400	4386	4374	4365	4358	4353	8
10	7200	7200	7200	5352	4361	3836	3530	3339	3211	3122	3058	3009	2972	2945	2922	2903	2865	2840	2826	2816	2806	2802	2797	10
12	7200	7200	6651	5196	3887	3209	2821	2581	2425	2319	2242	2187	2143	2110	2086	2065	2022	1997	1980	1969	1961	1956	1950	12
14	7200	7200	6054	4730	3817	2957	2472	2176	1987	1858	1770	1704	1655	1617	1587	1564	1518	1490	1472	1460	1450	1445	1439	14
16	7200	7200	5896	4301	3541	2924	2326	1968	1738	1587	1481	1405	1347	1304	1271	1245	1192	1161	1142	1130	1121	1114	1109	16
18	7200	7200	5769	4120	3228	2752	2310	1879	1606	1425	1302	1213	1147	1099	1060	1031	972	939	918	904	893	888	881	18
20	7200	7200	5547	4106	3066	2519	2201	1870	1549	1338	1192	1090	1015	960	916	883	817	780	758	744	734	727	720	20
22	7200	7200	5503	3970	3011	2383	2023	1801	1545	1300	1133	1015	928	866	817	779	706	666	641	626	614	607	601	22
24	7200	7200	5423	3852	3030	2317	1912	1662	1500	1299	1107	972	874	801	747	706	624	579	553	535	525	516	509	24
26	7200	7200	5309	3819	2899	2305	1848	1571	1392	1271	1107	954	843	761	701	654	563	515	485	468	455	447	440	26
28	7200	7200	5291	3810	2830	2289	1822	1514	1316	1182	1088	954	831	739	671	617	518	464	433	414	400	391	384	28
30	7200	7200	5352	3716	2806	2211	1825	1483	1265	1119	1017	944	831	730	654	594	485	426	393	370	356	348	339	30
32	7200	7200	5476	3677	2820	2166	1792	1474	1234	1076	965	885	826	730	647	581	461	396	360	337	322	311	304	32
34	7200	7200	5651	3678	2755	2149	1742	1483	1220	1046	927	840	777	730	647	575	443	374	334	309	294	282	275	34
36	7200	7200	5875	3716	2713	2154	1712	1443	1219	1031	900	807	739	688	648	577	431	356	313	287	269	257	249	36
38	7200	7200	6140	3784	2698	2128	1698	1408	1220	1024	883	782	709	655	614	581	426	344	297	269	250	238	229	38
40	7200	7200	6440	3880	2705	2091	1700	1387	1186	1026	874	767	688	629	584	549	422	334	285	254	235	221	212	40
42	7200	7200	6776	3998	2731	2072	1693	1377	1161	1017	873	756	673	610	563	525	424	329	275	242	221	207	196	42
44	7200	7200	7143	4139	2773	2065	1664	1375	1146	993	876	753	662	596	546	506	428	325	268	233	210	195	184	44
46	7200	7200	7200	4297	2828	2072	1644	1382	1139	975	862	753	657	586	532	490	410	323	262	224	200	184	174	46
48	7200	7200	7200	4473	2898	2091	1634	1356	1137	963	843	758	655	579	521	478	393	325	259	219	193	176	165	48

TABLE 6-11. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
25-27 OZ. WOVEN ROVING - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	8400	6
8	8400	8400	8400	8400	8400	8285	7904	7661	7496	7377	7290	7224	7177	7134	7101	7073	7021	6986	6964	6945	6931	6920	6913	8
10	8400	8400	8400	8400	6925	6093	5608	5302	5098	4959	4855	4779	4721	4676	4641	4612	4549	4511	4488	4471	4455	4448	4441	10
12	8400	8400	8400	8252	6173	5095	4480	4099	3852	3682	3562	3473	3405	3353	3311	3278	3211	3171	3145	3127	3115	3105	3096	12
14	8400	8400	8400	7511	6063	4695	3923	3457	3155	2952	2809	2705	2627	2567	2522	2434	2409	2364	2338	2319	2303	2293	2286	14
16	8400	8400	8400	6830	5622	4641	3694	3124	2762	2519	2350	2229	2140	2070	2018	1976	1893	1844	1815	1794	1780	1768	1761	16
18	8400	8400	8400	6543	5126	4368	3668	2983	2550	2265	2067	1926	1822	1744	1684	1636	1544	1490	1457	1436	1420	1410	1401	18
20	8400	8400	8400	6520	4869	4000	3494	2971	2461	2124	1895	1731	1613	1523	1455	1401	1299	1239	1205	1180	1165	1152	1144	20
22	8400	8400	8400	6305	4780	3784	3212	2860	2454	2065	1799	1611	1476	1373	1297	1236	1121	1057	1019	993	975	963	954	22
24	8400	8400	8400	6117	4810	3680	3035	2640	2383	2063	1757	1544	1389	1274	1187	1119	991	921	878	852	833	820	810	24
26	8400	8400	8400	6065	4605	3659	2936	2494	2209	2016	1757	1514	1338	1210	1113	1038	895	817	772	742	723	709	699	26
28	8400	8400	8400	6051	4494	3635	2894	2404	2089	1877	1730	1516	1319	1173	1064	980	822	739	688	657	636	621	610	28
30	8400	8400	8400	5903	4457	3511	2898	2355	2009	1778	1615	1498	1321	1158	1038	944	770	676	622	589	567	551	539	30
32	8400	8400	8400	5837	4478	3440	2847	2341	1961	1707	1531	1406	1312	1161	1026	923	730	629	572	535	511	494	482	32
34	8400	8400	8400	5841	4375	3412	2766	2354	1938	1662	1471	1335	1234	1158	1027	914	704	593	530	490	466	447	435	34
36	8400	8400	8400	5902	4309	3421	2719	2291	1936	1636	1429	1281	1173	1092	1029	916	687	567	497	455	428	409	396	36
38	8400	8400	8400	6011	4285	3378	2698	2235	1938	1625	1403	1243	1126	1040	973	921	676	546	471	426	396	377	363	38
40	8400	8400	8400	6162	4295	3320	2700	2202	1883	1631	1389	1217	1093	1000	928	873	673	532	452	403	372	351	335	40
42	8400	8400	8400	6350	4335	3289	2689	2185	1844	1617	1385	1201	1069	968	893	834	674	521	436	384	351	329	313	42
44	8400	8400	8400	6571	4403	3280	2640	2185	1820	1577	1392	1194	1052	946	866	803	680	516	424	369	334	309	292	44
46	8400	8400	8400	6823	4492	3291	2609	2194	1808	1547	1368	1196	1043	930	845	779	652	515	415	356	318	294	276	46
48	8400	8400	8400	7103	4603	3320	2595	2154	1804	1530	1338	1203	1041	920	829	760	624	516	410	348	308	280	261	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	6
8	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	9600	8
10	9600	9600	9600	9600	9600	9093	8370	7914	7610	7402	7247	7134	7047	6979	6927	6884	6792	6734	6699	6675	6651	6640	6628	10
12	9600	9600	9600	9600	9215	7605	6686	6119	5750	5497	5317	5184	5083	5005	4944	4893	4792	4733	4693	4669	4648	4636	4622	12
14	9600	9600	9600	9600	9050	7007	5858	5159	4711	4407	4193	4038	3922	3833	3763	3708	3595	3530	3489	3461	3438	3423	3412	14
16	9600	9600	9600	9600	8393	6929	5514	4664	4123	3760	3510	3327	3193	3091	3012	2950	2826	2753	2708	2679	2656	2640	2628	16
18	9600	9600	9600	9600	7652	6520	5474	4454	3807	3379	3085	2875	2720	2602	2514	2442	2303	2223	2175	2142	2119	2103	2091	18
20	9600	9600	9600	9600	7270	5969	5215	4434	3673	3172	2828	2585	2408	2274	2171	2093	1936	1851	1797	1763	1738	1721	1707	20
22	9600	9600	9600	9411	7136	5649	4796	4268	3664	3082	2686	2406	2202	2051	1935	1846	1672	1578	1519	1481	1457	1438	1424	22
24	9600	9600	9600	9131	7179	5495	4532	3941	3557	3080	2623	2303	2072	1902	1771	1672	1479	1373	1311	1271	1243	1224	1210	24
26	9600	9600	9600	9053	6873	5462	4382	3723	3299	3011	2623	2260	1999	1806	1660	1549	1335	1220	1151	1107	1078	1057	1043	26
28	9600	9600	9600	9032	6708	5427	4320	3588	3119	2802	2581	2263	1968	1752	1589	1464	1227	1102	1027	980	949	927	911	28
30	9600	9600	9600	8811	6652	5241	4325	3517	3000	2653	2411	2237	1971	1730	1549	1410	1149	1010	930	880	845	822	805	30
32	9600	9600	9600	8714	6684	5137	4250	3494	2927	2548	2286	2098	1959	1731	1531	1378	1092	940	854	798	763	737	720	32
34	9600	9600	9600	8719	6531	5095	4130	3515	2893	2481	2195	1992	1843	1728	1535	1366	1050	887	791	734	695	668	648	34
36	9600	9600	9600	8810	6433	5105	4059	3419	2891	2442	2133	1912	1752	1631	1537	1368	1024	845	742	680	640	610	591	36
38	9600	9600	9600	8971	6397	5043	4026	3338	2894	2427	2093	1857	1683	1552	1453	1375	1008	815	704	636	593	563	542	38
40	9600	9600	9600	9197	6413	4956	4029	3287	2811	2434	2072	1817	1631	1493	1387	1304	1003	793	674	601	555	523	501	40
42	9600	9600	9600	9479	6472	4909	4014	3263	2753	2413	2069	1794	1594	1446	1333	1246	1005	779	650	574	523	490	466	42
44	9600	9600	9600	9600	6573	4897	3942	3261	2717	2352	2077	1783	1571	1411	1292	1199	1015	770	633	551	497	461	436	44
46	9600	9600	9600	9600	6706	4912	3896	3275	2698	2310	2043	1785	1558	1389	1260	1161	972	768	621	532	476	438	412	46
48	9600	9600	9600	9600	6870	4956	3873	3214	2694	2282	1999	1796	1552	1373	1238	1133	932	770	612	518	459	417	389	48

TABLE 6-11. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 25-27 OZ. WOVEN ROVING - ALL EDGES CLAMPED (Cont'd)

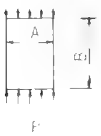
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	6
8	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	10800	8
10	10800	10800	10800	10800	10800	10800	10800	10800	10800	10539	10320	10157	10033	9938	9863	9801	9670	9588	9538	9503	9469	9455	9437	10
12	10800	10800	10800	10800	10800	10800	9519	8712	8186	7826	7570	7381	7237	7125	7038	6967	6825	6739	6682	6647	6619	6600	6581	12
14	10800	10800	10800	10800	10800	9978	8340	7346	6706	6274	5971	5749	5583	5458	5359	5281	5119	5025	4968	4928	4895	4872	4859	14
16	10800	10800	10800	10800	10800	9865	7850	6640	5870	5354	4996	4737	4547	4401	4288	4200	4024	3920	3856	3814	3783	3758	3743	16
18	10800	10800	10800	10800	10800	9284	7795	6340	5422	4813	4393	4094	3873	3706	3579	3478	3280	3167	3098	3051	3018	2995	2978	18
20	10800	10800	10800	10800	10350	8500	7426	6314	5231	4516	4028	3680	3426	3237	3092	2979	2759	2635	2559	2508	2475	2449	2430	20
22	10800	10800	10800	10800	10159	8043	6828	6075	5218	4389	3823	3424	3136	2920	2755	2628	2381	2246	2164	2110	2074	2048	2027	22
24	10800	10800	10800	10800	10223	7822	6453	5611	5064	4384	3736	3280	2952	2707	2522	2380	2105	1956	1867	1810	1770	1742	1721	24
26	10800	10800	10800	10800	9788	7777	6239	5302	4697	4287	3736	3219	2847	2571	2364	2204	1902	1737	1639	1577	1535	1505	1485	26
28	10800	10800	10800	10800	9552	7727	6150	5109	4441	3991	3675	3221	2802	2494	2263	2084	1749	1568	1462	1396	1351	1319	1297	28
30	10800	10800	10800	10800	9472	7464	6159	5006	4271	3777	3433	3186	2806	2461	2204	2008	1636	1439	1325	1252	1205	1172	1147	30
32	10800	10800	10800	10800	9517	7313	6051	4975	4168	3630	3256	2986	2788	2467	2180	1963	1554	1338	1215	1137	1086	1050	1024	32
34	10800	10800	10800	10800	9298	7254	5881	5003	4120	3532	3125	2837	2623	2461	2185	1945	1495	1262	1126	1043	989	951	925	34
36	10800	10800	10800	10800	9159	7270	5778	4867	4115	3477	3037	2724	2494	2321	2189	1949	1458	1203	1057	968	909	869	841	36
38	10800	10800	10800	10800	9107	7179	5733	4753	4120	3456	2979	2642	2395	2211	2069	1959	1436	1159	1003	907	845	801	772	38
40	10800	10800	10800	10800	9130	7057	5736	4680	4003	3464	2952	2588	2322	2124	1975	1857	1429	1128	960	857	791	744	713	40
42	10800	10800	10800	10800	9215	6990	5716	4646	3920	3435	2945	2554	2270	2060	1898	1773	1432	1109	927	817	746	697	664	42
44	10800	10800	10800	10800	9357	6972	5613	4643	3868	3350	2959	2540	2237	2011	1839	1707	1445	1097	902	784	707	657	621	44
46	10800	10800	10800	10800	9548	6995	5547	4662	3842	3291	2908	2541	2218	1976	1796	1655	1384	1093	885	758	678	624	586	46
48	10800	10800	10800	10800	9783	7056	5514	4575	3836	3251	2846	2555	2211	1956	1763	1613	1328	1097	873	737	652	594	555	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	6
8	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	8
10	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	10
12	12000	12000	12000	12000	12000	12000	12000	11951	11229	10734	10385	10124	9927	9773	9655	9559	9361	9244	9166	9117	9079	9053	9027	12
14	12000	12000	12000	12000	12000	12000	11440	10077	9199	8606	8191	7887	7659	7487	7351	7243	7023	6894	6814	6760	6715	6684	6665	14
16	12000	12000	12000	12000	12000	12000	10767	9109	8052	7344	6854	6500	6237	6039	5884	5761	5519	5377	5290	5232	5187	5156	5133	16
18	12000	12000	12000	12000	12000	12000	10692	8697	7436	6602	6025	5615	5312	5083	4909	4772	4500	4344	4248	4184	4139	4108	4083	18
20	12000	12000	12000	12000	12000	11661	10186	8660	7174	6195	5524	5048	4700	4440	4241	4087	3784	3614	3510	3442	3395	3360	3334	20
22	12000	12000	12000	12000	12000	11035	9366	8335	7158	6020	5244	4697	4301	4005	3779	3605	3268	3080	2967	2894	2844	2809	2781	22
24	12000	12000	12000	12000	12000	10731	8851	7697	6946	6015	5125	4499	4049	3713	3459	3265	2889	2684	2561	2482	2428	2390	2361	24
26	12000	12000	12000	12000	12000	10668	8558	7273	6442	5879	5125	4415	3904	3527	3244	3025	2607	2381	2249	2164	2107	2065	2036	26
28	12000	12000	12000	12000	12000	10600	8436	7009	6091	5474	5041	4419	3845	3421	3105	2860	2399	2152	2006	1916	1853	1811	1778	28
30	12000	12000	12000	12000	12000	10239	8448	6868	5858	5182	4711	4370	3849	3378	3023	2753	2244	1973	1817	1717	1651	1606	1573	30
32	12000	12000	12000	12000	12000	10032	8299	6825	5717	4978	4466	4097	3826	3383	2992	2693	2131	1836	1665	1559	1490	1441	1405	32
34	12000	12000	12000	12000	12000	9950	8066	6865	5651	4845	4288	3890	3598	3376	2997	2667	2051	1731	1545	1432	1356	1305	1267	34
36	12000	12000	12000	12000	12000	9973	7927	6679	5646	4770	4167	3736	3421	3185	3002	2674	1999	1650	1451	1328	1248	1192	1154	36
38	12000	12000	12000	12000	12000	9847	7864	6519	5651	4740	4088	3624	3287	3033	2839	2687	1969	1591	1375	1243	1158	1100	1059	38
40	12000	12000	12000	12000	12000	9681	7869	6420	5491	4753	4049	3550	3186	2915	2708	2547	1959	1549	1316	1175	1083	1022	979	40
42	12000	12000	12000	12000	12000	9588	7841	6373	5378	4711	4040	3504	3115	2825	2604	2434	1964	1521	1271	1119	1022	956	911	42
44	12000	12000	12000	12000	12000	9564	7699	6369	5305	4596	4059	3484	3068	2759	2524	2341	1983	1505	1238	1074	972	900	852	44
46	12000	12000	12000	12000	12000	9595	7610	6395	5269	4513	3989	3485	3042	2712	2461	2268	1898	1500	1213	1040	928	855	803	46
48	12000	12000	12000	12000	12000	9679	7565	6277	5262	4459	3902	3506	3033	2682	2418	2213	1822	1504	1196	1012	895	815	761	48

TABLE 6-12. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED



PHYSICAL CONSTANTS:

E_X 1.96x10^5 PSI

E_Y = 1.70x10^6 PSI

G_{XY} = 0.52x10^6 PSI

$\sigma_{XY} = \sigma_{YX}$ = 0.20

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	37	23	17	15	13	12	12	11	11	11	11	11	11	10	10	10	10	10	10	10	10	10	10	6
8	42	21	14	11	9	8	8	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	8
10	38	23	13	10	8	6	6	5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	10
12	37	23	14	9	7	6	5	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	12
14	39	21	15	10	7	5	4	4	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	14
16	38	21	14	10	7	5	4	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	1	16
18	37	22	14	10	8	5	4	3	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	18
20	38	22	13	10	8	6	4	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	20
22	37	21	14	9	7	6	4	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	22
24	37	21	14	9	7	6	5	4	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	24
26	38	21	14	9	7	5	5	4	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	26
28	37	21	13	10	7	5	4	4	3	2	2	2	1	1	1	1	1	1	1	1	1	1	1	28
30	37	21	13	10	7	5	4	4	3	3	2	2	1	1	1	1	1	1	1	1	1	1	1	30
32	38	21	14	9	7	5	4	3	3	3	2	2	2	1	1	1	1	1	1	1	1	0	0	32
34	37	21	14	9	7	5	4	3	3	3	2	2	2	1	1	1	1	1	1	1	0	0	0	34
36	37	21	14	9	7	5	4	3	3	3	2	2	2	1	1	1	1	1	1	0	0	0	0	36
38	38	21	13	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	1	0	0	0	0	38
40	37	21	13	10	7	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	0	40
42	37	21	14	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	0	42
44	37	21	14	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	0	44
46	37	21	13	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	0	46
48	37	21	13	9	7	5	4	3	3	2	2	2	2	1	1	1	1	1	0	0	0	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	299	181	137	117	106	99	94	91	89	87	86	85	84	84	83	83	82	81	81	80	80	80	80	6
8	336	168	112	87	74	66	61	57	55	53	52	51	50	49	49	48	47	47	46	46	46	45	45	8
10	306	181	108	77	61	52	46	42	39	38	36	35	34	33	33	32	31	31	30	30	30	29	29	10
12	299	181	114	75	56	45	39	34	31	29	28	26	26	25	24	24	23	22	21	21	21	21	21	12
14	311	170	121	78	55	42	35	30	27	25	23	21	20	20	19	18	17	17	16	16	16	15	15	14
16	301	168	112	84	57	42	33	28	24	22	20	18	17	16	16	15	14	13	13	12	12	12	12	16
18	299	173	108	80	60	43	33	27	23	20	18	16	15	14	14	13	12	11	10	10	10	10	10	18
20	306	172	108	77	61	45	34	27	22	19	17	15	14	13	12	11	10	9	9	9	8	8	8	20
22	300	169	110	75	58	48	35	27	22	19	16	14	13	12	11	10	9	8	8	7	7	7	7	22
24	299	168	112	75	56	45	37	28	23	19	16	14	12	11	10	10	8	7	7	6	6	6	6	24
26	303	171	109	76	55	43	36	30	23	19	16	14	12	11	10	9	8	7	6	6	5	5	5	26
28	299	170	108	78	55	42	35	30	24	19	16	14	12	11	10	9	7	6	6	5	5	5	4	28
30	299	168	108	77	56	42	34	29	25	20	17	14	12	11	9	9	7	6	5	5	4	4	4	30
32	301	168	109	75	57	42	33	28	24	21	17	14	12	11	9	8	6	5	5	4	4	4	4	32
34	299	170	110	75	57	42	33	27	24	21	18	15	12	11	9	8	6	5	5	4	4	3	3	34
36	299	169	108	75	56	43	33	27	23	20	18	15	13	11	9	8	6	5	4	4	3	3	3	36
38	300	168	108	75	55	44	34	27	23	20	17	16	13	11	10	8	6	5	4	4	3	3	3	38
40	299	168	108	76	55	43	34	27	22	19	17	15	13	11	10	8	6	5	4	3	3	3	3	40
42	299	170	108	76	55	42	35	27	22	19	16	15	13	12	10	9	6	5	4	3	3	3	3	42
44	300	169	109	75	55	42	34	27	22	19	16	14	13	12	10	9	6	5	4	3	3	3	2	44
46	299	168	108	75	56	42	34	28	22	19	16	14	13	12	11	9	6	5	4	3	3	3	2	46
48	299	168	108	75	56	42	33	28	23	19	16	14	12	11	10	9	6	5	4	3	3	2	2	48

TABLE 6-12. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	1010	609	464	395	357	334	319	308	301	295	291	287	285	282	280	279	276	274	272	271	270	270	269	6
8	1133	568	378	293	249	222	205	194	185	179	175	171	168	166	164	163	159	157	156	154	154	153	153	8
10	1034	612	364	258	205	174	155	142	133	127	122	118	115	112	110	109	105	103	102	100	100	99	99	10
12	1010	609	383	253	188	152	130	116	106	99	93	89	86	84	81	80	76	74	72	71	70	70	69	12
14	1051	574	407	263	186	143	118	102	91	83	77	73	69	66	64	62	59	56	55	54	53	52	52	14
16	1017	568	378	283	191	142	113	94	82	73	67	62	58	56	53	51	47	45	43	42	41	41	40	16
18	1010	583	365	271	203	146	112	91	77	68	61	56	52	48	46	44	40	37	35	34	33	33	32	18
20	1032	582	364	258	205	153	115	91	75	65	57	51	47	44	41	39	34	32	30	29	28	27	27	20
22	1012	569	370	253	194	161	119	93	75	63	55	49	44	40	37	35	30	28	26	25	24	23	23	22
24	1010	568	378	253	188	152	126	96	76	63	54	47	42	38	35	33	28	25	23	22	21	20	19	24
26	1022	576	368	256	186	147	123	100	79	64	54	46	41	37	33	31	26	22	20	19	18	18	17	26
28	1010	574	364	263	186	143	118	102	82	66	54	46	40	36	32	30	24	21	19	17	16	16	15	28
30	1010	568	364	258	188	142	115	97	86	68	56	47	40	36	32	29	23	19	17	16	15	14	14	30
32	1017	568	367	254	191	142	113	94	82	71	57	48	41	36	31	28	22	18	16	15	14	13	12	32
34	1010	574	370	252	192	143	112	92	79	70	60	49	42	36	31	28	21	18	15	14	13	12	11	34
36	1010	571	365	253	188	146	112	91	77	68	61	51	43	36	32	28	21	17	14	13	12	11	10	36
38	1014	568	363	255	186	148	113	91	76	66	59	53	44	37	32	28	21	16	14	12	11	10	10	38
40	1009	568	364	258	185	145	115	91	75	65	57	51	45	38	33	29	21	16	13	12	11	10	9	40
42	1010	572	366	255	186	143	117	92	75	64	56	50	45	39	34	29	21	16	13	11	10	9	9	42
44	1012	569	367	253	187	142	116	93	75	63	55	49	44	40	35	30	21	16	13	11	10	9	8	44
46	1009	568	364	252	189	142	114	94	76	63	54	48	43	39	36	31	21	16	13	11	9	8	8	46
48	1010	568	363	253	188	142	113	94	76	63	54	47	42	38	35	31	21	16	13	10	9	8	7	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	2395	1444	1099	936	847	792	756	731	713	699	689	681	675	669	665	661	654	649	645	643	641	640	638	6
8	2685	1347	896	695	589	527	487	459	440	425	414	406	399	393	389	385	377	372	369	366	364	363	362	8
10	2450	1450	862	613	486	413	367	337	316	300	288	279	272	266	262	258	250	244	241	238	236	235	234	10
12	2395	1444	908	599	446	361	309	275	251	234	221	212	204	198	193	189	180	175	171	169	167	165	164	12
14	2490	1360	965	623	440	340	280	241	215	196	182	172	164	157	152	148	139	133	130	127	125	123	122	14
16	2410	1347	896	671	454	337	268	224	194	174	159	147	139	132	126	122	112	106	102	100	98	96	95	16
18	2395	1381	866	642	481	345	266	216	183	160	144	132	122	115	109	104	94	88	84	81	79	78	77	18
20	2446	1378	862	613	486	362	272	216	179	153	135	121	111	103	97	92	81	75	71	68	66	64	63	20
22	2399	1349	878	600	461	382	283	219	178	150	130	115	104	95	89	83	72	66	61	58	56	55	53	22
24	2395	1347	896	599	446	361	298	227	181	150	128	112	100	90	83	77	65	59	54	51	49	47	46	24
26	2423	1366	872	607	440	348	292	238	186	152	128	110	97	87	79	73	60	53	49	45	43	42	40	26
28	2395	1360	862	623	440	340	280	241	194	156	129	110	96	85	77	70	57	49	44	41	39	37	36	28
30	2395	1346	862	613	445	337	272	231	203	161	132	111	96	84	75	68	54	46	41	37	35	33	32	30
32	2410	1347	871	602	454	337	268	224	194	168	136	113	97	84	75	67	52	43	38	35	32	30	29	32
34	2393	1359	877	598	455	340	266	219	188	166	141	117	98	85	75	66	51	42	36	32	30	28	27	34
36	2395	1353	866	599	446	345	266	216	183	160	144	120	101	86	75	67	50	40	34	31	28	26	25	36
38	2403	1346	861	603	441	351	268	215	180	156	139	125	104	88	76	67	49	39	33	29	26	24	23	38
40	2392	1347	862	611	439	345	272	216	179	153	135	121	107	91	78	68	49	38	32	28	25	23	21	40
42	2395	1356	868	604	440	340	277	217	178	151	132	118	107	93	80	69	49	38	31	27	24	22	20	42
44	2399	1349	869	600	443	337	274	219	178	150	130	115	104	95	82	71	49	37	30	26	23	21	19	44
46	2392	1345	863	598	447	336	270	223	179	149	128	113	102	93	85	73	50	37	30	25	22	20	18	46
48	2395	1347	861	599	446	337	268	224	181	150	128	112	100	90	83	75	50	37	30	25	22	19	18	48

TABLE 6-12. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4678	2821	2146	1829	1654	1547	1477	1428	1393	1366	1347	1331	1318	1307	1298	1292	1277	1267	1261	1256	1252	1250	1247	6
8	5245	2631	1749	1358	1151	1029	950	897	859	831	809	792	779	768	760	752	737	727	720	715	711	709	706	8
10	4786	2832	1684	1197	949	807	718	658	617	586	563	546	532	520	511	504	487	477	470	465	461	459	457	10
12	4678	2821	1774	1169	872	705	603	537	490	457	432	413	399	387	377	369	352	342	334	330	326	323	321	12
14	4864	2656	1885	1216	859	664	547	471	420	383	356	336	320	307	297	289	271	260	253	248	244	241	239	14
16	4707	2631	1750	1311	886	658	523	437	380	339	310	288	271	257	246	238	219	208	200	195	191	188	186	16
18	4678	2698	1691	1254	940	675	520	423	358	313	281	257	238	224	213	203	184	172	164	159	155	152	150	18
20	4777	2692	1684	1197	949	708	531	421	349	299	264	237	217	202	189	179	159	147	138	133	129	126	124	20
22	4685	2635	1714	1171	900	746	553	429	348	293	254	225	203	187	173	163	141	128	120	114	110	107	104	22
24	4678	2631	1750	1169	872	705	583	443	353	292	249	218	194	176	162	151	128	114	106	100	95	92	90	24
26	4733	2667	1704	1186	859	679	570	464	364	296	249	215	189	170	155	142	118	104	95	89	84	81	79	26
28	4677	2656	1684	1216	859	664	547	471	378	304	252	215	187	166	150	137	111	96	86	80	76	72	70	28
30	4678	2630	1684	1197	869	657	532	451	396	315	258	217	187	164	147	133	105	90	80	73	69	65	63	30
32	4707	2631	1701	1177	886	658	523	437	380	328	266	222	189	164	146	131	101	85	75	68	63	59	57	32
34	4674	2655	1712	1168	888	664	519	428	367	325	276	228	192	166	146	130	99	81	70	63	58	55	52	34
36	4678	2642	1691	1169	872	675	520	423	358	313	281	235	197	169	147	130	97	78	67	60	54	51	48	36
38	4693	2628	1682	1178	862	687	524	421	352	305	271	244	203	172	149	131	96	76	64	57	51	48	45	38
40	4672	2631	1684	1194	858	673	531	421	349	299	264	237	210	177	152	133	95	75	62	54	49	45	42	40
42	4678	2649	1695	1181	859	664	540	424	347	295	258	230	209	182	156	135	95	74	61	52	47	43	40	42
44	4685	2635	1698	1171	865	659	536	429	348	293	254	225	203	187	160	138	96	73	60	51	45	41	38	44
46	4671	2628	1686	1168	874	657	528	435	350	292	251	221	198	181	165	142	97	73	59	50	43	39	36	46
48	4678	2631	1682	1169	872	658	523	437	353	292	249	218	194	176	162	146	98	73	58	49	42	38	34	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7090	4875	3709	3160	2857	2673	2552	2467	2407	2361	2327	2300	2278	2259	2244	2232	2207	2190	2178	2170	2163	2160	2155	6
8	7090	4547	3023	2346	1989	1777	1642	1550	1484	1435	1399	1369	1347	1328	1313	1300	1273	1256	1244	1235	1229	1225	1220	8
10	7090	4893	2910	2068	1640	1394	1240	1138	1065	1013	973	943	919	899	883	870	842	824	812	804	797	793	790	10
12	7090	4875	3065	2021	1506	1219	1043	927	847	790	747	714	689	668	652	638	609	590	578	569	563	558	555	12
14	7090	4590	3258	2101	1485	1148	945	814	726	662	616	580	553	531	513	499	469	450	437	428	422	417	413	14
16	7090	4547	3023	2266	1531	1137	904	756	656	586	535	497	468	444	426	411	379	359	346	337	330	325	321	16
18	7090	4662	2922	2167	1625	1166	898	730	619	542	486	444	412	387	367	351	317	297	284	274	267	262	259	18
20	7090	4652	2910	2068	1639	1223	917	727	603	517	455	410	375	348	327	310	275	253	239	230	223	218	214	20
22	7090	4554	2963	2024	1555	1289	955	741	601	506	438	389	351	322	299	281	244	221	207	197	190	185	180	22
24	7090	4547	3023	2021	1506	1219	1007	766	611	505	431	377	336	305	280	261	221	197	182	172	165	159	155	24
26	7090	4609	2944	2049	1485	1174	985	802	629	512	430	371	327	293	267	246	204	179	164	153	146	140	136	26
28	7090	4590	2909	2101	1485	1148	945	814	654	525	436	371	323	287	259	236	191	166	149	138	130	125	120	28
30	7090	4544	2910	2068	1501	1136	919	780	685	544	446	375	323	284	254	230	182	155	138	126	118	113	108	30
32	7090	4547	2939	2033	1531	1137	904	756	656	566	459	383	327	284	252	226	175	147	129	117	109	103	98	32
34	7090	4588	2959	2019	1535	1147	897	740	635	561	476	393	332	287	252	224	171	140	122	109	101	94	90	34
36	7090	4565	2922	2021	1506	1166	898	730	619	542	486	406	341	291	254	225	167	135	116	103	94	88	83	36
38	7090	4541	2907	2036	1490	1186	905	727	609	527	469	421	351	298	258	226	166	132	111	98	89	82	77	38
40	7090	4547	2910	2064	1483	1163	917	727	603	517	455	410	362	306	263	229	165	129	108	94	84	78	72	40
42	7090	4577	2929	2040	1485	1147	934	732	600	510	445	398	362	315	269	233	165	128	105	90	81	74	68	42
44	7090	4554	2934	2024	1494	1138	926	741	601	506	438	389	351	322	277	239	166	126	103	88	78	70	65	44
46	7090	4540	2913	2018	1510	1135	913	752	605	504	434	382	343	313	285	245	168	126	101	86	75	68	62	46
48	7090	4547	2906	2021	1506	1137	904	756	611	505	431	377	336	305	280	252	170	126	100	84	73	65	59	48

TABLE 6-12. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8270	7741	5889	5018	4537	4244	4052	3918	3822	3748	3695	3652	3617	3587	3563	3545	3504	3477	3459	3445	3434	3431	3422	6
8	8270	7220	4801	3725	3158	2822	2608	2461	2356	2279	2221	2174	2139	2108	2085	2065	2021	1994	1976	1961	1952	1946	1938	8
10	8270	7770	4621	3283	2604	2214	1969	1806	1692	1609	1546	1497	1459	1428	1403	1382	1337	1309	1290	1276	1266	1259	1254	10
12	8270	7741	4867	3209	2392	1935	1656	1472	1346	1254	1187	1134	1094	1061	1035	1013	966	937	918	904	894	886	881	12
14	8270	7289	5173	3337	2358	1822	1501	1293	1152	1052	978	922	878	843	815	793	744	714	694	680	670	662	656	14
16	8270	7220	4801	3598	2431	1805	1435	1200	1042	931	850	790	743	706	676	652	601	570	549	535	524	516	510	16
18	8270	7404	4640	3440	2580	1851	1426	1160	983	860	771	705	654	615	583	558	504	472	450	435	425	416	411	18
20	8270	7387	4621	3283	2603	1943	1456	1155	957	821	723	651	596	553	520	492	436	402	380	365	354	346	339	20
22	8270	7231	4705	3214	2469	2047	1516	1176	955	803	696	617	558	512	476	446	387	351	328	313	301	293	287	22
24	8270	7220	4801	3209	2392	1935	1599	1217	970	802	684	598	533	484	445	414	351	314	290	273	262	253	247	24
26	8270	7319	4675	3253	2358	1864	1564	1273	998	813	684	590	519	466	424	391	324	285	260	243	231	222	216	26
28	8270	7288	4620	3337	2358	1822	1501	1293	1038	834	692	589	513	456	411	375	304	263	237	219	207	198	191	28
30	8270	7216	4621	3283	2384	1804	1459	1239	1088	863	708	596	513	451	403	365	289	246	219	201	188	179	172	30
32	8270	7220	4667	3229	2431	1805	1435	1200	1042	899	729	608	519	451	399	359	278	233	204	186	172	163	156	32
34	8270	7285	4699	3206	2438	1821	1425	1175	1008	891	756	624	528	455	400	356	271	223	193	173	160	150	143	34
36	8270	7249	4640	3209	2392	1851	1426	1160	983	860	771	645	541	463	403	357	266	215	184	164	150	139	132	36
38	8270	7212	4615	3234	2365	1884	1437	1154	967	837	744	669	557	473	409	359	263	209	177	156	141	130	123	38
40	8270	7220	4621	3277	2355	1847	1456	1155	957	821	723	651	576	486	417	364	262	205	171	149	134	123	115	40
42	8270	7268	4652	3239	2358	1822	1483	1163	953	810	707	632	575	501	427	371	262	202	167	144	128	117	109	42
44	8270	7231	4659	3214	2372	1808	1471	1176	955	803	696	617	558	512	439	379	264	201	163	139	123	112	103	44
46	8270	7210	4626	3204	2397	1802	1449	1194	960	801	688	606	544	496	453	389	266	200	161	136	119	107	98	46
48	8270	7220	4614	3209	2392	1805	1435	1200	970	802	684	598	533	484	445	400	270	201	159	133	116	103	94	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9450	9450	8791	7490	6773	6335	6048	5848	5705	5595	5515	5452	5400	5355	5318	5292	5231	5190	5163	5143	5126	5121	5108	6
8	9450	9450	7166	5561	4714	4213	3892	3673	3517	3402	3315	3246	3193	3147	3113	3082	3017	2977	2949	2927	2914	2904	2893	8
10	9450	9450	6897	4901	3887	3304	2940	2696	2526	2401	2308	2234	2177	2132	2094	2063	1996	1953	1925	1905	1890	1879	1871	10
12	9450	9450	7265	4790	3570	2889	2471	2198	2009	1872	1771	1693	1632	1584	1545	1512	1443	1399	1370	1350	1334	1323	1314	12
14	9450	9450	7722	4981	3519	2720	2240	1931	1720	1570	1459	1376	1310	1259	1217	1183	1111	1066	1036	1015	999	988	979	14
16	9450	9450	7166	5370	3629	2694	2142	1791	1556	1390	1269	1179	1109	1053	1009	973	897	851	820	798	782	770	762	16
18	9450	9450	6926	5136	3852	2763	2129	1731	1468	1284	1151	1052	977	918	870	832	753	704	672	650	634	622	613	18
20	9450	9450	6897	4901	3886	2900	2174	1724	1429	1225	1079	972	890	826	776	735	651	600	567	544	528	516	506	20
22	9450	9450	7022	4797	3685	3056	2263	1756	1425	1199	1039	921	832	764	710	666	578	525	490	467	450	437	428	22
24	9450	9450	7166	4790	3571	2889	2387	1816	1447	1197	1021	893	796	722	664	618	524	468	432	408	391	378	368	24
26	9450	9450	6979	4856	3520	2782	2334	1901	1490	1214	1020	880	775	695	633	584	484	425	388	363	345	332	322	26
28	9450	9450	6896	4981	3519	2720	2240	1930	1550	1245	1033	880	766	680	613	560	454	393	354	328	309	296	286	28
30	9450	9450	6897	4901	3558	2693	2178	1849	1624	1289	1056	889	766	673	601	545	432	367	327	300	281	267	256	30
32	9450	9450	6966	4820	3629	2694	2142	1792	1556	1343	1089	907	774	674	596	536	416	348	305	277	257	243	233	32
34	9450	9450	7014	4786	3639	2719	2127	1753	1504	1330	1129	932	788	680	597	532	404	332	288	259	239	224	213	34
36	9450	9450	6926	4790	3571	2763	2129	1731	1468	1284	1151	963	807	691	602	532	397	321	275	244	223	208	197	36
38	9450	9450	6890	4827	3531	2812	2145	1722	1443	1250	1111	999	831	706	611	536	392	312	264	232	210	195	183	38
40	9450	9450	6897	4892	3515	2757	2174	1724	1429	1225	1079	972	859	725	623	544	391	306	255	222	200	184	172	40
42	9450	9450	6944	4835	3519	2720	2214	1736	1423	1209	1056	943	858	747	638	553	391	302	249	215	191	174	162	42
44	9450	9450	6954	4797	3541	2699	2196	1756	1425	1199	1039	921	832	764	656	566	393	300	244	208	184	167	154	44
46	9450	9450	6906	4783	3578	2691	2164	1783	1433	1196	1028	905	812	741	676	580	398	299	240	203	178	160	147	46
48	9450	9450	6887	4790	3571	2694	2142	1792	1447	1197	1021	893	796	722	664	597	403	299	238	199	173	154	141	48

TABLE 6-12. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

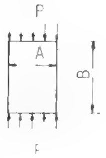
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10630	10630	10630	10630	9644	9021	8612	8326	8123	7967	7853	7762	7688	7624	7573	7534	7448	7390	7352	7322	7299	7292	7272	6
8	10630	10630	10203	7917	6712	5999	5542	5230	5008	4844	4720	4621	4546	4481	4432	4388	4296	4238	4199	4167	4149	4135	4119	8
10	10630	10630	9821	6978	5534	4705	4185	3839	3596	3419	3286	3181	3100	3035	2981	2938	2843	2781	2741	2712	2691	2676	2665	10
12	10630	10630	10344	6820	5084	4113	3519	3129	2860	2666	2522	2411	2324	2255	2199	2153	2054	1992	1950	1922	1900	1884	1871	12
14	10630	10630	10630	7092	5011	3873	3189	2749	2449	2236	2078	1959	1866	1793	1733	1684	1582	1518	1475	1445	1423	1406	1394	14
16	10630	10630	10203	7647	5167	3836	3050	2551	2215	1979	1307	1678	1578	1500	1437	1385	1278	1211	1167	1136	1114	1097	1085	16
18	10630	10630	9861	7312	5484	3934	3031	2465	2090	1828	1639	1498	1391	1306	1239	1185	1072	1002	957	925	903	885	873	18
20	10630	10630	9821	6978	5533	4129	3095	2455	2034	1744	1537	1383	1267	1176	1104	1046	927	855	807	775	752	734	721	20
22	10630	10630	9999	6831	5247	4351	3222	2500	2029	1708	1479	1312	1185	1088	1011	949	822	747	698	665	641	623	609	22
24	10630	10630	10203	6820	5084	4113	3398	2586	2061	1705	1454	1271	1134	1028	946	880	746	667	616	581	556	538	524	24
26	10630	10630	9936	6914	5012	3961	3324	2706	2122	1729	1453	1253	1104	990	901	831	689	606	553	517	491	473	459	26
28	10630	10630	9819	7092	5011	3873	3189	2749	2207	1773	1471	1253	1091	968	873	797	646	559	504	466	440	421	407	28
30	10630	10630	9821	6978	5066	3334	3101	2632	2312	1835	1504	1266	1091	959	856	775	615	523	465	427	400	380	365	30
32	10630	10630	9919	6862	5167	3836	3050	2551	2215	1912	1550	1292	1102	959	849	763	592	495	435	395	367	346	331	32
34	10630	10630	9987	6814	5181	3871	3029	2497	2142	1893	1607	1327	1122	968	850	757	576	473	410	369	340	319	303	34
36	10630	10630	9861	6820	5084	3934	3031	2465	2090	1828	1639	1371	1149	983	857	758	565	457	391	348	318	296	280	36
38	10630	10630	9810	6872	5027	4004	3054	2452	2055	1779	1581	1422	1183	1065	869	764	559	445	376	331	300	277	261	38
40	10630	10630	9821	6965	5005	3925	3095	2455	2034	1744	1537	1383	1223	1032	887	774	556	436	364	317	285	262	245	40
42	10630	10630	9886	6885	5011	3873	3152	2472	2027	1721	1503	1343	1222	1064	908	788	557	430	354	305	272	248	231	42
44	10630	10630	9902	6831	5042	3842	3126	2500	2029	1708	1479	1312	1185	1088	934	806	560	427	347	296	262	237	219	44
46	10630	10630	9832	6811	5095	3831	3081	2533	2041	1703	1463	1288	1156	1055	963	826	566	426	342	289	253	228	209	46
48	10630	10630	9807	6820	5084	3836	3050	2551	2061	1705	1454	1271	1134	1028	946	850	574	426	339	283	246	220	201	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	11810	11810	11810	11810	11810	11810	11810	11422	11142	10928	10772	10648	10546	10459	10388	10335	10216	10137	10085	10045	10012	10002	9976	6
8	11810	11810	11810	10860	9207	8229	7602	7174	6870	6645	6475	6339	6236	6147	6080	6019	5893	5814	5760	5717	5691	5673	5650	8
10	11810	11810	11810	9572	7591	6454	5741	5266	4933	4690	4507	4364	4253	4163	4089	4030	3899	3815	3760	3721	3692	3671	3655	10
12	11810	11810	11810	9355	6973	5642	4827	4293	3923	3657	3459	3307	3188	3093	3017	2953	2817	2732	2675	2637	2606	2584	2567	12
14	11810	11810	11810	9728	6873	5313	4375	3771	3359	3067	2650	2687	2559	2459	2377	2311	2170	2082	2024	1982	1952	1929	1912	14
16	11810	11810	11810	10489	7088	5262	4184	3499	3039	2715	2475	2202	2165	2057	1971	1901	1753	1661	1601	1559	1528	1505	1488	16
18	11810	11810	11810	10430	7523	5396	4158	3382	2866	2508	2249	2056	1908	1792	1700	1625	1470	1375	1313	1269	1238	1214	1197	18
20	11810	11810	11810	9572	7590	5663	4246	3368	2791	2393	2108	1898	1738	1613	1515	1435	1271	1173	1108	1063	1031	1008	989	20
22	11810	11810	11810	9370	7198	5968	4420	3429	2783	2343	2029	1799	1626	1492	1386	1302	1128	1025	958	912	879	854	835	22
24	11810	11810	11810	9355	6974	5642	4662	3547	2827	2339	1994	1743	1555	1410	1297	1207	1023	914	845	797	763	738	719	24
26	11810	11810	11810	9484	6875	5433	4559	3712	2911	2371	1993	1719	1514	1358	1237	1140	945	831	758	709	674	648	629	26
28	11810	11810	11810	9728	6873	5313	4375	3771	3027	2432	2017	1718	1497	1328	1197	1094	887	767	691	640	604	578	558	28
30	11810	11810	11810	9572	6949	5260	4254	3611	3172	2517	2063	1737	1497	1315	1174	1064	843	717	638	585	548	521	501	30
32	11810	11810	11810	9413	7088	5262	4184	3499	3039	2622	2126	1772	1512	1316	1165	1046	812	679	596	541	503	475	454	32
34	11810	11810	11810	9347	7107	5310	4154	3425	2939	2597	2205	1820	1539	1328	1165	1039	790	649	563	506	466	437	416	34
36	11810	11810	11810	9355	6974	5396	4158	3382	2866	2508	2249	1881	1577	1349	1175	1039	775	627	536	477	436	406	384	36
38	11810	11810	11810	9427	6896	5492	4190	3364	2818	2441	2169	1951	1623	1379	1192	1048	766	610	515	453	411	380	358	38
40	11810	11810	11810	9554	6865	5384	4246	3368	2791	2393	2108	1898	1678	1416	1216	1062	763	598	499	434	390	359	336	40
42	11810	11810	11810	9444	6873	5312	4324	3390	2780	2361	2062	1842	1676	1459	1246	1081	764	590	486	419	373	341	317	42
44	11810	11810	11810	9370	6916	5271	4288	3429	2783	2342	2029	1799	1626	1492	1281	1105	768	586	476	406	359	325	301	44
46	11810	11810	11810	9342	6989	5255	4226	3482	2800	2336	2007	1767	1586	1447	1320	1133	777	584	470	397	347	313	287	46
48	11810	11810	11810	9355	6974	5262	4184	3499	2827	2339	1994	1743	1555	1411	1297	1165	788	585	465	389	338	302	275	48

TABLE 6-13. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED



PHYSICAL CONSTANTS:

$E_X = 1.96 \times 10^6$ PSI

$E_Y = 1.70 \times 10^6$ PSI

$G_{XY} = 0.52 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.20$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	76	41	25	19	16	14	13	12	12	11	11	11	11	11	11	11	10	10	10	10	10	10	10	6
8	71	43	27	18	13	11	9	8	8	7	7	7	7	6	6	6	6	6	6	6	6	6	6	8
10	72	40	27	19	13	10	8	7	6	6	5	5	5	5	4	4	4	4	4	4	4	4	4	10
12	71	41	25	19	15	10	8	6	5	5	4	4	4	4	3	3	3	3	3	3	3	3	3	12
14	71	40	26	18	14	11	8	6	5	4	4	3	3	3	3	3	2	2	2	2	2	2	2	14
16	71	40	26	18	13	11	9	7	5	4	4	3	3	3	2	2	2	2	2	2	2	2	2	16
18	71	40	25	18	13	10	8	7	6	5	4	3	3	3	2	2	2	2	1	1	1	1	1	18
20	71	40	25	18	13	10	8	7	6	5	4	3	3	2	2	2	2	1	1	1	1	1	1	20
22	71	40	26	18	14	10	8	7	6	5	4	3	3	2	2	2	2	1	1	1	1	1	1	22
24	71	40	25	18	13	10	8	6	5	5	4	4	3	3	2	2	1	1	1	1	1	1	1	24
26	71	40	25	18	13	10	8	6	5	5	4	4	3	3	2	2	1	1	1	1	1	1	1	26
28	71	40	26	18	13	10	8	6	5	4	4	3	3	3	2	2	1	1	1	1	1	1	1	28
30	71	40	25	18	13	10	8	7	5	4	4	3	3	3	3	2	1	1	1	1	1	1	1	30
32	71	40	25	18	13	10	8	7	5	4	4	3	3	3	2	2	2	1	1	1	1	1	1	32
34	70	40	26	18	13	10	8	6	6	4	4	3	3	3	2	2	2	1	1	1	1	1	1	34
36	71	40	25	18	13	10	8	6	5	5	4	3	3	3	2	2	2	1	1	1	1	1	0	36
38	70	40	25	18	13	10	8	6	5	5	4	3	3	2	2	2	2	1	1	1	1	1	0	38
40	71	40	25	18	13	10	8	6	5	5	4	3	3	2	2	2	2	1	1	1	1	1	0	40
42	70	40	25	18	13	10	8	6	5	4	4	3	3	2	2	2	2	1	1	1	1	0	0	42
44	71	40	25	18	13	10	8	7	5	4	4	3	3	2	2	2	2	1	1	1	1	0	0	44
46	70	40	25	18	13	10	8	6	5	4	4	3	3	3	2	2	1	1	1	1	1	0	0	46
48	71	40	25	18	13	10	8	6	5	4	4	3	3	3	2	2	1	1	1	1	1	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	610	330	204	152	127	113	104	98	95	92	90	88	87	86	85	84	83	82	81	81	80	80	80	6
8	566	343	218	142	105	86	74	67	62	59	56	54	53	52	51	50	48	47	47	46	46	46	45	8
10	578	317	220	156	106	79	64	55	49	44	41	39	37	36	35	34	33	31	31	30	30	30	30	10
12	566	330	204	152	117	82	63	51	43	38	34	32	30	28	27	26	24	23	22	22	21	21	21	12
14	570	321	206	142	112	91	66	51	42	36	31	28	26	24	22	21	19	18	17	16	16	16	16	14
16	566	318	212	142	105	86	73	55	43	35	30	26	24	21	20	19	16	15	14	13	13	12	12	16
18	567	324	204	147	104	81	68	59	46	37	30	26	23	20	18	17	14	13	12	11	11	10	10	18
20	566	317	204	145	106	79	64	55	49	39	32	26	23	20	18	16	13	11	10	9	9	9	8	20
22	565	320	209	141	109	80	63	52	45	41	34	28	23	20	18	16	12	10	9	8	8	7	7	22
24	566	319	204	142	105	82	63	51	43	38	34	29	24	21	18	16	12	10	8	7	7	7	6	24
26	565	318	203	144	104	82	64	51	42	37	32	30	26	22	18	16	12	9	8	7	6	6	6	26
28	566	321	206	142	104	80	66	51	42	36	31	28	26	23	19	17	12	9	7	6	6	5	5	28
30	564	317	204	141	106	79	64	53	42	35	30	27	24	22	20	17	12	9	7	6	5	5	5	30
32	566	318	203	142	105	80	63	53	43	35	30	26	24	21	20	18	12	9	7	6	5	5	4	32
34	564	318	204	143	104	81	63	52	44	36	30	26	23	21	19	18	12	9	7	6	5	4	4	34
36	566	317	204	142	104	81	63	51	43	37	30	26	23	20	18	17	13	9	7	6	5	4	4	36
38	564	319	203	141	104	80	64	51	43	37	31	26	23	20	18	16	13	9	7	6	5	4	4	38
40	566	317	204	142	105	79	64	51	42	36	32	26	23	20	18	16	13	10	7	6	5	4	4	40
42	564	318	204	142	104	79	63	51	42	36	31	27	23	20	18	16	12	10	7	6	5	4	3	42
44	565	318	203	141	104	80	63	52	42	35	31	27	23	20	18	16	12	10	8	6	5	4	3	44
46	564	317	203	141	104	80	63	51	42	35	30	27	24	20	18	16	12	10	8	6	5	4	3	46
48	565	318	204	142	104	80	63	51	43	35	30	26	24	21	18	16	12	10	8	6	5	4	3	48

TABLE 6-13. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	2058	1113	689	515	429	381	352	332	319	309	302	297	293	289	286	284	279	276	274	273	272	271	270	6
8	1911	1158	737	478	355	289	251	226	209	198	189	183	178	174	171	168	163	160	158	156	155	154	153	8
10	1952	1072	741	526	357	268	217	185	164	150	140	132	127	122	119	116	110	106	104	102	101	100	100	10
12	1911	1113	689	515	395	278	212	172	146	129	116	107	100	95	91	88	81	77	75	73	72	71	70	12
14	1923	1082	695	481	378	307	224	174	142	120	105	95	87	80	76	72	65	60	58	56	54	53	53	14
16	1911	1075	715	478	355	289	246	184	145	119	102	89	79	72	67	63	54	49	46	44	43	42	41	16
18	1913	1093	689	495	350	273	229	201	155	124	102	87	77	68	62	57	48	42	39	37	35	34	34	18
20	1911	1072	688	488	356	268	217	185	164	132	107	89	76	67	60	54	43	38	34	32	30	29	28	20
22	1908	1081	705	477	368	270	212	176	153	137	113	93	78	68	59	53	41	34	30	28	26	25	24	22
24	1911	1076	689	478	355	278	212	172	146	129	116	99	82	70	60	53	39	32	28	25	23	22	21	24
26	1906	1072	686	487	350	277	216	172	143	123	110	100	87	73	62	54	39	31	26	23	21	20	19	26
28	1911	1082	695	481	351	270	224	174	142	120	105	95	87	77	65	56	39	30	25	22	19	18	17	28
30	1905	1072	689	476	357	268	217	178	143	119	103	91	82	76	69	58	40	30	24	21	18	17	16	30
32	1911	1075	686	478	355	269	213	179	145	119	102	89	79	72	67	62	41	30	24	20	17	16	14	32
34	1905	1074	690	484	351	272	212	174	149	121	102	88	78	70	64	60	42	30	24	19	17	15	14	34
36	1911	1071	689	478	350	273	212	172	146	124	102	87	77	68	62	57	44	31	24	19	16	14	13	36
38	1904	1078	686	476	352	269	215	171	144	125	104	88	76	67	61	55	45	32	24	19	16	14	12	38
40	1910	1072	688	478	355	268	217	172	142	122	107	89	76	67	60	54	43	33	24	19	16	14	12	40
42	1904	1073	689	481	351	268	214	174	142	120	105	91	77	67	59	53	42	34	25	19	16	13	12	42
44	1908	1073	686	477	350	270	212	176	142	119	103	92	78	68	59	53	41	34	26	20	16	13	11	44
46	1904	1071	687	476	350	271	212	174	143	119	102	90	80	68	60	53	40	33	26	20	16	13	11	46
48	1907	1075	689	478	353	269	212	172	145	119	102	89	79	70	60	53	39	32	27	20	16	13	11	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4730	2638	1632	1220	1017	903	833	788	756	733	717	704	694	685	679	673	662	655	650	647	644	643	641	6
8	4529	2745	1748	1132	842	686	594	536	496	469	449	433	422	412	405	399	387	379	374	370	367	366	364	8
10	4626	2540	1756	1247	845	635	514	439	390	356	332	314	300	289	281	274	260	252	246	242	240	238	236	10
12	4529	2637	1632	1220	936	659	503	408	347	305	276	254	238	226	216	208	193	183	177	173	170	168	167	12
14	4559	2564	1646	1140	896	729	531	412	336	285	250	224	205	191	180	171	153	143	136	132	129	127	125	14
16	4529	2547	1694	1132	842	686	583	437	344	283	241	210	188	172	159	149	129	117	110	105	102	100	98	16
18	4534	2591	1632	1172	829	648	542	476	366	293	243	207	181	162	147	136	113	100	93	88	84	81	80	18
20	4529	2540	1630	1157	845	635	514	439	390	312	253	211	181	159	142	129	103	89	80	75	71	69	67	20
22	4523	2561	1672	1131	872	640	503	418	363	325	269	221	186	160	141	126	97	81	72	66	62	59	57	22
24	4529	2550	1632	1132	842	659	503	408	347	305	276	234	194	165	143	126	94	76	66	60	55	52	50	24
26	4518	2541	1626	1155	830	657	513	407	338	292	260	236	206	172	147	128	92	73	62	55	50	47	44	26
28	4529	2564	1646	1140	832	641	531	412	336	285	250	224	205	182	154	133	92	71	59	51	46	43	40	28
30	4515	2540	1632	1129	845	635	514	422	338	282	243	216	195	180	162	139	94	71	57	49	43	40	37	30
32	4529	2547	1625	1132	842	637	505	424	344	283	241	210	188	172	159	146	96	71	56	47	41	37	34	32
34	4514	2546	1636	1147	831	645	502	414	354	287	241	208	184	166	152	141	100	72	56	46	40	35	32	34
36	4529	2540	1632	1134	829	648	503	408	347	293	243	207	181	162	147	136	104	73	56	45	39	34	31	36
38	4514	2554	1625	1128	834	639	409	406	340	296	247	209	181	160	144	131	107	75	57	45	38	33	29	38
40	4528	2540	1630	1132	842	635	514	408	337	289	253	211	181	159	142	129	103	78	58	45	37	32	28	40
42	4514	2543	1632	1140	833	636	507	412	336	285	250	215	183	159	141	127	100	81	59	46	37	32	28	42
44	4523	2544	1625	1131	829	640	503	418	337	283	245	218	186	160	141	126	97	81	61	46	37	31	27	44
46	4514	2539	1627	1128	830	643	502	412	340	282	242	214	190	162	141	125	95	79	63	47	38	31	27	46
48	4520	2547	1632	1132	836	638	503	408	344	283	241	210	188	165	143	126	94	76	65	49	38	31	27	48

TABLE 6-13. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	5900	5152	3188	2382	1985	1763	1628	1538	1477	1432	1400	1375	1355	1339	1325	1315	1293	1279	1270	1263	1257	1255	1251	6
8	5900	5360	3413	2211	1645	1340	1160	1046	970	916	876	846	824	806	792	780	755	740	730	722	718	714	711	8
10	5900	4961	3431	2436	1650	1240	1004	858	761	695	648	613	586	565	549	536	508	492	481	474	468	464	461	10
12	5900	5151	3188	2382	1828	1288	983	797	677	596	538	496	465	441	422	407	376	358	346	339	333	329	326	12
14	5900	5008	3216	2226	1750	1423	1036	804	656	557	487	438	401	373	351	333	299	279	266	258	252	247	244	14
16	5900	4975	3310	2211	1645	1340	1139	853	673	553	470	411	368	335	310	290	251	229	215	206	200	195	192	16
18	5900	5061	3188	2289	1620	1265	1059	929	716	572	474	405	354	316	287	265	221	196	181	171	164	159	156	18
20	5900	4961	3184	2259	1650	1240	1004	858	761	609	494	413	354	310	277	251	201	174	157	146	139	134	130	20
22	5900	5002	3265	2208	1704	1251	981	816	709	635	525	431	363	313	275	245	189	159	141	129	121	115	111	22
24	5900	4981	3188	2211	1645	1288	983	797	677	596	538	457	379	322	279	246	183	149	129	116	108	102	97	24
26	5900	4963	3176	2255	1621	1284	1002	794	660	571	507	462	402	337	288	251	180	143	121	107	98	91	87	26
28	5900	5008	3216	2226	1625	1252	1036	804	656	556	487	438	401	356	301	259	181	139	115	100	90	83	78	28
30	5900	4961	3188	2205	1650	1240	1004	824	660	551	476	421	381	351	317	271	183	138	112	95	85	77	72	30
32	5900	4975	3174	2211	1645	1244	986	827	673	553	470	411	368	335	310	285	188	138	110	92	80	73	67	32
34	5900	4973	3195	2240	1624	1260	980	808	691	560	470	406	359	324	297	276	195	140	109	90	77	69	63	34
36	5900	4960	3188	2214	1620	1265	983	797	677	572	474	405	354	316	287	265	203	143	109	89	75	66	60	36
38	5900	4989	3174	2204	1629	1248	994	793	664	577	482	407	353	312	281	257	210	147	110	88	74	64	57	38
40	5900	4961	3184	2211	1645	1240	1004	796	658	565	494	413	354	310	277	251	201	152	112	88	73	63	56	40
42	5900	4966	3188	2226	1627	1242	989	804	656	556	487	421	357	310	275	247	194	158	115	89	73	62	54	42
44	5900	4969	3174	2208	1620	1251	982	816	658	552	479	426	363	313	275	245	189	159	118	91	73	61	53	44
46	5900	4959	3179	2204	1622	1257	980	804	664	551	473	417	370	317	276	245	185	153	122	93	74	61	53	46
48	5900	4975	3188	2211	1632	1245	983	797	673	553	470	411	368	322	279	246	183	149	127	95	75	61	52	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7090	7090	5509	4117	3431	3047	2813	2658	2552	2475	2419	2376	2341	2313	2290	2273	2235	2210	2194	2182	2173	2169	2162	6
8	7090	7090	5898	3821	2842	2316	2005	1808	1675	1582	1514	1463	1424	1392	1368	1347	1304	1278	1261	1248	1240	1234	1228	8
10	7090	7090	5928	4209	2852	2143	1735	1482	1316	1201	1119	1058	1013	977	948	926	878	849	831	818	809	802	797	10
12	7090	7090	5509	4117	3158	2225	1698	1377	1170	1029	930	858	803	762	729	703	650	619	599	585	575	568	563	12
14	7090	7090	5557	3846	3025	2459	1791	1389	1133	962	842	756	692	644	606	576	517	482	460	445	435	428	422	14
16	7090	7090	5719	3821	2842	2316	1969	1474	1162	955	812	710	635	579	535	501	434	396	372	356	345	337	331	16
18	7090	7090	5509	3956	2799	2186	1830	1606	1236	989	820	700	612	547	496	457	381	339	313	295	284	275	269	18
20	7090	7090	5502	3904	2852	2143	1735	1482	1316	1052	853	713	611	536	478	434	348	300	272	253	240	231	225	20
22	7090	7090	5643	3816	2944	2161	1696	1411	1225	1098	907	744	627	540	475	424	327	274	243	223	209	200	192	22
24	7090	7090	5509	3821	2842	2225	1698	1377	1170	1029	930	790	655	556	482	425	316	257	223	201	186	176	168	24
26	7090	7090	5488	3897	2801	2218	1732	1372	1141	986	877	798	694	582	497	433	311	246	209	185	169	158	150	26
28	7090	7090	5557	3846	2807	2164	1791	1389	1133	962	842	756	692	615	520	448	312	240	199	173	156	144	135	28
30	7090	7090	5509	3810	2852	2143	1735	1424	1141	952	822	728	659	606	548	468	317	238	193	165	146	133	124	30
32	7090	7090	5484	3821	2842	2149	1704	1430	1162	955	812	710	635	579	535	492	325	239	189	159	139	125	116	32
34	7090	7090	5520	3871	2806	2178	1693	1396	1195	968	812	701	620	560	513	476	337	242	188	155	134	119	109	34
36	7090	7090	5509	3826	2799	2186	1698	1377	1170	989	820	700	612	547	496	457	351	247	189	153	130	114	103	36
38	7090	7090	5484	3808	2815	2156	1717	1371	1148	998	834	704	609	539	485	444	363	254	191	152	128	111	99	38
40	7090	7090	5502	3821	2842	2143	1735	1376	1137	976	853	713	611	536	478	434	348	263	194	153	126	108	96	40
42	7090	7090	5509	3846	2811	2145	1710	1389	1133	962	842	727	617	536	475	427	336	273	199	154	126	107	94	42
44	7090	7090	5485	3816	2799	2161	1696	1411	1137	954	827	736	627	540	475	424	327	274	205	157	126	106	92	44
46	7090	7090	5493	3809	2802	2172	1693	1390	1147	952	817	721	640	547	477	423	320	265	211	160	127	106	91	46
48	7090	7090	5509	3821	2821	2152	1698	1377	1162	955	812	710	635	556	482	425	316	257	219	164	129	106	90	48

TABLE 6-13. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8270	8270	8270	6537	5448	4839	4466	4221	4053	3930	3841	3773	3718	3673	3637	3609	3549	3510	3484	3465	3451	3444	3433	6
8	8270	8270	8270	6068	4512	3677	3184	2871	2660	2512	2405	2323	2261	2211	2172	2139	2071	2030	2003	1982	1969	1960	1950	8
10	8270	8270	8270	6683	4529	3403	2755	2353	2089	1908	1778	1681	1608	1551	1506	1470	1395	1349	1320	1299	1285	1274	1266	10
12	8270	8270	8270	6537	5015	3534	2697	2187	1858	1634	1477	1362	1276	1210	1158	1117	1032	982	951	930	914	902	894	12
14	8270	8270	8270	6108	4803	3904	2844	2206	1799	1527	1337	1201	1099	1022	962	915	820	766	731	707	691	679	670	14
16	8270	8270	8270	6068	4512	3677	3126	2341	1846	1517	1290	1128	1009	919	850	796	689	628	590	565	548	535	526	16
18	8270	8270	8270	6282	4444	3472	2905	2550	1963	1571	1302	1111	972	868	788	726	605	538	496	469	450	437	427	18
20	8270	8270	8270	6199	4529	3403	2755	2353	2089	1671	1355	1132	971	851	760	689	552	477	431	402	382	367	357	20
22	8270	8270	8270	6060	4675	3432	2693	2240	1945	1743	1440	1182	996	858	754	673	519	436	386	354	332	317	305	22
24	8270	8270	8270	6068	4512	3534	2697	2187	1858	1634	1477	1254	1041	883	765	674	501	409	354	319	296	279	267	24
26	8270	8270	8270	6188	4447	3522	2750	2179	1812	1565	1393	1267	1102	924	790	688	494	391	331	293	268	251	238	26
28	8270	8270	8270	6108	4458	3436	2843	2206	1799	1527	1337	1201	1099	976	826	711	495	382	316	275	248	229	215	28
30	8270	8270	8270	6050	4529	3403	2755	2262	1812	1512	1305	1156	1046	963	871	743	503	378	306	261	232	212	198	30
32	8270	8270	8270	6068	4512	3413	2706	2270	1846	1517	1290	1128	1009	919	850	782	517	379	301	252	221	199	184	32
34	8270	8270	8270	6148	4456	3458	2688	2217	1897	1537	1290	1114	985	889	814	756	535	384	299	246	212	189	173	34
36	8270	8270	8270	6075	4444	3472	2697	2187	1858	1571	1302	1111	972	868	788	726	557	393	300	243	206	182	164	36
38	8270	8270	8270	6047	4470	3423	2727	2177	1823	1585	1324	1118	968	856	771	704	576	404	303	242	203	176	157	38
40	8270	8270	8270	6068	4512	3403	2755	2184	1805	1550	1355	1132	971	851	759	689	552	418	309	243	201	172	152	40
42	8270	8270	8270	6108	4463	3407	2715	2206	1799	1527	1337	1154	980	852	754	679	534	434	316	245	200	170	149	42
44	8270	8270	8270	6060	4444	3432	2693	2240	1805	1515	1313	1169	996	858	754	673	519	436	325	249	201	168	146	44
46	8270	8270	8270	6048	4450	3449	2688	2207	1821	1512	1298	1145	1016	869	758	672	509	421	336	254	202	168	144	46
48	8270	8270	8270	6068	4479	3417	2697	2187	1846	1517	1290	1128	1009	883	765	674	501	409	347	260	205	169	143	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9450	9450	9450	9450	8132	7223	6667	6301	6050	5866	5734	5631	5550	5483	5429	5388	5297	5239	5201	5173	5151	5141	5125	6
8	9450	9450	9450	9057	6736	5489	4753	4285	3971	3750	3589	3467	3375	3300	3242	3193	3092	3030	2990	2959	2940	2926	2911	8
10	9450	9450	9450	9450	6760	5080	4112	3513	3119	2848	2653	2509	2400	2315	2248	2194	2082	2014	1970	1940	1918	1902	1890	10
12	9450	9450	9450	9450	7486	5275	4026	3265	2773	2440	2205	2033	1904	1806	1728	1667	1541	1467	1419	1388	1364	1347	1334	12
14	9450	9450	9450	9117	7169	5828	4245	3293	2686	2280	1996	1792	1641	1526	1436	1366	1225	1143	1091	1056	1032	1013	1000	14
16	9450	9450	9450	9057	6736	5489	4667	3495	2755	2264	1926	1684	1506	1372	1269	1188	1029	938	881	844	817	798	785	16
18	9450	9450	9450	9377	6634	5182	4337	3807	2931	2345	1943	1659	1451	1296	1177	1084	904	803	741	700	672	652	637	18
20	9450	9450	9450	9253	6760	5080	4112	3513	3119	2494	2023	1690	1449	1270	1134	1028	824	712	644	600	570	549	532	20
22	9450	9450	9450	9045	6978	5122	4020	3344	2903	2602	2149	1764	1486	1281	1125	1005	775	651	576	528	496	473	456	22
24	9450	9450	9450	9057	6736	5275	4026	3265	2773	2440	2204	1872	1553	1319	1142	1006	748	610	528	476	441	417	399	24
26	9450	9450	9450	9236	6639	5257	4105	3252	2705	2337	2079	1892	1645	1379	1179	1026	738	584	495	438	400	374	355	26
28	9450	9450	9450	9117	6654	5129	4244	3293	2686	2279	1996	1792	1641	1457	1232	1061	739	570	472	410	370	341	321	28
30	9450	9450	9450	9031	6760	5080	4112	3376	2705	2258	1948	1725	1561	1437	1300	1108	751	564	457	390	347	316	295	30
32	9450	9450	9450	9057	6736	5095	4039	3389	2755	2264	1926	1684	1506	1372	1269	1167	771	566	449	377	329	297	274	32
34	9450	9450	9450	9177	6651	5162	4013	3309	2832	2294	1925	1663	1470	1326	1216	1129	798	574	446	368	317	282	258	34
36	9450	9450	9450	9068	6634	5182	4026	3265	2773	2344	1943	1658	1451	1296	1177	1084	832	586	447	363	308	271	245	36
38	9450	9450	9450	9027	6672	5110	4071	3250	2722	2365	1976	1668	1444	1277	1150	1051	859	603	452	361	302	263	235	38
40	9450	9450	9450	9057	6736	5080	4112	3261	2694	2313	2023	1690	1449	1270	1134	1028	824	624	461	362	299	257	227	40
42	9450	9450	9450	9117	6662	5085	4052	3293	2686	2279	1996	1722	1464	1271	1126	1013	797	648	472	366	298	253	222	42
44	9450	9450	9450	9045	6634	5122	4020	3344	2695	2261	1961	1745	1486	1281	1125	1005	775	651	485	372	299	251	218	44
46	9450	9450	9450	9028	6643	5148	4012	3295	2718	2257	1938	1709	1517	1297	1131	1003	760	628	501	379	302	251	215	46
48	9450	9450	9450	9057	6686	5101	4026	3265	2755	2264	1926	1684	1506	1319	1142	1006	748	610	519	388	306	252	214	48

TABLE 6-13. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES SIMPLY SUPPORTED - REMAINING EDGES CLAMPED (Cont'd)

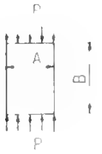
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10630	10630	10630	10630	10630	10284	9492	8971	8614	8353	8164	8018	7902	7807	7729	7671	7542	7460	7405	7365	7334	7320	7297	6
8	10630	10630	10630	10630	9591	7815	6768	6101	5654	5339	5111	4936	4805	4698	4616	4546	4403	4315	4257	4213	4186	4166	4144	8
10	10630	10630	10630	10630	9626	7233	5855	5002	4441	4055	3778	3572	3417	3297	3200	3124	2964	2867	2805	2762	2730	2708	2691	10
12	10630	10630	10630	10630	10630	7511	5732	4648	3948	3474	3139	2895	2712	2571	2461	2373	2194	2088	2021	1976	1942	1918	1900	12
14	10630	10630	10630	10630	10208	8298	6044	4689	3824	3246	2843	2552	2336	2173	2045	1945	1743	1627	1554	1504	1469	1443	1424	14
16	10630	10630	10630	10630	9591	7815	6645	4976	3922	3224	2742	2398	2145	1954	1807	1692	1464	1335	1255	1201	1164	1137	1117	16
18	10630	10630	10630	10630	9445	7379	6175	5420	4173	3338	2767	2361	2066	1845	1676	1544	1287	1143	1055	997	957	928	907	18
20	10630	10630	10630	10630	9625	7233	5855	5002	4441	3551	2880	2406	2063	1808	1614	1464	1174	1014	917	854	811	781	758	20
22	10630	10630	10630	10630	9936	7294	5724	4761	4134	3705	3060	2512	2116	1823	1602	1431	1104	926	820	752	706	673	649	22
24	10630	10630	10630	10630	9591	7510	5732	4648	3948	3474	3139	2665	2212	1878	1626	1433	1066	868	752	678	628	593	568	24
26	10630	10630	10630	10630	9452	7485	5845	4631	3852	3327	2960	2693	2342	1963	1679	1461	1050	832	704	624	570	533	506	26
28	10630	10630	10630	10630	9475	7302	6043	4689	3824	3245	2842	2552	2337	2075	1755	1511	1053	811	671	584	526	486	457	28
30	10630	10630	10630	10630	9626	7233	5855	4807	3851	3215	2773	2457	2223	2046	1851	1578	1070	804	651	556	493	451	420	30
32	10630	10630	10630	10630	9591	7254	5751	4825	3922	3224	2742	2398	2145	1954	1807	1661	1098	806	639	536	469	423	390	32
34	10630	10630	10630	10630	9470	7350	5713	4711	4032	3267	2741	2368	2094	1888	1731	1607	1137	817	635	523	451	402	367	34
36	10630	10630	10630	10630	9446	7379	5732	4648	3948	3338	2766	2361	2066	1845	1676	1544	1184	835	637	516	439	386	349	36
38	10630	10630	10630	10630	9501	7276	5796	4627	3875	3368	2814	2375	2057	1819	1638	1497	1223	858	644	514	431	374	335	38
40	10630	10630	10630	10630	9591	7233	5855	4643	3836	3294	2880	2406	2063	1808	1614	1464	1173	888	656	516	426	366	324	40
42	10630	10630	10630	10630	9486	7241	5770	4689	3824	3245	2842	2452	2084	1810	1603	1442	1134	922	672	521	425	361	316	42
44	10630	10630	10630	10630	9445	7294	5724	4761	3837	3220	2791	2484	2116	1823	1602	1431	1104	926	691	529	426	358	310	44
46	10630	10630	10630	10630	9458	7329	5713	4691	3871	3213	2759	2433	2159	1846	1610	1428	1081	894	713	540	430	357	307	46
48	10630	10630	10630	10630	9520	7263	5732	4648	3922	3224	2742	2398	2145	1878	1626	1433	1066	868	738	553	436	358	305	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	11810	11810	11810	11810	11810	11810	11810	11810	11810	11458	11199	10999	10840	10709	10603	10523	10346	10233	10158	10103	10060	10041	10009	6
8	11810	11810	11810	11810	11810	10721	9283	8369	7756	7324	7010	6771	6591	6445	6332	6236	6039	5919	5839	5779	5742	5714	5685	8
10	11810	11810	11810	11810	11810	9921	8032	6861	6092	5562	5182	4900	4688	4522	4390	4285	4066	3933	3847	3788	3745	3714	3692	10
12	11810	11810	11810	11810	11810	10303	7862	6376	5416	4765	4306	3971	3720	3527	3376	3255	3010	2864	2772	2710	2664	2631	2606	12
14	11810	11810	11810	11810	11810	11383	8290	6432	5246	4453	3899	3501	3205	2981	2806	2667	2392	2232	2131	2062	2015	1979	1953	14
16	11810	11810	11810	11810	11810	10721	9115	6826	5381	4423	3761	3289	2942	2680	2479	2321	2009	1831	1721	1648	1597	1559	1532	16
18	11810	11810	11810	11810	11810	10122	8471	7436	5724	4579	3795	3239	2834	2530	2299	2118	1765	1567	1447	1367	1313	1273	1244	18
20	11810	11810	11810	11810	11810	9921	8032	6861	6092	4871	3950	3301	2830	2480	2214	2008	1610	1391	1258	1172	1113	1071	1040	20
22	11810	11810	11810	11810	11810	10005	7852	6531	5670	5083	4198	3446	2903	2501	2198	1963	1514	1271	1125	1032	969	924	891	22
24	11810	11810	11810	11810	11810	10302	7862	6376	5416	4765	4305	3655	3034	2576	2231	1966	1462	1191	1031	930	862	814	779	24
26	11810	11810	11810	11810	11810	10268	8018	6352	5284	4564	4060	3694	3212	2693	2303	2004	1441	1141	966	856	782	731	693	26
28	11810	11810	11810	11810	11810	10017	8290	6432	5246	4452	3899	3501	3205	2846	2407	2073	1444	1113	921	801	722	667	627	28
30	11810	11810	11810	11810	11810	9921	8032	6594	5283	4410	3804	3270	3049	2807	2539	2165	1467	1102	892	762	677	618	576	30
32	11810	11810	11810	11810	11810	9951	7889	6619	5381	4423	3761	3289	2942	2680	2479	2279	1506	1106	877	736	643	580	535	32
34	11810	11810	11810	11810	11810	10082	7837	6462	5530	4481	3761	3248	2872	2591	2374	2205	1560	1120	871	718	619	551	503	34
36	11810	11810	11810	11810	11810	10122	7862	6376	5416	4579	3795	3239	2834	2530	2299	2118	1625	1145	874	708	602	529	478	36
38	11810	11810	11810	11810	11810	9980	7951	6347	5316	4620	3860	3258	2821	2495	2246	2053	1678	1178	884	705	591	513	459	38
40	11810	11810	11810	11810	11810	9921	8031	6369	5262	4518	3950	3301	2830	2480	2214	2008	1610	1218	900	708	585	502	444	40
42	11810	11810	11810	11810	11810	9932	7915	6432	5246	4452	3899	3364	2859	2483	2199	1979	1556	1265	921	715	583	495	433	42
44	11810	11810	11810	11810	11810	10005	7852	6531	5263	4417	3829	3407	2903	2501	2198	1963	1514	1271	947	726	585	491	426	44
46	11810	11810	11810	11810	11810	10054	7837	6435	5310	4408	3784	3338	2962	2532	2209	1959	1483	1227	978	740	590	490	420	46
48	11810	11810	11810	11810	11810	9963	7862	6376	5381	4423	3761	3289	2942	2576	2230	1966	1462	1191	1013	758	598	491	418	48

TABLE 6-14. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED



PHYSICAL CONSTANTS:

$E_x = 1.96 \times 10^6$ PSI

$E_Y = 1.70 \times 10^6$ PSI

$G_{XY} = 0.52 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.20$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	65	52	46	44	42	42	42	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	6
8	53	36	31	27	25	25	25	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	8
10	52	31	23	19	17	17	17	15	15	15	15	15	8	8	8	8	8	8	8	8	8	8	8	14
12	46	31	21	15	13	13	11	11	11	11	11	11	6	6	6	6	6	6	6	6	6	6	6	16
14	44	29	19	13	11	10	10	10	10	8	8	8	6	6	6	6	4	4	4	4	4	4	4	18
16	44	25	19	13	11	10	8	8	8	8	6	6	4	4	4	4	4	4	4	4	4	4	4	20
18	42	25	17	13	10	8	8	6	6	6	6	6	4	4	4	4	4	4	4	4	4	4	4	22
20	40	25	17	13	10	8	6	6	6	6	4	4	4	4	4	4	2	2	2	2	2	2	2	24
22	40	25	15	11	10	8	6	6	6	4	4	4	4	4	2	2	2	2	2	2	2	2	2	26
24	40	23	15	11	10	8	6	6	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	28
26	40	23	15	11	10	8	6	6	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	30
28	40	23	15	11	8	8	6	6	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	32
30	42	23	15	11	8	6	6	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	34
32	42	23	15	11	8	6	6	6	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	36
34	44	23	15	11	8	6	6	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	38
36	46	23	15	10	8	6	6	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	40
38	48	23	15	10	8	6	6	4	4	4	2	2	2	2	2	2	2	2	2	2	2	0	0	42
40	50	23	13	10	8	6	6	4	4	4	2	2	2	2	2	2	2	2	2	0	0	0	0	44
42	53	23	13	10	8	6	6	4	4	4	2	2	2	2	2	2	2	2	0	0	0	0	0	46
44	55	25	13	10	8	6	6	4	4	4	2	2	2	2	2	2	2	2	0	0	0	0	0	48
46	59	25	15	10	8	6	6	4	4	4	2	2												
48	63	27	15	10	8	6	6	4	4	2	2	2												

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	LENGTH-B INCHES
6	513	410	372	353	342	336	332	328	326	324	323	323	321	321	321	321	319	319	319	317	317	317	317	6
8	429	288	240	218	206	198	193	191	189	187	185	183	183	183	181	181	181	179	179	179	179	179	179	8
10	412	246	185	158	143	135	130	128	124	122	122	120	118	118	118	118	116	116	114	114	114	114	114	10
12	364	239	160	128	113	103	97	94	90	88	86	86	84	84	84	82	82	80	80	80	80	80	80	12
14	347	223	153	114	94	84	76	73	71	67	67	65	63	63	63	61	61	61	59	59	59	59	59	14
16	345	204	155	107	84	73	65	59	57	55	53	52	50	50	50	48	48	46	46	46	46	46	46	16
18	330	197	139	105	80	65	57	52	48	46	44	42	42	40	40	40	38	38	36	36	36	36	36	18
20	326	195	132	103	78	61	52	46	42	40	38	36	34	34	32	32	31	31	31	31	29	29	29	20
22	323	191	126	95	78	59	50	42	38	34	32	31	31	29	29	29	27	25	25	25	25	25	25	22
24	317	185	124	92	74	59	48	40	36	32	31	29	27	25	25	25	23	23	21	21	21	21	21	24
26	317	183	126	86	71	59	48	38	34	31	27	25	25	23	23	21	19	19	19	19	17	17	17	26
28	321	185	122	88	67	55	48	38	32	29	25	23	23	21	19	19	17	17	17	15	15	15	15	28
30	328	181	118	86	65	53	46	38	32	27	25	23	21	19	19	17	15	15	15	13	13	13	13	30
32	340	179	118	86	65	52	44	38	31	27	23	21	19	17	17	15	15	13	13	13	11	11	11	32
34	353	177	118	84	63	50	42	36	32	27	23	21	19	17	15	15	13	11	11	11	11	11	11	34
36	368	179	116	82	63	50	40	34	31	27	23	19	17	17	15	13	13	11	11	10	10	10	10	36
38	385	181	114	82	63	50	40	34	31	27	23	19	17	15	15	13	11	11	10	10	10	10	10	38
40	405	185	114	82	61	50	38	32	29	27	23	19	17	15	13	13	11	10	10	10	8	8	8	40
42	426	189	114	82	61	50	38	32	29	25	23	19	17	15	13	13	10	10	8	8	8	8	8	42
44	448	195	114	80	61	48	38	32	27	25	21	19	17	15	13	11	10	10	8	8	8	8	8	44
46	471	200	114	80	59	48	38	31	27	23	21	19	17	15	13	11	10	8	8	8	8	6	6	46
48	498	206	116	80	61	46	38	31	27	23	21	19	17	15	13	11	10	8	8	6	6	6	6	48

TABLE 6-14. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	1733	1385	1254	1191	1155	1134	1118	1107	1101	1095	1092	1088	1086	1082	1080	1078	1076	1074	1072	1072	1071	1071	1071	6
8	1446	975	811	735	695	670	655	643	635	630	624	620	618	616	614	613	609	607	605	605	603	603	603	8
10	1395	832	624	532	487	458	441	429	420	414	408	405	403	401	399	397	393	391	389	389	387	387	387	10
12	1229	803	544	433	378	345	326	313	303	298	292	288	286	282	281	279	277	273	273	271	271	269	269	12
14	1174	754	515	384	319	282	260	246	235	229	223	219	216	214	210	210	206	202	202	200	200	198	198	14
16	1164	691	519	361	286	244	219	202	191	183	177	174	170	168	166	164	160	156	156	155	155	153	153	16
18	1116	664	471	357	269	221	193	174	162	155	147	143	139	135	134	132	128	126	124	122	122	122	122	18
20	1105	658	443	349	263	208	176	156	143	134	126	122	118	114	113	111	107	103	101	101	99	99	99	20
22	1092	647	427	323	263	202	166	143	130	118	111	107	101	99	95	94	90	88	86	84	84	82	82	22
24	1072	628	422	307	250	200	160	135	120	109	101	95	90	86	84	82	76	74	73	71	71	71	69	24
26	1071	622	424	298	235	200	158	132	113	101	92	86	82	78	74	73	67	65	63	61	61	59	59	26
28	1084	624	410	294	225	189	160	130	109	95	86	80	74	71	67	65	59	57	55	53	53	52	52	28
30	1111	611	403	292	219	179	155	128	107	92	82	74	69	65	61	59	53	52	50	48	46	46	46	30
32	1145	603	399	292	216	174	147	130	107	90	80	71	65	61	57	55	50	46	44	42	42	40	40	32
34	1189	601	399	284	216	168	141	124	107	90	78	69	63	57	53	52	46	42	40	38	38	36	36	34
36	1240	605	395	279	216	166	137	118	105	90	76	67	61	55	52	48	42	38	36	34	34	32	32	36
38	1300	613	389	277	212	164	134	114	101	90	76	67	59	53	50	46	40	36	32	32	31	31	29	38
40	1364	624	385	277	208	164	132	111	97	88	76	65	57	52	48	44	36	32	31	29	29	27	27	40
42	1435	639	385	277	204	166	130	109	94	84	76	65	57	52	46	42	36	31	29	27	27	25	25	42
44	1511	656	385	273	204	162	130	107	92	80	73	67	57	50	46	42	34	31	27	25	25	23	23	44
46	1593	676	389	269	202	158	130	105	90	78	71	65	57	50	46	40	32	29	25	25	23	21	21	46
48	1681	698	393	267	202	156	130	105	88	76	69	63	57	50	44	40	32	27	25	23	21	21	19	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4109	3282	2971	2820	2737	2685	2651	2626	2609	2595	2586	2578	2572	2565	2561	2557	2551	2546	2542	2540	2538	2538	2536	6
8	3427	2311	1920	1742	1645	1588	1550	1523	1504	1490	1481	1471	1466	1460	1456	1452	1443	1439	1435	1431	1431	1429	1427	8
10	3305	1973	1479	1263	1151	1086	1044	1015	996	981	969	962	954	948	945	941	931	927	924	920	920	918	916	10
12	2912	1906	1288	1027	895	821	775	742	721	706	693	685	677	672	666	662	655	649	645	643	641	639	639	12
14	2780	1784	1223	908	756	668	616	582	557	540	529	519	511	504	500	496	487	481	477	475	473	471	471	14
16	2761	1639	1231	857	677	578	519	481	454	435	422	412	403	397	391	387	378	372	368	366	364	363	363	16
18	2645	1572	1118	847	637	523	456	414	385	364	349	340	330	323	319	313	303	298	294	292	290	288	288	18
20	2618	1561	1050	826	622	492	418	370	338	317	300	288	279	271	265	261	252	246	240	239	237	235	235	20
22	2588	1530	1011	767	626	479	393	342	305	281	263	252	240	233	227	223	212	206	202	198	197	197	195	22
24	2540	1488	998	729	593	477	382	323	282	258	239	223	214	206	198	193	183	176	172	170	168	166	164	24
26	2538	1473	1004	706	559	475	376	311	269	239	219	204	193	183	177	172	160	153	149	147	143	143	141	26
28	2570	1479	973	695	534	447	378	305	260	227	204	189	177	168	160	155	143	135	130	128	126	124	122	28
30	2632	1446	952	693	521	426	366	305	254	219	195	177	164	155	147	141	128	120	116	113	111	109	107	30
32	2716	1429	943	691	511	410	349	307	252	214	189	170	155	145	135	130	116	109	105	101	99	97	95	32
34	2819	1426	943	672	510	399	334	292	252	212	183	164	149	137	128	120	107	99	94	92	88	86	86	34
36	2943	1435	937	662	511	393	324	279	250	212	181	158	143	132	122	114	99	92	86	82	80	78	76	36
38	3080	1452	922	656	504	391	317	269	239	214	179	156	139	126	116	109	94	84	78	76	73	71	71	38
40	3235	1481	914	655	492	389	311	261	229	206	181	156	137	124	113	105	88	78	73	71	67	65	63	40
42	3402	1513	912	656	487	391	309	258	221	198	181	156	135	120	111	101	84	74	69	65	61	59	59	42
44	3584	1555	916	647	483	384	307	254	218	191	174	156	135	120	107	99	80	71	65	61	57	55	53	44
46	3777	1603	922	639	481	376	309	250	212	187	168	155	135	118	107	97	78	67	61	57	53	52	50	46
48	3983	1654	933	635	481	372	307	250	210	181	162	149	137	118	105	95	74	65	57	53	50	48	48	48

TABLE 6-14. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	5900	5900	5805	5511	5345	5244	5177	5128	5095	5068	5051	5036	5023	5011	5002	4996	4983	4973	4965	4962	4958	4958	4954	6
8	5900	4515	3752	3402	3214	3099	3027	2975	2939	2912	2891	2874	2862	2851	2843	2836	2819	2809	2803	2798	2794	2794	2788	8
10	5900	3853	2889	2467	2250	2120	2038	1985	1945	1916	1895	1876	1864	1853	1843	1838	1821	1809	1803	1798	1796	1792	1790	10
12	5689	3721	2515	2006	1750	1603	1511	1450	1408	1378	1355	1336	1322	1311	1301	1294	1277	1267	1259	1256	1252	1248	1246	12
14	5429	3486	2387	1775	1475	1305	1204	1135	1090	1055	1030	1011	996	985	975	968	950	941	933	927	924	922	920	14
16	5393	3200	2406	1674	1322	1128	1013	937	887	851	824	803	788	775	765	756	739	727	721	716	712	708	708	16
18	5166	3072	2185	1654	1244	1023	891	809	752	712	683	662	645	632	620	613	593	582	574	571	567	563	561	18
20	5112	3048	2048	1614	1216	964	815	723	660	616	586	563	544	531	519	510	490	479	471	466	462	460	456	20
22	5053	2990	1977	1498	1223	935	769	666	597	550	515	490	471	456	445	435	414	403	395	389	385	382	380	22
24	4962	2906	1950	1422	1158	931	744	630	553	502	466	437	416	401	387	378	357	343	336	330	326	324	321	24
26	4958	2876	1960	1378	1090	929	735	607	525	468	427	399	376	359	345	334	313	300	292	284	281	279	275	26
28	5021	2887	1901	1357	1046	872	739	597	506	445	401	368	345	326	313	302	279	263	256	250	244	242	240	28
30	5139	2824	1861	1355	1015	830	718	595	496	427	382	347	321	302	286	275	250	235	227	221	216	214	210	30
32	5303	2792	1842	1349	1000	800	681	601	492	418	366	330	303	282	265	254	227	212	202	197	193	189	187	32
34	5507	2786	1842	1313	994	780	653	571	494	414	359	319	290	267	250	237	210	195	183	177	174	170	166	34
36	5746	2801	1830	1292	998	767	632	546	489	414	353	311	279	256	237	223	195	177	168	160	156	153	151	36
38	5900	2838	1801	1280	983	761	618	527	466	416	353	305	273	246	227	212	181	166	155	147	143	139	137	38
40	5900	2891	1786	1279	962	761	609	511	448	403	353	303	267	240	219	204	172	155	143	135	132	128	124	40
42	5900	2958	1782	1284	948	765	603	502	433	387	353	303	265	237	214	197	164	145	134	126	120	116	114	42
44	5900	3038	1788	1263	941	748	601	494	424	374	340	305	265	235	210	193	156	137	126	118	113	109	105	44
46	5900	3130	1801	1248	939	735	603	490	414	364	326	300	265	233	208	189	151	132	118	111	105	101	97	46
48	5900	3233	1822	1240	941	727	599	487	408	355	317	290	267	233	206	185	147	126	113	105	99	95	92	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	6
8	7090	7090	6481	5878	5553	5357	5229	5141	5078	5032	4996	4965	4946	4925	4912	4899	4872	4855	4845	4832	4828	4826	4818	8
10	7090	6656	4992	4265	3887	3664	3523	3427	3361	3311	3273	3242	3219	3202	3185	3174	3147	3128	3116	3107	3101	3097	3095	10
12	7090	6431	4347	3467	3023	2771	2612	2508	2433	2380	2341	2309	2284	2265	2250	2237	2208	2189	2177	2170	2164	2158	2154	12
14	7090	6025	4126	3069	2548	2258	2080	1964	1883	1824	1782	1748	1723	1702	1685	1672	1643	1624	1613	1603	1597	1592	1588	14
16	7090	5530	4156	2893	2284	1950	1750	1620	1532	1469	1424	1387	1361	1340	1322	1307	1277	1258	1246	1237	1229	1225	1221	16
18	7090	5307	3775	2859	2149	1767	1542	1397	1300	1231	1181	1143	1114	1092	1072	1057	1027	1008	994	985	979	973	969	18
20	7090	5267	3540	2788	2101	1664	1408	1248	1141	1067	1011	971	941	916	897	882	847	828	815	805	798	794	790	20
22	7090	5168	3414	2588	2112	1616	1328	1151	1032	950	891	847	815	788	767	752	716	695	681	672	666	660	656	22
24	7090	5023	3370	2458	2000	1609	1286	1086	956	866	803	756	719	693	670	653	616	595	580	571	565	559	555	24
26	7090	4969	3385	2382	1883	1605	1269	1050	906	807	739	687	649	620	597	578	540	517	504	492	487	481	477	26
28	7090	4990	3282	2345	1805	1506	1275	1030	874	767	691	637	595	565	540	519	479	456	441	431	424	418	414	28
30	7090	4880	3214	2341	1756	1433	1238	1029	857	740	658	599	555	521	494	473	431	406	391	382	374	368	364	30
32	7090	4822	3183	2330	1729	1382	1176	1040	849	723	635	571	523	489	460	437	393	368	351	340	332	326	323	32
34	7090	4813	3183	2269	1719	1347	1128	987	853	716	620	551	500	462	431	408	363	334	319	307	300	292	288	34
36	7090	4841	3162	2233	1725	1326	1092	943	843	714	611	538	483	443	410	385	336	307	290	279	271	265	260	36
38	7090	4904	3112	2212	1696	1317	1067	910	805	719	609	529	471	427	393	366	315	286	267	256	246	240	237	38
40	7090	4994	3086	2208	1662	1317	1051	885	775	697	611	525	464	416	380	353	298	267	248	235	227	219	216	40
42	7090	5110	3080	2217	1639	1321	1042	866	750	670	611	525	458	408	370	342	282	250	231	218	210	202	198	42
44	7090	5250	3088	2183	1626	1292	1040	853	731	647	586	529	456	405	364	332	271	237	218	204	195	187	183	44
46	7090	5408	3112	2158	1622	1271	1042	845	718	628	565	519	458	403	359	326	261	227	204	191	181	176	170	46
48	7090	5586	3149	2143	1626	1256	1036	842	708	614	548	500	462	403	357	321	254	218	195	179	170	164	158	48

TABLE 6-14. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	6
8	8270	8270	8270	8270	8270	8270	8270	8164	8064	7990	7935	7885	7855	7822	7801	7778	7736	7710	7694	7675	7668	7666	7652	8
10	8270	8270	7929	6773	6171	5818	5595	5442	5336	5257	5198	5151	5114	5084	5059	5040	4996	4967	4946	4935	4925	4918	4914	10
12	8270	8270	6902	5505	4801	4399	4149	3983	3864	3780	3717	3668	3628	3597	3572	3551	3506	3477	3458	3446	3435	3427	3422	12
14	8270	8270	6551	4872	4046	3584	3301	3118	2990	2899	2830	2777	2737	2704	2677	2654	2609	2580	2561	2546	2536	2528	2521	14
16	8270	8270	6601	4593	3626	3097	2778	2572	2433	2334	2259	2204	2160	2126	2099	2076	2029	1998	1977	1964	1952	1945	1941	16
18	8270	8270	5992	4540	3414	2807	2446	2217	2065	1954	1876	1817	1769	1733	1704	1679	1630	1599	1578	1563	1553	1546	1540	18
20	8270	8270	5620	4429	3336	2643	2237	1983	1813	1693	1607	1544	1494	1454	1424	1399	1347	1315	1294	1279	1267	1259	1254	20
22	8270	8206	5423	4109	3355	2567	2111	1826	1637	1508	1414	1345	1292	1252	1219	1193	1137	1105	1082	1067	1057	1048	1042	22
24	8270	7975	5351	3902	3175	2553	2042	1725	1519	1376	1275	1200	1143	1099	1065	1036	979	945	924	906	897	887	882	24
26	8270	7891	5376	3782	2992	2549	2017	1666	1439	1282	1174	1092	1032	985	948	918	859	822	798	782	771	763	756	26
28	8270	7925	5213	3725	2868	2391	2027	1637	1387	1217	1099	1011	947	897	857	826	761	725	700	683	672	664	656	28
30	8270	7748	5103	3717	2788	2277	1967	1634	1359	1174	1046	950	882	828	786	752	685	647	622	605	593	584	578	30
32	8270	7658	5055	3700	2744	2195	1866	1651	1349	1149	1008	906	832	775	729	695	624	584	557	540	529	519	511	32
34	8270	7643	5055	3605	2729	2141	1790	1567	1355	1135	985	874	794	733	685	649	574	532	506	487	475	466	458	34
36	8270	7689	5021	3544	2738	2107	1735	1498	1340	1135	971	853	767	702	651	613	534	489	462	443	429	420	412	36
38	8270	7788	4942	3513	2695	2091	1695	1445	1279	1143	966	840	748	677	624	582	500	452	424	405	391	382	374	38
40	8270	7931	4901	3507	2641	2091	1670	1405	1229	1107	969	834	735	660	603	559	471	424	393	374	359	349	342	40
42	8270	8116	4889	3523	2605	2097	1654	1376	1191	1063	971	834	727	649	588	542	450	399	366	347	332	323	315	42
44	8270	8270	4904	3465	2584	2051	1651	1355	1162	1027	931	838	725	641	578	527	431	378	343	323	309	298	290	44
46	8270	8270	4942	3427	2576	2017	1654	1343	1139	998	899	824	727	637	571	517	416	359	324	303	288	277	269	46
48	8270	8270	5000	3404	2582	1994	1645	1338	1122	975	870	794	733	637	567	510	403	343	309	286	271	260	252	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	6
8	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	8
10	9450	9450	9450	9450	9213	8687	8351	8126	7965	7849	7759	7687	7633	7589	7551	7523	7458	7414	7385	7366	7351	7341	7336	10
12	9450	9450	9450	8219	7166	6566	6192	5944	5769	5643	5547	5473	5416	5370	5332	5301	5233	5189	5160	5145	5128	5114	5107	12
14	9450	9450	9450	7273	6038	5349	4929	4652	4464	4326	4223	4145	4084	4036	3996	3964	3895	3851	3822	3799	3786	3775	3765	14
16	9450	9450	9450	6857	5414	4624	4147	3841	3631	3483	3374	3290	3225	3174	3133	3099	3027	2981	2952	2931	2916	2903	2897	16
18	9450	9450	8946	6776	5095	4189	3652	3311	3080	2918	2799	2710	2641	2588	2544	2508	2433	2385	2357	2334	2319	2307	2298	18
20	9450	9450	8389	6610	4979	3944	3340	2958	2704	2527	2399	2303	2229	2172	2126	2088	2009	1962	1929	1908	1893	1882	1872	20
22	9450	9450	8095	6133	5007	3830	3149	2725	2445	2252	2112	2008	1929	1868	1819	1780	1698	1649	1616	1593	1576	1565	1555	22
24	9450	9450	7988	5826	4740	3811	3048	2576	2267	2055	1903	1792	1708	1641	1590	1548	1462	1410	1378	1353	1338	1324	1317	24
26	9450	9450	8024	5645	4467	3805	3009	2487	2147	1916	1750	1630	1540	1469	1414	1370	1280	1227	1193	1168	1151	1139	1130	26
28	9450	9450	7782	5559	4280	3570	3025	2445	2071	1819	1639	1509	1412	1338	1279	1233	1137	1082	1046	1021	1004	990	981	28
30	9450	9450	7618	5549	4162	3399	2939	2439	2029	1754	1559	1420	1315	1235	1174	1124	1023	966	927	903	885	872	863	30
32	9450	9450	7545	5523	4097	3277	2786	2464	2015	1714	1504	1353	1240	1156	1090	1036	931	870	832	807	788	775	765	32
34	9450	9450	7545	5379	4074	3194	2674	2340	2023	1695	1469	1305	1185	1093	1023	968	857	794	754	727	708	695	683	34
36	9450	9450	7496	5290	4088	3145	2590	2237	2000	1695	1448	1273	1145	1048	971	914	796	729	689	660	641	628	616	36
38	9450	9450	7379	5244	4023	3122	2530	2156	1908	1706	1443	1254	1116	1011	931	870	746	676	634	605	584	571	559	38
40	9450	9450	7316	5234	3941	3122	2492	2097	1836	1653	1446	1244	1097	987	901	836	704	632	588	557	536	523	511	40
42	9450	9450	7299	5257	3887	3132	2471	2053	1779	1586	1448	1244	1086	969	878	807	672	593	548	517	496	481	469	42
44	9450	9450	7320	5173	3857	3063	2464	2023	1733	1532	1389	1252	1084	958	863	788	643	563	513	483	460	445	433	44
46	9450	9450	7377	5114	3845	3011	2471	2006	1700	1490	1340	1231	1086	952	851	773	620	536	485	452	429	414	403	46
48	9450	9450	7463	5080	3853	2975	2454	1996	1675	1456	1300	1185	1095	952	845	761	601	513	460	427	403	387	374	48

TABLE 6-14. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - LOADED EDGES CLAMPED - REMAINING EDGES SIMPLY SUPPORTED (Cont'd)

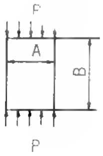
THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	6
8	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	8
10	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10618	10555	10515	10486	10467	10454	10444	10
12	10630	10630	10630	10630	10204	9349	8816	8463	8215	8034	7900	7793	7711	7645	7593	7547	7450	7389	7347	7324	7301	7282	7273	12
14	10630	10630	10630	10354	8597	7616	7019	6626	6355	6160	6013	5902	5815	5748	5689	5643	5546	5484	5442	5410	5391	5374	5360	14
16	10630	10630	10630	9763	7708	6582	5906	5469	5171	4960	4803	4685	4593	4519	4460	4412	4311	4246	4204	4173	4151	4133	4124	16
18	10630	10630	10630	9646	7253	5965	5200	4714	4387	4154	3986	3860	3761	3683	3622	3570	3464	3397	3355	3322	3301	3284	3273	18
20	10630	10630	10630	9412	7089	5616	4755	4214	3851	3599	3416	3278	3174	3091	3027	2973	2862	2794	2748	2717	2695	2677	2664	20
22	10630	10630	10630	8732	7129	5454	4485	3881	3481	3206	3007	2859	2748	2660	2590	2534	2418	2347	2301	2269	2246	2229	2214	22
24	10630	10630	10630	8295	6750	5427	4339	3668	3227	2925	2710	2551	2431	2338	2263	2204	2082	2009	1962	1927	1904	1887	1874	24
26	10630	10630	10630	8038	6360	5418	4286	3542	3057	2727	2492	2320	2193	2093	2013	1950	1822	1746	1696	1664	1639	1622	1607	26
28	10630	10630	10630	7916	6095	5082	4305	3481	2948	2588	2334	2149	2011	1904	1821	1754	1620	1540	1488	1454	1429	1410	1397	28
30	10630	10630	10630	7900	5925	4839	4183	3473	2889	2496	2221	2021	1872	1759	1670	1599	1458	1374	1321	1286	1259	1242	1227	30
32	10630	10630	10630	7864	5832	4666	3967	3507	2868	2441	2143	1927	1767	1645	1551	1477	1326	1240	1185	1149	1122	1103	1088	32
34	10630	10630	10630	7660	5801	4549	3805	3330	2880	2414	2091	1859	1689	1559	1458	1378	1221	1130	1072	1034	1008	988	973	34
36	10630	10630	10630	7532	5820	4479	3687	3185	2847	2412	2063	1813	1630	1490	1384	1300	1134	1038	979	941	912	893	878	36
38	10630	10630	10507	7467	5729	4446	3603	3072	2717	2429	2053	1786	1590	1441	1326	1238	1063	964	901	861	832	811	796	38
40	10630	10630	10417	7454	5612	4444	3548	2986	2612	2353	2061	1773	1563	1405	1282	1189	1004	899	836	794	765	742	727	40
42	10630	10630	10393	7486	5534	4460	3519	2924	2530	2259	2063	1773	1548	1380	1250	1151	956	845	780	737	706	685	668	42
44	10630	10630	10423	7366	5490	4360	3509	2882	2467	2183	1979	1782	1542	1364	1227	1120	916	801	733	687	656	634	616	44
46	10630	10630	10503	7282	5475	4288	3519	2855	2420	2122	1908	1752	1548	1357	1212	1099	884	763	691	645	613	590	572	46
48	10630	10630	10627	7234	5486	4236	3494	2843	2387	2074	1851	1687	1559	1357	1204	1084	857	731	656	607	574	551	534	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	6
8	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	8
10	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	10
12	11810	11810	11810	11810	11810	11810	11810	11608	11269	11020	10837	10690	10578	10486	10416	10353	10219	10135	10080	10047	10015	9990	9977	12
14	11810	11810	11810	11810	11793	10448	9627	9089	8715	8450	8248	8097	7977	7883	7805	7740	7606	7523	7465	7421	7395	7370	7353	14
16	11810	11810	11810	11810	10572	9030	8101	7502	7093	6803	6587	6427	6301	6200	6118	6053	5912	5824	5765	5725	5694	5670	5656	16
18	11810	11810	11810	11810	9950	8183	7135	6467	6017	5700	5467	5294	5160	5053	4967	4899	4752	4660	4601	4559	4528	4504	4488	18
20	11810	11810	11810	11810	9725	7704	6523	5778	5282	4937	4685	4498	4355	4242	4151	4078	3925	3832	3769	3727	3696	3673	3654	20
22	11810	11810	11810	11810	9780	7482	6152	5322	4776	4397	4124	3923	3769	3649	3553	3477	3317	3219	3156	3112	3080	3057	3038	22
24	11810	11810	11810	11379	9259	7444	5952	5030	4427	4013	3717	3500	3334	3206	3105	3023	2857	2756	2691	2645	2612	2588	2570	24
26	11810	11810	11810	11026	8725	7431	5879	4857	4193	3740	3420	3185	3007	2870	2763	2677	2502	2395	2328	2282	2248	2223	2206	26
28	11810	11810	11810	10858	8360	6973	5906	4775	4046	3551	3202	2948	2757	2612	2498	2406	2221	2112	2042	1994	1960	1935	1916	28
30	11810	11810	11810	10837	8127	6637	5738	4763	3964	3423	3046	2773	2569	2412	2290	2195	2000	1885	1813	1763	1729	1704	1683	30
32	11810	11810	11810	10786	8002	6400	5442	4811	3935	3347	2939	2643	2424	2258	2128	2025	1821	1700	1626	1574	1540	1513	1492	32
34	11810	11810	11810	10509	7958	6240	5221	4568	3950	3311	2868	2551	2315	2137	2000	1891	1674	1550	1471	1420	1384	1357	1336	34
36	11810	11810	11810	10333	7984	6143	5057	4368	3904	3309	2830	2488	2237	2046	1899	1784	1555	1426	1343	1290	1252	1225	1204	36
38	11810	11810	11810	10244	7858	6099	4942	4214	3727	3334	2817	2448	2179	1977	1821	1698	1458	1321	1237	1181	1141	1114	1093	38
40	11810	11810	11810	10225	7698	6097	4868	4097	3584	3227	2826	2431	2143	1925	1759	1632	1376	1235	1147	1088	1048	1019	998	40
42	11810	11810	11810	10269	7591	6116	4826	4011	3473	3099	2830	2431	2122	1891	1716	1578	1311	1160	1071	1009	968	939	916	42
44	11810	11810	11810	10104	7532	5981	4813	3952	3385	2994	2714	2445	2116	1870	1683	1538	1256	1099	1004	943	899	868	847	44
46	11810	11810	11810	9990	7511	5881	4826	3916	3320	2910	2618	2403	2122	1861	1662	1508	1212	1048	948	884	840	809	786	46
48	11810	11810	11810	9923	7524	5813	4794	3901	3275	2845	2540	2315	2137	1861	1651	1488	1176	1004	901	834	788	756	733	48

TABLE 6-15. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES CLAMPED



PHYSICAL CONSTANTS:

$E_X = 1.96 \times 10^6$ PSI
$E_Y = 1.70 \times 10^6$ PSI

$G_{XY} = 0.52 \times 10^6$ PSI
$\sigma_{XY} = \sigma_{YX} = 0.20$

THICKNESS-H EQUALS 0.0625 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	107	67	53	48	46	44	42	42	42	40	40	40	40	40	40	40	40	40	40	40	34	40	40	6
8	88	59	40	32	29	27	25	25	25	25	23	23	23	23	23	23	23	23	23	23	23	23	23	8
10	84	52	38	27	23	19	19	17	17	15	15	15	15	15	15	15	15	15	15	15	15	15	15	10
12	80	48	34	27	19	17	15	13	13	11	11	11	11	11	11	11	10	10	10	10	10	10	10	12
14	78	48	31	25	19	15	13	11	10	10	10	10	8	8	8	8	8	8	8	8	8	8	8	14
16	76	44	31	23	19	15	11	10	10	8	8	8	8	8	6	6	6	6	6	6	6	6	6	16
18	76	44	31	21	17	13	11	10	8	8	8	6	6	6	6	6	6	6	4	4	4	4	4	18
20	80	44	29	21	15	13	11	10	8	8	6	6	6	6	4	4	4	4	4	4	4	4	4	20
22	84	42	29	21	15	11	10	10	8	6	6	6	6	4	4	4	4	4	4	4	4	4	4	22
24	92	44	29	19	15	11	10	8	8	6	6	6	4	4	4	4	4	4	2	2	2	2	2	24
26	99	44	27	19	15	11	10	8	8	6	6	6	4	4	4	4	4	2	2	2	2	2	2	26
28	109	46	27	19	15	11	10	8	8	6	6	6	4	4	4	4	2	2	2	2	2	2	2	28
30	118	48	27	19	15	11	10	8	6	6	6	6	4	4	4	4	2	2	2	2	2	2	2	30
32	130	52	29	19	15	11	10	8	6	6	6	4	4	4	4	4	2	2	2	2	2	2	2	32
34	143	55	29	19	13	11	10	8	6	6	6	4	4	4	4	4	2	2	2	2	2	2	2	34
36	156	59	31	19	13	11	10	8	6	6	4	4	4	4	4	4	2	2	2	2	2	2	2	36
38	170	63	31	19	13	11	10	8	6	6	4	4	4	4	4	4	2	2	2	2	2	2	2	38
40	185	67	32	19	13	11	10	8	6	6	4	4	4	4	4	2	2	2	2	2	2	2	2	40
42	200	73	34	21	13	11	10	8	6	6	4	4	4	4	4	2	2	2	2	2	2	2	2	42
44	218	76	36	21	13	11	8	8	6	6	4	4	4	4	2	2	2	2	2	2	2	2	0	44
46	235	82	38	23	15	11	8	8	6	6	4	4	4	4	2	2	2	2	2	2	2	0	0	46
48	254	88	40	23	15	11	8	8	6	6	4	4	4	4	2	2	2	2	2	2	2	0	0	48

THICKNESS-H EQUALS 0.1250 INCHES

LENGTH-B INCHES											WIDTH-A INCHES												LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	853	529	426	382	361	347	340	334	330	328	326	324	324	323	323	321	321	319	319	319	267	317	317	6
8	710	479	324	261	231	216	204	198	195	191	189	187	185	185	183	183	181	181	179	179	179	179	179	8
10	676	416	307	219	179	158	145	137	132	128	126	124	122	120	120	120	118	116	116	116	114	114	114	10
12	635	382	275	214	160	132	116	107	99	95	92	90	88	88	86	86	84	82	82	80	80	80	80	12
14	630	378	250	195	156	122	101	90	82	76	73	71	69	67	65	65	63	61	61	59	59	59	59	14
16	607	357	242	177	147	120	95	80	73	65	61	57	55	53	52	52	50	48	48	46	46	46	46	16
18	613	355	239	170	134	113	95	76	67	59	53	50	48	46	44	42	40	38	38	36	36	36	36	18
20	637	345	229	168	126	103	92	76	63	55	50	46	42	40	38	36	34	32	31	31	31	31	31	20
22	679	340	227	164	124	97	84	74	63	53	46	42	38	36	34	32	29	27	27	25	25	25	25	22
24	733	343	223	158	124	95	78	69	61	53	46	40	36	32	31	29	25	25	23	23	21	21	21	24
26	796	355	219	156	120	95	76	65	57	52	46	40	34	31	29	27	23	21	19	19	19	19	17	26
28	870	368	218	156	116	95	74	63	53	50	46	40	34	31	27	25	21	19	17	17	17	15	15	28
30	952	389	219	153	116	92	74	61	52	46	42	38	34	31	27	25	19	17	15	15	15	13	13	30
32	1044	412	225	151	116	90	74	61	52	44	40	36	34	31	27	25	19	17	15	13	13	13	13	32
34	1141	439	233	151	114	88	73	61	50	44	38	34	32	31	27	23	19	15	13	13	11	11	11	34
36	1246	468	240	153	113	88	71	59	50	42	36	32	31	29	27	23	17	15	13	11	11	11	10	36
38	1359	500	252	156	111	88	71	57	50	42	36	32	29	27	25	25	17	13	11	11	10	10	10	38
40	1479	536	263	160	111	86	71	57	50	42	36	32	29	27	25	23	17	13	11	10	10	10	10	40
42	1607	574	277	164	113	86	71	57	48	42	36	31	29	25	23	21	17	13	11	10	10	8	8	42
44	1740	614	292	170	114	86	69	57	48	40	36	31	27	25	23	21	17	13	11	10	10	8	8	44
46	1880	656	307	176	116	86	69	57	48	40	36	31	27	25	21	21	17	13	11	10	8	8	8	46
48	2027	700	324	183	118	86	67	55	48	40	34	31	27	25	21	19	17	13	11	10	8	8	8	48

TABLE 6-15. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	2878	1782	1435	1290	1216	1174	1147	1130	1116	1107	1101	1097	1093	1090	1086	1084	1080	1076	1074	1074	905	1072	1071	6
8	2395	1618	1093	882	780	725	693	670	655	645	637	632	628	622	620	618	613	609	607	605	605	605	603	8
10	2280	1403	1036	742	607	534	490	464	447	433	426	418	412	408	405	403	397	393	391	389	389	387	387	10
12	2145	1288	926	719	540	447	391	359	338	323	311	303	298	294	290	286	281	277	275	273	271	271	271	12
14	2124	1277	842	658	529	410	343	303	277	258	246	237	229	225	221	218	210	206	204	202	200	200	200	14
16	2046	1206	819	599	492	405	323	273	242	221	206	195	187	181	177	174	166	160	158	156	155	155	155	16
18	2065	1197	803	572	448	384	321	261	223	198	181	168	160	153	147	143	135	130	128	126	124	122	122	18
20	2153	1164	773	571	427	351	307	260	216	185	166	151	141	134	128	122	114	109	105	103	101	101	99	20
22	2290	1149	765	553	418	332	282	250	214	179	156	141	130	120	113	109	97	92	90	88	86	84	84	22
24	2471	1162	756	536	420	323	265	231	210	179	153	135	122	111	103	97	86	80	76	74	73	73	71	24
26	2689	1195	739	531	405	321	258	219	195	177	153	132	116	105	97	92	78	71	67	65	63	61	61	26
28	2937	1246	737	531	393	319	254	210	183	164	151	132	114	103	94	86	73	65	61	57	55	53	53	28
30	3215	1311	744	517	389	307	254	206	176	156	141	132	114	101	90	82	67	59	55	52	50	48	48	30
32	3521	1389	760	511	391	302	250	204	172	149	134	124	114	101	90	80	65	55	50	48	44	44	42	32
34	3540	1479	782	511	384	300	242	206	170	145	130	116	109	101	90	80	61	52	46	44	40	40	38	34
36	3540	1580	813	517	378	300	239	200	170	143	126	113	103	95	90	80	59	50	44	40	38	36	34	36
38	3540	1689	849	525	376	296	237	197	170	143	122	109	99	92	86	80	59	48	42	38	34	32	32	38
40	3540	1809	889	538	376	292	237	193	166	143	122	107	95	88	82	76	59	46	40	34	32	31	29	40
42	3540	1935	935	553	380	288	237	191	162	141	122	105	94	86	78	73	59	46	38	34	31	29	27	42
44	3540	2072	985	572	385	288	231	191	160	137	122	105	92	82	76	71	59	46	36	32	29	27	25	44
46	3540	2216	1038	593	393	288	229	193	158	135	120	105	92	82	74	69	57	46	36	31	29	25	25	46
48	3540	2366	1095	618	401	290	227	189	158	134	118	105	92	80	73	67	55	46	36	31	27	25	23	48

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	4730	4227	3402	3055	2880	2780	2717	2675	2647	2626	2611	2599	2590	2580	2574	2569	2559	2551	2548	2544	2145	2540	2538	6
8	4730	3838	2590	2091	1851	1719	1639	1588	1553	1529	1511	1496	1487	1477	1471	1464	1452	1445	1441	1435	1433	1433	1429	8
10	4730	3324	2456	1761	1437	1265	1164	1099	1057	1029	1008	990	979	969	962	954	943	933	927	926	922	920	920	10
12	4730	3055	2195	1706	1279	1057	929	851	800	763	739	719	706	695	687	679	664	656	651	647	645	643	641	12
14	4730	3025	1996	1561	1254	971	813	718	655	613	582	561	546	532	523	515	500	490	485	479	477	475	473	14
16	4730	2859	1943	1420	1168	960	765	647	572	523	489	462	445	429	418	410	393	382	376	372	368	366	364	16
18	4730	2838	1904	1359	1065	908	758	618	529	469	429	399	378	363	349	340	321	309	302	298	294	292	290	18
20	4730	2761	1830	1351	1011	832	727	614	510	441	393	359	334	317	302	290	269	258	250	244	240	239	237	20
22	4730	2725	1813	1311	992	786	668	593	508	427	372	334	305	284	269	256	233	219	212	206	202	200	198	22
24	4730	2754	1790	1271	996	763	632	550	496	426	364	321	288	263	246	233	206	191	181	176	172	170	168	24
26	4730	2834	1752	1259	958	760	609	519	460	420	363	313	277	250	231	216	185	170	160	155	149	147	145	26
28	4730	2954	1744	1259	933	756	601	500	435	391	359	313	273	242	221	204	170	153	143	135	132	128	126	28
30	4730	3109	1761	1227	926	731	601	489	418	370	336	311	273	240	216	197	160	141	130	122	118	114	113	30
32	4730	3296	1801	1212	929	716	592	485	406	355	319	292	273	240	212	191	151	130	118	111	107	103	99	32
34	4730	3507	1857	1212	910	708	574	489	403	345	305	277	256	240	212	189	145	124	111	101	97	94	90	34
36	4730	3744	1927	1223	895	710	565	477	401	340	298	267	244	227	214	189	141	118	103	95	90	84	82	36
38	4730	4006	2011	1244	889	702	559	466	403	338	292	258	235	216	202	191	139	113	97	88	82	78	74	38
40	4730	4286	2109	1275	891	691	559	458	391	338	288	252	227	208	193	181	139	111	94	84	76	73	69	40
42	4730	4588	2216	1313	899	683	559	454	384	336	288	250	221	202	185	174	139	109	90	80	73	69	65	42
44	4730	4730	2334	1357	912	681	550	454	378	328	288	248	218	197	179	166	141	107	88	76	69	65	61	44
46	4730	4730	2462	1408	929	683	542	456	376	323	284	248	216	193	176	162	135	107	86	74	67	61	57	46
48	4730	4730	2597	1464	952	689	538	448	374	317	279	250	216	191	172	158	130	107	86	73	63	57	53	48

TABLE 6-15. FIBERGLASS POLYESTER LAMINATES
CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH
10 OZ. CLOTH - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.3125 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	5900	5900	5900	5900	5626	5429	5309	5227	5171	5128	5099	5076	5057	5040	5026	5017	5000	4984	4975	4969	4189	4962	4958	6
8	5900	5900	5059	4084	3614	3357	3202	3103	3034	2986	2950	2922	2903	2883	2872	2861	2836	2822	2813	2805	2799	2798	2794	8
10	5900	5900	4797	3439	2807	2469	2273	2149	2067	2009	1967	1935	1910	1893	1878	1866	1840	1824	1813	1807	1801	1798	1796	10
12	5900	5900	4288	3332	2498	2063	1615	1662	1561	1492	1443	1406	1380	1357	1342	1326	1300	1282	1271	1265	1259	1254	1252	12
14	5900	5900	3901	3049	2448	1899	1590	1401	1279	1197	1139	1095	1065	1040	1021	1006	975	956	945	937	931	927	924	14
16	5900	5584	3792	2773	2282	1874	1494	1265	1118	1021	952	905	866	840	819	801	767	746	735	725	719	716	712	16
18	5900	5542	3721	2653	2080	1775	1481	1206	1032	918	838	780	739	706	683	662	626	603	590	580	574	571	567	18
20	5900	5393	3574	2639	1975	1624	1418	1198	994	861	767	702	653	618	590	569	527	502	487	477	471	466	462	20
22	5900	5322	3542	2561	1937	1536	1303	1160	990	834	727	653	597	557	525	502	454	427	412	403	395	389	385	22
24	5900	5378	3498	2483	1946	1492	1233	1072	968	832	710	624	563	515	481	454	401	372	355	345	338	332	328	24
26	5900	5534	3422	2458	1870	1481	1191	1013	897	819	710	613	542	490	450	420	363	332	313	302	292	286	282	26
28	5900	5769	3406	2458	1824	1477	1172	975	847	763	702	613	532	475	431	397	334	300	279	265	258	252	246	28
30	5900	5900	3443	2397	1807	1426	1174	954	815	721	656	609	532	468	420	382	311	275	252	239	229	223	219	30
32	5900	5900	3517	2368	1813	1397	1156	948	796	693	622	571	532	468	414	374	296	256	231	218	206	200	195	32
34	5900	5900	3626	2368	1777	1384	1124	952	786	674	597	542	502	469	414	370	284	240	216	198	189	181	176	34
36	5900	5900	3765	2391	1750	1385	1103	929	784	662	580	521	477	443	418	370	277	229	202	185	174	166	160	36
38	5900	5900	3929	2431	1738	1372	1093	908	788	658	569	504	458	422	395	374	273	221	191	174	160	153	147	38
40	5900	5900	4118	2490	1740	1347	1093	893	765	660	563	494	443	406	378	355	271	216	183	164	151	141	135	40
42	5900	5900	4328	2565	1756	1334	1093	885	748	656	561	487	433	393	363	340	273	212	177	156	141	134	126	42
44	5900	5900	4559	2651	1782	1330	1072	885	739	639	563	485	427	384	351	326	275	208	172	149	135	126	118	44
46	5900	5900	4807	2750	1817	1334	1059	889	733	628	555	485	424	378	343	317	265	208	168	145	130	118	113	46
48	5900	5900	5074	2861	1859	1345	1053	874	731	620	544	487	422	372	336	307	254	208	166	141	124	113	105	48

THICKNESS-H EQUALS 0.3750 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																						LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	7090	6
8	7090	7090	7090	7057	6246	5801	5534	5360	5244	5160	5099	5049	5015	4984	4963	4942	4901	4878	4862	4845	4839	4836	4826	8
10	7090	7090	7090	5944	4849	4267	3927	3712	3570	3471	3399	3343	3301	3269	3242	3223	3179	3151	3133	3122	3112	3107	3103	10
12	7090	7090	7090	5757	4317	3567	3137	2872	2698	2578	2494	2429	2382	2345	2317	2294	2244	2216	2196	2185	2175	2168	2162	12
14	7090	7090	6740	5269	4229	3280	2746	2420	2210	2069	1967	1895	1840	1798	1763	1738	1685	1654	1634	1618	1611	1603	1597	14
16	7090	7090	6553	4790	3944	3238	2580	2185	1933	1765	1647	1561	1498	1450	1412	1384	1324	1290	1269	1254	1244	1235	1231	16
18	7090	7090	6429	4584	3595	3065	2559	2084	1784	1586	1446	1349	1277	1221	1179	1145	1080	1042	1019	1004	992	985	979	18
20	7090	7090	6175	4559	3412	2805	2452	2072	1719	1487	1326	1212	1130	1067	1019	981	908	868	842	826	815	805	800	20
22	7090	7090	6120	4423	3345	2653	2254	2006	1712	1443	1258	1128	1032	962	908	866	784	740	712	695	683	674	666	22
24	7090	7090	6044	4288	3364	2578	2130	1853	1672	1439	1227	1078	971	891	830	784	695	645	614	595	582	572	567	24
26	7090	7090	5912	4248	3231	2561	2057	1750	1550	1416	1227	1057	937	847	779	727	626	572	540	519	506	496	489	26
28	7090	7090	5887	4248	3151	2551	2027	1685	1466	1317	1214	1057	922	821	744	687	576	517	483	460	445	435	427	28
30	7090	7090	5948	4141	3122	2464	2027	1651	1408	1246	1134	1051	922	809	725	660	538	473	437	412	397	385	378	30
32	7090	7090	6078	4093	3133	2412	1998	1639	1374	1197	1074	987	920	809	716	645	511	441	401	374	357	345	338	32
34	7090	7090	6267	4091	3070	2391	1941	1647	1357	1164	1032	937	866	813	718	639	492	416	372	343	326	313	303	34
36	7090	7090	6505	4130	3023	2395	1906	1607	1355	1145	1002	899	822	767	723	639	479	397	349	319	300	286	277	36
38	7090	7090	6792	4202	3004	2370	1889	1569	1361	1137	983	872	790	729	683	647	471	382	330	300	279	263	254	38
40	7090	7090	7090	4303	3009	2330	1889	1544	1322	1139	971	853	767	702	651	613	469	372	317	282	260	246	235	40
42	7090	7090	7090	4431	3034	2307	1887	1532	1294	1134	969	842	748	679	626	586	469	364	305	269	246	229	219	42
44	7090	7090	7090	4580	3078	2300	1853	1530	1277	1107	973	836	737	664	607	563	473	361	298	258	233	216	204	44
46	7090	7090	7090	4752	3139	2305	1830	1536	1267	1086	960	836	731	653	592	546	456	359	290	250	223	206	193	46
48	7090	7090	7090	4942	3214	2322	1819	1511	1263	1072	939	842	729	645	582	532	439	361	286	242	216	197	183	48

TABLE 6-15. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	8270	6
8	8270	8270	8270	8270	8270	8270	8270	8270	8270	8194	8097	8019	7965	7914	7881	7847	7782	7744	7721	7694	7683	7679	7664	8
10	8270	8270	8270	8270	7700	6776	6234	5895	5668	5511	5397	5309	5244	5192	5151	5118	5047	5004	4975	4956	4942	4933	4925	10
12	8270	8270	8270	8270	6853	5662	4981	4559	4284	4093	3960	3859	3784	3725	3679	3641	3563	3517	3488	3469	3454	3443	3435	12
14	8270	8270	8270	8270	6715	5210	4360	3843	3509	3284	3124	3007	2920	2855	2801	2759	2675	2626	2593	2570	2555	2544	2534	14
16	8270	8270	8270	7606	6263	5141	4099	3471	3070	2801	2614	2479	2380	2303	2244	2196	2103	2048	2013	1990	1975	1962	1954	16
18	8270	8270	8270	7278	5710	4868	4063	3309	2834	2517	2298	2141	2027	1939	1872	1819	1716	1654	1618	1593	1576	1563	1555	18
20	8270	8270	8270	7240	5420	4454	3893	3290	2729	2359	2105	1925	1794	1695	1618	1559	1443	1378	1338	1311	1292	1280	1269	20
22	8270	8270	8270	7024	5313	4214	3578	3185	2719	2290	1998	1790	1639	1527	1443	1376	1246	1176	1132	1103	1084	1069	1059	22
24	8270	8270	8270	6811	5343	4093	3380	2941	2654	2286	1950	1714	1542	1416	1321	1244	1101	1023	977	947	926	910	899	24
26	8270	8270	8270	6746	5131	4067	3267	2778	2462	2246	1946	1679	1487	1343	1237	1153	994	908	857	824	803	786	775	26
28	8270	8270	8270	6746	5004	4051	3217	2675	2328	2091	1927	1679	1462	1303	1183	1090	914	821	765	731	706	691	677	28
30	8270	8270	8270	6576	4958	3912	3217	2620	2237	1981	1800	1670	1462	1284	1151	1050	855	754	693	655	630	613	599	30
32	8270	8270	8270	6500	4977	3830	3172	2601	2181	1901	1706	1567	1462	1286	1137	1025	813	700	635	595	569	550	536	32
34	8270	8270	8270	6498	4876	3798	3082	2614	2154	1849	1637	1487	1374	1290	1139	1015	782	660	590	546	517	498	483	34
36	8270	8270	8270	6559	4799	3801	3027	2551	2151	1819	1592	1427	1307	1217	1147	1015	761	630	553	506	475	454	441	36
38	8270	8270	8270	6673	4769	3765	3002	2490	2160	1807	1561	1384	1256	1158	1084	1027	750	607	525	475	441	420	403	38
40	8270	8270	8270	6834	4776	3698	3000	2452	2099	1811	1544	1355	1217	1114	1034	973	744	590	502	448	414	389	372	40
42	8270	8270	8270	7036	4818	3662	2998	2433	2055	1801	1540	1336	1189	1078	994	929	746	578	485	427	389	364	347	42
44	8270	8270	8270	7274	4889	3651	2943	2429	2027	1756	1546	1328	1170	1053	964	895	752	572	471	410	370	343	324	44
46	8270	8270	8270	7545	4984	3660	2906	2441	2011	1723	1525	1328	1160	1034	941	866	725	571	462	397	355	326	307	46
48	8270	8270	8270	7849	5103	3689	2889	2399	2008	1702	1492	1336	1156	1023	924	845	697	571	456	385	342	311	290	48

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	6
8	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	9450	8
10	9450	9450	9450	9450	9450	9450	9307	8799	8461	8227	8055	7925	7828	7752	7687	7641	7536	7469	7427	7398	7377	7362	7353	10
12	9450	9450	9450	9450	9450	8452	7435	6805	6395	6110	5910	5761	5647	5559	5492	5435	5320	5252	5206	5179	5156	5137	5126	12
14	9450	9450	9450	9450	9450	7778	6509	5736	5238	4901	4662	4490	4359	4261	4181	4120	3994	3920	3872	3838	3815	3798	3784	14
16	9450	9450	9450	9450	9351	7675	6118	5181	4582	4181	3902	3700	3551	3437	3349	3280	3139	3057	3007	2971	2946	2929	2918	16
18	9450	9450	9450	9450	8522	7267	6065	4941	4229	3757	3431	3196	3025	2895	2794	2716	2561	2471	2416	2378	2353	2334	2320	18
20	9450	9450	9450	9450	8089	6650	5811	4912	4074	3523	3143	2874	2677	2528	2416	2326	2154	2057	1996	1956	1929	1910	1895	20
22	9450	9450	9450	9450	7931	6290	5341	4755	4059	3420	2981	2672	2448	2280	2153	2053	1861	1754	1689	1647	1616	1597	1580	22
24	9450	9450	9450	9450	7975	6110	5046	4391	3964	3412	2910	2557	2303	2112	1969	1859	1645	1529	1458	1412	1382	1359	1343	24
26	9450	9450	9450	9450	7658	6068	4876	4147	3675	3355	2906	2508	2219	2006	1845	1721	1485	1357	1280	1231	1198	1176	1158	26
28	9450	9450	9450	9450	7469	6049	4801	3994	3473	3122	2876	2506	2183	1945	1765	1628	1366	1225	1143	1090	1055	1030	1011	28
30	9450	9450	9450	9450	7400	5839	4803	3910	3340	2956	2687	2492	2183	1918	1717	1565	1277	1124	1034	977	941	914	895	30
32	9450	9450	9450	9450	7427	5717	4736	3883	3257	2838	2548	2338	2181	1920	1698	1529	1212	1046	948	887	847	821	800	32
34	9450	9450	9450	9450	7278	5668	4601	3902	3217	2761	2445	2219	2051	1925	1700	1513	1168	985	880	815	773	742	721	34
36	9450	9450	9450	9450	7164	5675	4519	3809	3212	2716	2374	2130	1952	1817	1712	1515	1137	939	826	756	710	679	656	36
38	9450	9450	9450	9450	7120	5620	4481	3717	3225	2698	2328	2067	1874	1731	1620	1532	1118	905	782	708	660	626	603	38
40	9450	9450	9450	9450	7131	5521	4479	3660	3133	2702	2305	2023	1817	1662	1544	1452	1113	880	750	670	616	582	557	40
42	9450	9450	9450	9450	7192	5467	4475	3630	3067	2689	2298	1996	1775	1611	1485	1387	1114	864	723	637	582	544	517	42
44	9450	9450	9450	9450	7297	5448	4393	3626	3025	2622	2307	1983	1748	1572	1439	1336	1124	855	704	613	553	513	485	44
46	9450	9450	9450	9450	7440	5463	4339	3643	3002	2574	2277	1983	1731	1546	1403	1294	1082	851	689	592	529	487	458	46
48	9450	9450	9450	9450	7616	5507	4311	3582	2996	2542	2227	1994	1725	1529	1378	1261	1038	853	679	576	510	464	433	48

TABLE 6-15. FIBERGLASS POLYESTER LAMINATES CRITICAL BUCKLING LOADS - POUNDS PER LINEAR INCH 10 OZ. CLOTH - ALL EDGES CLAMPED (Cont'd)

THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	6
8	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	8
10	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10630	10574	10534	10505	10484	10471	10
12	10630	10630	10630	10630	10630	10630	10585	9690	9104	8702	8416	8202	8042	7916	7818	7740	7574	7477	7412	7374	7341	7315	7299	12
14	10630	10630	10630	10630	10630	10630	9267	8169	7460	6979	6639	6393	6208	6066	5954	5866	5687	5582	5513	5463	5433	5408	5389	14
16	10630	10630	10630	10630	10630	10630	8711	7376	6524	5954	5557	5269	5057	4895	4769	4670	4469	4353	4280	4233	4196	4170	4152	16
18	10630	10630	10630	10630	10630	10345	8635	7034	6023	5349	4883	4551	4307	4122	3979	3868	3645	3519	3441	3387	3351	3322	3305	18
20	10630	10630	10630	10630	10630	9467	8274	6994	5801	5015	4475	4091	3811	3601	3439	3313	3067	2929	2841	2786	2748	2719	2698	20
22	10630	10630	10630	10630	10630	8954	7606	6771	5780	4868	4244	3805	3485	3246	3065	2924	2649	2496	2404	2345	2303	2273	2250	22
24	10630	10630	10630	10630	10630	8700	7185	6252	5643	4857	4143	3641	3278	3009	2805	2647	2341	2175	2076	2009	1966	1935	1912	24
26	10630	10630	10630	10630	10630	8641	6942	5904	5233	4776	4139	3570	3160	2857	2628	2450	2114	1931	1822	1754	1706	1674	1649	26
28	10630	10630	10630	10630	10630	8612	6837	5687	4946	4446	4095	3569	3109	2769	2513	2317	1945	1744	1626	1551	1502	1466	1441	28
30	10630	10630	10630	10630	10536	8314	6839	5568	4755	4208	3826	3549	3109	2731	2446	2229	1819	1601	1473	1393	1338	1301	1275	30
32	10630	10630	10630	10630	10576	8141	6742	5530	4637	4042	3626	3328	3107	2733	2418	2177	1727	1488	1351	1263	1206	1168	1139	32
34	10630	10630	10630	10630	10362	8070	6549	5555	4580	3931	3481	3160	2922	2742	2420	2156	1662	1403	1254	1160	1099	1057	1027	34
36	10630	10630	10630	10630	10202	8082	6433	5425	4572	3866	3382	3034	2778	2586	2439	2158	1618	1338	1176	1076	1011	968	935	36
38	10630	10630	10630	10630	10137	8002	6379	5294	4591	3841	3317	2943	2668	2464	2305	2181	1593	1288	1114	1008	939	891	857	38
40	10630	10630	10630	10630	10154	7862	6378	5212	4460	3847	3280	2880	2586	2366	2198	2069	1584	1254	1067	952	878	828	792	40
42	10630	10630	10630	10630	10242	7784	6372	5170	4366	3828	3273	2841	2527	2294	2114	1977	1586	1231	1030	908	828	775	739	42
44	10630	10630	10630	10630	10391	7759	6255	5164	4307	3733	3284	2822	2488	2238	2050	1901	1599	1217	1002	872	788	731	691	44
46	10630	10630	10630	10630	10593	7780	6179	5187	4275	3664	3240	2822	2466	2200	1998	1842	1542	1212	981	842	754	693	651	46
48	10630	10630	10630	10630	10630	7841	6139	5099	4265	3618	3170	2840	2458	2175	1962	1796	1479	1214	968	819	725	662	618	48

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																							LENGTH-B INCHES
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	42	48	54	60	66	72	78	
6	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	6
8	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	8
10	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	10
12	11810	11810	11810	11810	11810	11810	11810	11810	11810	11810	11543	11251	11030	10858	10727	10616	10391	10255	10167	10116	10070	10034	10013	12
14	11810	11810	11810	11810	11810	11810	11810	11206	10232	9574	9106	8769	8515	8322	8168	8045	7799	7656	7563	7496	7452	7418	7391	14
16	11810	11810	11810	11810	11810	11810	11810	10118	8950	8168	7622	7229	6937	6713	6542	6406	6131	5971	5872	5805	5757	5719	5698	16
18	11810	11810	11810	11810	11810	11810	11810	9650	8261	7337	6700	6244	5908	5654	5458	5305	5000	4826	4719	4645	4597	4557	4532	18
20	11810	11810	11810	11810	11810	11810	11351	9595	7958	6879	6139	5612	5227	4939	4717	4544	4206	4017	3899	3822	3769	3731	3700	20
22	11810	11810	11810	11810	11810	11810	10435	9286	7929	6677	5822	5219	4780	4452	4204	4009	3633	3425	3299	3215	3158	3118	3088	22
24	11810	11810	11810	11810	11810	11810	9854	8576	7740	6662	5683	4996	4498	4128	3847	3630	3214	2985	2847	2757	2696	2654	2622	24
26	11810	11810	11810	11810	11810	11810	9522	8099	7177	6551	5677	4897	4334	3918	3605	3362	2901	2649	2500	2404	2341	2294	2261	26
28	11810	11810	11810	11810	11810	11810	9379	7801	6786	6099	5616	4895	4263	3798	3446	3177	2668	2393	2231	2128	2061	2011	1977	28
30	11810	11810	11810	11810	11810	11406	9383	7639	6523	5773	5248	4870	4265	3746	3355	3057	2494	2195	2019	1910	1836	1786	1748	30
32	11810	11810	11810	11810	11810	11167	9250	7585	6362	5544	4975	4565	4261	3748	3317	2986	2368	2042	1853	1735	1656	1601	1561	32
34	11810	11810	11810	11810	11810	11070	8984	7620	6282	5393	4776	4334	4007	3761	3320	2958	2279	1924	1719	1592	1508	1450	1408	34
36	11810	11810	11810	11810	11810	11085	8824	7440	6271	5305	4637	4160	3811	3548	3345	2962	2219	1834	1613	1477	1387	1326	1282	36
38	11810	11810	11810	11810	11810	10977	8750	7261	6299	5269	4547	4036	3660	3380	3162	2994	2185	1767	1529	1384	1288	1223	1177	38
40	11810	11810	11810	11810	11810	10784	8748	7148	6118	5278	4500	3950	3548	3246	3017	2838	2172	1719	1464	1307	1206	1135	1088	40
42	11810	11810	11810	11810	11810	10677	8740	7091	5990	5250	4488	3897	3467	3147	2901	2710	2175	1687	1412	1244	1137	1063	1011	42
44	11810	11810	11810	11810	11810	10643	8580	7082	5908	5120	4505	3872	3412	3070	2811	2609	2195	1670	1374	1195	1080	1002	948	44
46	11810	11810	11810	11810	11810	10671	8475	7116	5862	5026	4444	3872	3382	3017	2742	2527	2114	1662	1345	1155	1032	950	893	46
48	11810	11810	11810	11810	11810	10755	8421	6996	5851	4963	4349	3895	3372	2985	2691	2464	2029	1666	1328	1124	994	908	847	48

Design Example 6-21 illustrates the advantage of Tables 6-4 through 6-15.

DESIGN EXAMPLE 6-21. CRITICAL COMPRESSIVE BUCKLING OF A PANEL

For the panel indicated in Fig. 6-44 assume a mat laminate with the following properties:

Width of panel $a = 20$ in.
Length of panel $b = 40$ in.
Thickness $h = 0.50$ in.
Moduli of elasticity $E_T = E_L = 0.86 \times 10^6$ psi (Table 5-10)
Poisson's ratio $\sigma_{TL} = \sigma_{LT} = 0.37$ (Average of Tables 5-8 and 5-13)
Shear modulus $G_{TL} = 0.40 \times 10^6$ psi (Table 5-14)

Find the critical buckling load, P_{cr}, for all edge conditions:

Case 1. All edges are simply supported.
Case 2. Loaded edges simply supported, remaining edges clamped.
Case 3. Loaded edges clamped, remaining edges simply supported.
Case 4. All edges clamped.

Constants:

$$A = E_T\,\sigma_{LT} + 2\lambda\,G_{TL} = 0.86\text{x}10^6\text{x}0.37 + 2(1-0.37^2)0.40\text{x}10^6 \qquad (6.45)$$

$$= 1.0087 \times 10^6$$

$$K = \frac{Ah^3}{12} = \frac{1.0087 \times 10^6 \times 0.50^3}{12(0.8631)} = 12170 \qquad (6.46)$$

$$D_1 = D_2 = \frac{Eh^3}{12\lambda} = \frac{0.86 \times 10^6 \times 0.50^3}{12(0.8631)} = 10376 \qquad (6.44)$$

$$\kappa = \frac{K}{\left(D_1 D_2\right)^{\frac{1}{2}}} = \frac{12170}{10376} = 1.1729 \qquad (6.47)$$

$$r = \frac{40}{20} \times \left[\frac{10376}{10376}\right]^{\frac{1}{4}} = 2 \qquad (6.48)$$

Case 1. All Edges Simply Supported

$$\sqrt{n(n-1)} < 2 < \sqrt{n(n+1)} \qquad n = 2 \tag{6.52}$$

$$k_{cr} = \frac{\pi^2}{12}\left[\frac{r^2}{n^2} + \frac{n^2}{r^2} + 2\kappa\right] = \frac{9.8696}{12}\left[\frac{4}{4} + \frac{4}{4} + 2.3458\right] = 3.57 \tag{6.51}$$

$$P_{cr} = k_{cr}\,\frac{12\sqrt{D_1D_2}}{a^2} = 3.57 \times \frac{12 \times 10376}{20^2} = 3.57 \times 311.28 = 1112 \text{ lbs./in.} \tag{6.50}$$

Case 2. Loaded Edges Simply Supported - Remaining Edges Clamped

$$\frac{1}{2}\sqrt{n(n-1)\sqrt{3}} < 2 < \frac{1}{2}\sqrt{n\,(n+1)\sqrt{3}} \qquad n = 3 \tag{6.52a}$$

$$k_{cr} = \frac{4\pi^2}{9}\left[\frac{r^2}{n^2} + \frac{3n^2}{16r^2} + \frac{\kappa}{2}\right] = \frac{4 \times 9.8696}{9}\left[\frac{4}{9} + \frac{3 \times 9}{16 \times 4} + 0.5864\right] = 6.3739 \tag{6.51a}$$

$$P_{cr} = 6.3739 \times 311.28 = 1985 \text{ lbs./in.} \tag{6.50}$$

Case 3. Loaded Edges Clamped - Remaining Edges Simply Supported

a. $$k_{cr_1} = \frac{\pi^2}{48}\left[3r^2 + \frac{16}{r^2} + 8\kappa\right] = 5.23 \tag{6.51b}$$

b. $$k_{cr_2} = \frac{\pi^2}{60}\left[r^2 + \frac{41}{r^2} + 10\kappa\right] = 4.26 \quad \text{Controls} \tag{6.51c}$$

c. $$k_{cr_3} = \frac{\pi^2}{120}\left[r^2 + \frac{136}{r^2} + 20\kappa\right] = 5.04 \tag{6.51d}$$

d. $$k_{cr_4} = \frac{\pi^2}{204}\left[r^2 + \frac{353}{r^2} + 34\kappa\right] = 6.34 \tag{6.51e}$$

$$P_{cr} = 4.26 \times 311.28 = 1326 \text{ lbs./in.} \tag{6.50}$$

Case 4. All Edges Clamped

a. $$k_{cr_1} = \frac{\pi^2}{9}\left[3r^2 + \frac{3}{r^2} + 2\kappa\right] = 16.56 \tag{6.51f}$$

b. $$k_{cr_2} = \frac{\pi^2}{180}\left[16r^2 + \frac{123}{r^2} + 40\kappa\right] = 7.36 \tag{6.51g}$$

c. $$k_{cr_3} = \frac{\pi^2}{45}\left[2r^2 + \frac{51}{r^2} + 10\kappa\right] = 7.12 \quad \text{Controls} \tag{6.51h}$$

d. $$k_{cr_4} = \frac{\pi^2}{612}\left[16r^2 + \frac{1059}{r^2} + 136\kappa\right] = 7.88 \qquad (6.51i)$$

$$P_{cr} = 7.12 \times 311.28 = 2217 \text{ lbs/in.} \qquad (6.50)$$

Summary: Case 1 = 1,112 lbs./in.
Case 2 = 1,985 lbs./in.
Case 3 = 1,326 lbs./in.
Case 4 = 2,217 lbs./in.

The critical buckling values, P_{cr}, for Design Example 6-21 can be obtained very quickly from Tables 6-4 through 6-7. For a = 20 in., b = 40 in. and h = 0.50 in., the values are:

Case 1 P_{cr} = 1,113 lbs./in.
Case 2 P_{cr} = 1,984 lbs./in.
Case 3 P_{cr} = 1,331 lbs./in.
Case 4 P_{cr} = 2,218 lbs./in.

B. Plates Loaded In Uniform Shear

The critical shearing stresses in a rectangular plate under a uniform shear load was investigated and reported by March (16). The discussion presented here is for loads applied parallel to or at 90 degrees to the warp direction, Fig. 6-45.

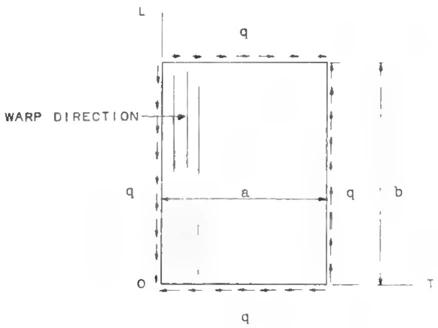


Fig. 6-45. Flat Plate in Uniform Shear Load Parallel to Warp

The following terminology not previously given will apply:

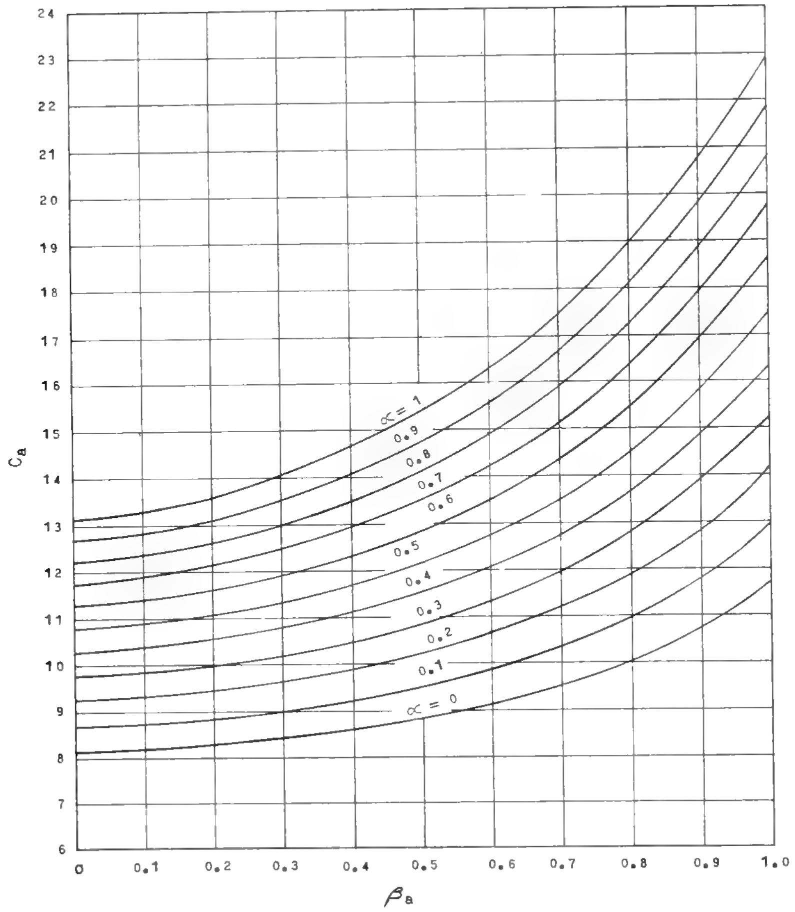
q = uniform shearing stress and is positive when directed as indicated in Fig. 6-45.

q_{cr} = value of q for which buckling occurs.

To determine the critical shear stress in equation 6.55, the following constants are necessary to obtain the factor "C_a" for simply supported panels from Fig. 6-46:

$$\alpha = \frac{A}{(E_1E_2)^{\frac{1}{2}}} \tag{6.53}$$

$$B_a = \frac{a}{b}\left[\frac{E_2}{E_1}\right]^{\frac{1}{4}} \tag{6.54}$$



REFERENCE 17

Fig. 6-46. Curves for Calculating the Buckling Shear Stress in Orthotropic Rectangular Plates with Simply Supported Edges Whose Axes of Elastic Symmetry are Parallel to the Edges

For the case where the orthotropic laminate is subjected to uniform shear and the warp is parallel to the L axis, the following relationships have been obtained:

The critical shearing stress can be calculated from:

$$q_{cr} = \frac{C_a h^2}{3\lambda\ a^2} (E_1{}^3 E_2)^{\frac{1}{4}} \qquad (6.55)$$

$$q_{cr} = k_s\ E_L \frac{h^2}{a^2} \qquad (6.55a)$$

where $$k_s = \frac{C_a}{3\lambda} \left[\left(\frac{E_1}{E_L}\right)^3 \frac{E_2}{E_L}\right]^{\frac{1}{4}} \qquad (6.56)$$

where E_1 and E_2 are measured parallel to the sides a and b respectively. For a laminate with the warp oriented parallel to the side b, the values of $E_1 = E_T$ and $E_2 = E_L$. The value for k_s now becomes:

$$k_s = \frac{C_a}{3\lambda} \left[\frac{E_L}{E_T}\right]^{\frac{1}{4}} \qquad (6.56a)$$

and

$$\alpha = \frac{A}{(E_T E_L)^{\frac{1}{2}}} \qquad (6.53a)$$

$$\beta_a = \frac{a}{b} \left[\frac{E_L}{E_T}\right]^{\frac{1}{4}} \qquad (6.54a)$$

The dimensions a and b are assigned to the panel in such a way that β_a is less than or equal to unity.

DESIGN EXAMPLE 6-22. CRITICAL SHEAR BUCKLING OF A 10 OZ. CLOTH OR ORTHOTROPIC PANEL

Compute the critical shearing stress for the plate shown in Fig. 6-45 when:

$a = 20$ in.

$b = 40$ in.

$t = 0.50$ in.

Laminate: 10 oz. cloth

Warp parallel to side "b"

$E_1 = E_T = 1.96 \times 10^6$ $\qquad E_2 = E_L = 1.70 \times 10^6$ (Table 5-10)

$G_{TL} = 0.52 \times 10^6$ (Table 5-14)

$\sigma_{LT} = \sigma_{TL} = 0.20$ (Average of Tables 5-8 and 5-13)

Determine constants:

$$\lambda = 1 - \sigma_{TL}\sigma_{LT} = 1 - 0.20^2 = 0.96$$

$$A = E_T\,\sigma_{LT} + 2\,\lambda\,G_{TL} = 1.96\text{x}10^6\text{x}0.20 + 2(0.96)\text{x}0.52\text{x}10^6 \tag{6.45}$$

$$= 0.392 \text{ x } 10^6 + 0.9984 \text{ x } 10^6 = 1.39 \text{ x } 10^6$$

$$\alpha = \frac{A}{(E_T E_L)^{\frac{1}{2}}} = \frac{1.39 \text{ x } 10^6}{(1.96\text{x}1.70) \text{ x } 10^6} = \frac{1.39}{1.83} = 0.7596 \tag{6.53a}$$

$$\beta_a = \frac{a}{b}\left[\frac{E_L}{E_T}\right]^{\frac{1}{4}} = \frac{20}{40}\left[\frac{1.70\text{x}10^6}{1.96\text{x}10^6}\right]^{\frac{1}{4}} = 0.5 \text{ x } 0.965 = 0.48 \tag{6.54a}$$

Referring to Fig. 6-46, for the value of $\beta_a = 0.48$ and $\alpha = 0.76$, the value of C_a is found to be 13.7.

$$\text{and } k_s = \frac{C_a}{3\lambda}\left[\frac{E_L}{E_T}\right]^{\frac{1}{4}} = \frac{13.7}{3\text{x}0.96}\left[\frac{1.70\text{x}10^6}{1.96\text{x}10^6}\right]^{\frac{1}{4}} = 4.76 \text{ x } 0.965 = 4.59 \tag{6.56a}$$

$$\text{and } q_{cr} = k_s E_L \frac{h^2}{a^2} = \frac{4.59\text{x}1.96\text{x}10^6\text{x}0.50^2}{400} = 5625 \text{ psi} \tag{6.55a}$$

This value is less than the ultimate parallel shear stress;

F_{su} = 10500 psi (Table 5-14)

DESIGN EXAMPLE 6-23. CRITICAL SHEAR BUCKLING OF A MAT OR ISOTROPIC PANEL

Compute the critical shear stress for a mat laminate with similar dimensions as those given in Design Example 6-22.

$E_T = E_L = 0.86 \text{ x } 10^6$ (Table 5-10)

$G_{TL} = 0.40 \text{ x } 10^6$ (Table 5-14)

$\sigma_{TL} = \sigma_{LT} = 0.37$ (Average of Tables 5-8 and 5-13)

$$\lambda = 1 - 0.37^2 = 0.863$$

$$A = 0.86\text{x}10^6\text{x}0.37 + 2\text{x}0.86\text{x}0.40\text{x}10^6 = 1.006 \text{ x } 10^6 \tag{6.45}$$

$$\alpha = \frac{1.006\text{x}10^6}{0.86\text{x}10^6} = 1.17 \tag{6.53a}$$

$$\beta_a = 0.5 \times 1 = 0.5 \qquad (6.54a)$$

$C_a = 15.45$ from Fig. 6-46

$$k_s = \frac{15.45}{3 \times 0.863} \times \left[\frac{0.86 \times 10^6}{0.86 \times 10^6}\right]^{\frac{1}{4}} = 5.99$$

$$q_{cr} = \frac{5.99 \times 0.86 \times 10^6 \times 0.50^2}{400} = 3225 \text{ psi} < 10100 \text{ psi} \qquad \text{(Table 5-14)}$$

C. Plates Loaded Laterally

The mathematical solution of flat plates with lateral loads is much more complex and time consuming than for flat plates in edge compression. The problem is further complicated because of deflection considerations. When the deflection of the plate is equal to or less than one-half the thickness of the plate, the loads are assumed transmitted mainly by bending stresses. When the deflection exceeds one-half the thickness of the plate, direct stresses are developed and these stresses must then be considered. Consequently for plates with large deflections the loads are carried by both direct stresses and flexural stresses and a new approach to the problem is necessary.

Therefore, to properly analyze plates under lateral loads, it is necessary that the following criteria be specified:

1. Boundary Conditions

    a. Simply supported edges
    b. Clamped edges
    c. Combinations of above

2. Loading Conditions

    a. Uniformly distributed load
    b. Concentrated loads
    c. Variable loads
    d. Edge moments
    e. Combinations of above

3. Plate Material

    a. Isotropic
    b. Orthotropic

4. Deflection Limitation

    a. Plates with small deflections equal to or less than one-half the thickness.
    b. Plates with deflections greater than one-half the thickness.

March (18) has developed procedures by which plywood plates under uniform or concentrated loads may be analyzed. Since most fiberglass laminates are orthotropic the approach established by March will be used but the results are subject to verification by future tests.

Boat hulls and other marine structures are usually subject to hydrostatic or uniform pressures. Since the preparation of plate load tables covering all conditions would be a voluminous task, only tables for uniformly loaded plates with simply supported edges have been completed at this time. However methods of analyses are also presented for plates under uniform loads and clamped edges. Fig. 6-47 indicates the direction of the plate axes. The coordinate planes are parallel to the planes of elastic symmetry.

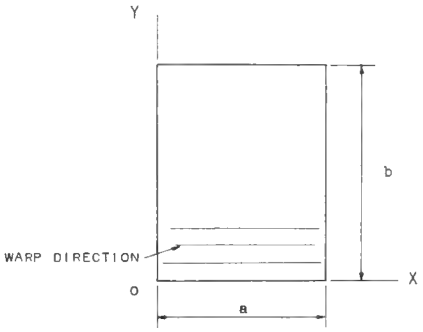


Fig. 6-47. Flat Plate Under Uniform Lateral Load

The following terminology previously not given will apply:

p = load per unit area

ε = unit strain

m_x = bending moment per unit length of a vertical section of the plate perpendicular to the X-axis

m_y = bending moment per unit length of a vertical section of the plate perpendicular to the Y-axis

m_{xy} = twisting moment per unit length of a vertical section of the plate perpendicular to either the X- or the Y-axis

Plates With Small Deflections: For this condition, the deflection of the plate is limited to a maximum of one-half the thickness of the plate, ($w \leq \frac{h}{2}$).

Case 1. Simply Supported Plates Under Uniform Loads

The deflection of a uniformly loaded simply supported plate is obtained from the following equation (18):

$$w = \sum_n \frac{A}{\lambda_n{}^5} (1 - Y_n) \sin \lambda_n x \qquad (6.57)$$

where

$$A = \frac{4p}{aD_1} \; ; \; \lambda_n = \frac{n\pi}{a}$$

$$Y_n = C_n\left\{\kappa\left[\sinh \gamma_n\eta \, \sin\delta_n\left(\beta-\eta\right) + \sinh \gamma_n\left(\beta-\eta\right) \sin \delta_n\eta\right] + \sqrt{1-\kappa^2}\left[\cosh \gamma_n\eta \, \cos\delta_n\left(\beta-\eta\right) + \cosh \gamma_n\left(\beta-\eta\right) \cos\delta_n\eta\right]\right\}$$

$$C_n = \frac{1}{\sqrt{1-\kappa^2} \quad \cosh \gamma_n\beta + \cos \delta_n\beta} \qquad \eta = \varepsilon y \; ; \; \beta = \varepsilon b$$

$$\varepsilon = \left[\frac{D_1}{D_2}\right]^{\frac{1}{4}} = \left[\frac{E_1}{E_2}\right]^{\frac{1}{4}}$$

$$\rho = \sqrt{\frac{1+\kappa}{2}} \; ; \; \gamma_n = \lambda_n\rho \qquad \kappa = \frac{K}{\sqrt{D_1D_2}}$$

$$\sigma = \sqrt{\frac{1-\kappa}{2}} \; ; \; \delta_n = \lambda_n\sigma \qquad K = \left[\frac{E_L\,\sigma_{TL}}{\lambda} + 2G_{LT}\right]\frac{h^3}{12}$$

The basic plate moment equations are given as follows (18):

bending moment $$m_x = -D_1\left[\frac{\partial^2 w}{\partial x^2} + \sigma_1\varepsilon^2\frac{\partial^2 w}{\partial\eta^2}\right] \qquad (6.58)$$

bending moment $$m_y = -D_2\left[\varepsilon^2\frac{\partial^2 w}{\partial\eta^2} + \sigma_2\frac{\partial^2 w}{\partial x^2}\right] \qquad (6.59)$$

twisting moment $$m_{xy} = -\frac{G_{LT}\,\varepsilon h^3}{6}\frac{\partial^2 w}{\partial x\partial\eta} \qquad (6.60)$$

The solution of these equations becomes a formidable task when more than one plate configuration has to be investigated. To reduce the amount of work required by the designer, Tables 6-16 through 6-18 have been established with the use of electronic digital computers. These tables give the ultimate uniform lateral loads in psi that mat, woven roving and cloth laminates can sustain when considered as rectangular plates with a deflection limitation of one-half the laminate thickness or for the ultimate flexural stresses of the laminates. For the development of these tables, the low average physical properties values previously given were also used but the direction of the axes has been modified.

X = 90 degrees and warp direction

Y = 0 degrees and fill direction

The advantage of these tables is illustrated in Design Examples 6-24 and 6-25.

TABLE 6-16. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED

PHYSICAL CONSTANTS:

$E_X = E_Y = 0.86 \times 10^6$ PSI

$G_{XY} = 0.40 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.37$

THICKNESS—H EQUALS 0.0625 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	.12																					
8	.07	.04																				
10	.06	.03	.02																			
12	.05	.02	.01																			
14	.04	.02	.01																			
16	.04	.02	.01																			
18	.04	.01	.01																			
20	.04	.01	.01																			
22	.04	.01	.01																			
24	.04	.01	.01																			
26	.04	.01	.01																			
28	.04	.01	.01																			
30	.04	.01	.01																			
32	.04	.01	.01																			
34	.04	.01	.01																			
36	.04	.01																				
42	.04	.01																				
48	.04	.01																				
54	.04	.01																				
60	.04	.01																				
66	.04	.01																				
72	.04	.01																				
78	.04	.01																				

THICKNESS—H EQUALS 0.1250 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	1.90																					
8	1.17	.60																				
10	.90	.41	.25																			
12	.77	.32	.18	.12																		
14	.70	.27	.14	.09	.06																	
16	.66	.24	.12	.07	.05	.04																
18	.64	.23	.11	.06	.04	.03	.02															
20	.62	.21	.10	.06	.04	.03	.02	.02														
22	.61	.21	.09	.05	.03	.02	.02	.01														
24	.61	.20	.09	.05	.03	.02	.01	.01														
26	.60	.20	.09	.05	.03	.02	.01	.01														
28	.60	.20	.08	.04	.03	.02	.01	.01														
30	.60	.19	.08	.04	.02	.02	.01	.01														
32	.60	.19	.08	.04	.02	.02	.01	.01														
34	.60	.19	.08	.04	.02	.01	.01	.01														
36	.60	.19	.08	.04	.02	.01	.01	.01														
42	.60	.19	.08	.04	.02	.01	.01	.01														
48	.60	.19	.08	.04	.02	.01	.01	.01														
54	.60	.19	.08	.04	.02	.01	.01	.01														
60	.60	.19	.08	.04	.02	.01	.01	.01														
66	.60	.19	.08	.04	.02	.01	.01	.01														
72	.60	.19	.08	.04	.02	.01	.01															
78	.60	.19	.08	.04	.02	.01	.01															

TABLE 6-16. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS—H EQUALS 0.1875 INCHES

LENGTH—B INCHES	WIDTH—A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	9.63																					
8	5.93	3.05																				
10	4.56	2.06	1.25																			
12	3.89	1.61	.90	.60																		
14	3.54	1.37	.72	.45	.33																	
16	3.34	1.23	.62	.37	.25	.19																
18	3.22	1.14	.55	.32	.21	.15	.12															
20	3.15	1.09	.50	.28	.18	.13	.10	.08														
22	3.11	1.05	.47	.26	.16	.11	.08	.07	.05													
24	3.08	1.02	.45	.24	.15	.10	.07	.06	.05	.04												
26	3.06	1.00	.44	.23	.14	.09	.07	.05	.04	.03	.03											
28	3.05	.99	.43	.22	.13	.09	.06	.04	.04	.03	.02	.02										
30	3.04	.98	.42	.21	.13	.08	.06	.04	.03	.03	.02	.02	.02									
32	3.04	.97	.41	.21	.12	.08	.05	.04	.03	.02	.02	.02	.01	.01								
34	3.04	.97	.41	.20	.12	.07	.05	.04	.03	.02	.02	.01	.01	.01								
36	3.04	.97	.40	.20	.11	.07	.05	.03	.03	.02	.02	.01	.01	.01								
42	3.04	.97	.40	.20	.11	.07	.04	.03	.02	.02	.01	.01	.01	.01								
48	3.04	.97	.39	.19	.11	.06	.04	.03	.02	.02	.01	.01	.01	.01								
54	3.04	.97	.39	.19	.10	.06	.04	.03	.02	.01	.01	.01	.01	.01								
60	3.04	.97	.39	.19	.10	.06	.04	.03	.02	.01	.01	.01	.01	.01								
66	3.04	.97	.39	.19	.10	.06	.04	.03	.02	.01	.01	.01	.01									
72	3.04	.97	.39	.19	.10	.06	.04	.03	.02	.01	.01	.01	.01									
78	3.04	.97	.39	.19	.10	.06	.04	.02	.02	.01	.01	.01	.01									

THICKNESS—H EQUALS 0.2500 INCHES

LENGTH—B INCHES	WIDTH—A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	30.45																					
8	18.74	9.63																				
10	14.40	6.52	3.95																			
12	12.30	5.09	2.85	1.90																		
14	11.20	4.34	2.27	1.44	1.03																	
16	10.56	3.89	1.95	1.17	.80	.60																
18	10.19	3.61	1.73	1.01	.67	.48	.38															
20	9.96	3.43	1.59	.90	.58	.41	.31	.25														
22	9.81	3.31	1.50	.82	.52	.36	.26	.21	.17													
24	9.72	3.22	1.43	.77	.47	.32	.23	.18	.14	.12												
26	9.67	3.17	1.38	.73	.44	.29	.21	.16	.12	.10	.09											
28	9.63	3.13	1.35	.70	.42	.27	.19	.14	.11	.09	.07	.06										
30	9.61	3.10	1.32	.68	.40	.26	.18	.13	.10	.08	.07	.06	.05									
32	9.61	3.08	1.30	.66	.38	.24	.17	.12	.09	.07	.06	.05	.04	.04								
34	9.61	3.06	1.29	.65	.37	.23	.16	.11	.09	.07	.05	.05	.04	.03	.03							
36	9.61	3.05	1.27	.64	.36	.23	.15	.11	.08	.06	.05	.04	.04	.03	.03	.02						
42	9.61	3.05	1.26	.62	.34	.21	.14	.10	.07	.05	.04	.03	.03	.02	.02	.02	.02	.01	.01			
48	9.61	3.05	1.25	.61	.33	.20	.13	.09	.06	.05	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01		
54	9.61	3.05	1.25	.60	.33	.20	.13	.09	.06	.04	.03	.03	.02	.02	.01	.01	.01	.01	.01	.01		
60	9.61	3.05	1.25	.60	.33	.19	.12	.08	.06	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01	.01		
66	9.61	3.05	1.25	.60	.32	.19	.12	.08	.06	.04	.03	.02	.02	.01	.01	.01	.01	.01	.01	.01		
72	9.61	3.05	1.25	.60	.32	.19	.12	.08	.06	.04	.03	.02	.02	.01	.01	.01	.01	.01	.01	.01		
78	9.61	3.05	1.25	.60	.32	.19	.12	.08	.05	.04	.03	.02	.02	.01	.01	.01	.01	.01	.01			

TABLE 6-16. FIBERGLASS POLYESTER LAMINATES
RECTANGULAR PLATES - LATERALLY LOADED
ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH
2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS—H EQUALS 0.3125 INCHES

WIDTH—A INCHES

LENGTH—B INCHES	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	74.34																					
8	45.75	23.52																				
10	35.15	15.91	9.63																			
12	30.03	12.43	6.95	4.65																		
14	27.33	10.61	5.55	3.51	2.51																	
16	25.79	9.50	4.76	2.86	1.96	1.47																
18	24.87	8.82	4.23	2.46	1.63	1.18	.92															
20	24.31	8.37	3.89	2.20	1.41	.99	.75	.60														
22	23.96	8.07	3.66	2.01	1.26	.87	.64	.50	.41													
24	23.74	7.87	3.49	1.88	1.15	.78	.56	.43	.35	.29												
26	23.60	7.73	3.37	1.78	1.07	.71	.51	.38	.30	.25	.21											
28	23.52	7.63	3.29	1.71	1.01	.66	.47	.35	.27	.22	.18	.16										
30	23.46	7.56	3.22	1.65	.97	.62	.43	.32	.25	.20	.16	.14	.12									
32	23.46	7.51	3.18	1.61	.93	.59	.41	.30	.23	.18	.15	.12	.11	.09								
34	23.46	7.48	3.14	1.58	.90	.57	.39	.28	.21	.16	.13	.11	.09	.08	.07							
36	23.46	7.45	3.11	1.55	.88	.55	.37	.26	.20	.15	.12	.10	.09	.07	.06	.06						
42	23.46	7.45	3.07	1.51	.84	.51	.34	.24	.17	.13	.10	.08	.07	.06	.05	.04	.04	.03	.03			
48	23.46	7.45	3.04	1.48	.82	.49	.32	.22	.16	.12	.09	.07	.06	.05	.04	.04	.03	.03	.02	.02	.02	.02
54	23.46	7.45	3.04	1.47	.80	.48	.31	.21	.15	.11	.08	.07	.05	.04	.04	.03	.03	.02	.02	.02	.02	.01
60	23.46	7.45	3.04	1.47	.80	.47	.30	.20	.14	.10	.08	.06	.05	.04	.03	.03	.02	.02	.02	.02	.01	.01
66	23.46	7.45	3.04	1.47	.79	.47	.30	.20	.14	.10	.07	.06	.05	.04	.03	.02	.02	.02	.02	.01	.01	.01
72	23.46	7.45	3.04	1.47	.79	.47	.29	.19	.13	.10	.07	.06	.04	.03	.03	.02	.02	.02	.01	.01	.01	.01
78	23.46	7.45	3.04	1.47	.79	.46	.29	.19	.13	.10	.07	.05	.04	.03	.03	.02	.02	.02	.01	.01	.01	.01

THICKNESS—H EQUALS 0.3750 INCHES

WIDTH—A INCHES

LENGTH—B INCHES	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	154.15																					
8	94.86	48.77																				
10	72.89	32.99	19.98																			
12	62.28	25.78	14.41	9.63																		
14	56.68	21.99	11.51	7.27	5.20																	
16	53.48	19.70	9.86	5.93	4.07	3.05																
18	51.58	18.29	8.78	5.09	3.37	2.45	1.90															
20	50.41	17.36	8.07	4.56	2.92	2.06	1.56	1.25														
22	49.68	16.74	7.59	4.17	2.61	1.80	1.33	1.04	.85													
24	49.23	16.32	7.24	3.89	2.39	1.61	1.17	.90	.72	.60												
26	48.94	16.03	7.00	3.69	2.23	1.48	1.05	.80	.63	.52	.44											
28	48.76	15.82	6.82	3.54	2.10	1.37	.96	.72	.56	.45	.38	.33										
30	48.65	15.68	6.68	3.43	2.01	1.29	.90	.66	.51	.41	.34	.28	.25									
32	48.65	15.58	6.58	3.34	1.93	1.23	.85	.62	.47	.37	.30	.25	.22	.19								
34	48.65	15.50	6.51	3.28	1.88	1.18	.80	.58	.44	.34	.28	.23	.20	.17	.15							
36	48.65	15.45	6.45	3.22	1.83	1.14	.77	.55	.41	.32	.26	.21	.18	.15	.13	.12						
42	48.65	15.45	6.36	3.13	1.74	1.06	.70	.49	.36	.27	.21	.17	.14	.12	.10	.09	.08	.07	.06			
48	48.65	15.45	6.31	3.08	1.69	1.02	.66	.45	.33	.24	.19	.15	.12	.10	.09	.07	.06	.06	.05	.05	.04	.04
54	48.65	15.45	6.31	3.05	1.67	.99	.64	.43	.31	.23	.17	.13	.11	.09	.07	.06	.05	.05	.04	.04	.03	.03
60	48.65	15.45	6.31	3.04	1.65	.98	.62	.42	.29	.21	.16	.13	.10	.08	.07	.06	.05	.04	.04	.03	.03	.03
66	48.65	15.45	6.31	3.04	1.64	.97	.61	.41	.29	.21	.15	.12	.09	.08	.06	.05	.04	.04	.03	.03	.02	.02
72	48.65	15.45	6.31	3.04	1.64	.97	.61	.40	.28	.20	.15	.11	.09	.07	.06	.05	.04	.03	.03	.03	.02	.02
78	48.65	15.45	6.31	3.04	1.64	.96	.60	.40	.28	.20	.15	.11	.09	.07	.06	.05	.04	.03	.03	.02	.02	.02

TABLE 6-16. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS—H EQUALS 0.4375 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	285.59																					
8	175.74	90.36																				
10	135.04	61.11	37.01																			
12	115.38	47.77	26.69	17.85																		
14	105.01	40.74	21.32	13.48	9.63																	
16	99.09	36.51	18.27	10.98	7.53	5.65																
18	95.55	33.88	16.27	9.44	6.25	4.54	3.53															
20	93.38	32.16	14.95	8.44	5.41	3.82	2.89	2.31														
22	92.04	31.02	14.05	7.72	4.83	3.33	2.47	1.93	1.58													
24	91.20	30.23	13.42	7.21	4.43	2.99	2.17	1.67	1.34	1.12												
26	90.67	29.69	12.96	6.84	4.12	2.74	1.95	1.48	1.17	.96	.81											
28	90.34	29.31	12.63	6.56	3.89	2.55	1.79	1.33	1.04	.84	.70	.60										
30	90.13	29.04	12.38	6.35	3.72	2.40	1.67	1.22	.94	.75	.62	.53	.46									
32	90.13	28.86	12.20	6.19	3.58	2.28	1.57	1.14	.87	.69	.56	.47	.40	.35								
34	90.13	28.72	12.06	6.07	3.47	2.19	1.49	1.07	.81	.63	.51	.43	.36	.31	.28							
36	90.13	28.63	11.96	5.97	3.39	2.12	1.42	1.02	.76	.59	.47	.39	.33	.28	.25	.22						
42	90.13	28.63	11.77	5.79	3.22	1.97	1.30	.90	.66	.50	.40	.32	.26	.22	.19	.17	.15	.13	.12			
48	90.13	28.63	11.70	5.70	3.14	1.89	1.22	.84	.60	.45	.35	.28	.23	.19	.16	.14	.12	.10	.09	.08	.08	.07
54	90.13	28.63	11.70	5.66	3.09	1.84	1.18	.80	.57	.42	.32	.25	.20	.16	.14	.12	.10	.09	.08	.07	.06	.06
60	90.13	28.63	11.70	5.63	3.06	1.82	1.15	.77	.54	.40	.30	.23	.18	.15	.12	.10	.09	.08	.07	.06	.05	.05
66	90.13	28.63	11.70	5.63	3.05	1.80	1.14	.76	.53	.38	.29	.22	.17	.14	.11	.10	.08	.07	.06	.05	.05	.04
72	90.13	28.63	11.70	5.63	3.05	1.79	1.13	.75	.52	.37	.28	.21	.17	.13	.11	.09	.07	.06	.05	.05	.04	.04
78	90.13	28.63	11.70	5.63	3.05	1.78	1.12	.74	.51	.37	.27	.21	.16	.13	.10	.08	.07	.06	.05	.04	.04	.03

THICKNESS—H EQUALS 0.5000 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	434.72																					
8	299.80	154.15																				
10	230.37	104.26	63.14																			
12	196.83	81.49	45.53	30.45																		
14	179.14	69.50	36.37	22.99	16.44																	
16	169.04	62.28	31.17	18.74	12.85	9.63																
18	163.00	57.79	27.75	16.10	10.66	7.74	6.01															
20	159.31	54.87	25.51	14.40	9.22	6.52	4.94	3.95														
22	157.02	52.91	23.98	13.17	8.24	5.68	4.21	3.30	2.70													
24	155.58	51.58	22.90	12.30	7.56	5.09	3.70	2.85	2.29	1.90												
26	154.68	50.65	22.12	11.67	7.03	4.68	3.33	2.52	1.99	1.63	1.38											
28	154.12	50.00	21.55	11.20	6.64	4.34	3.05	2.27	1.77	1.44	1.20	1.03										
30	153.76	49.55	21.13	10.84	6.34	4.09	2.84	2.09	1.61	1.29	1.06	.90	.78									
32	153.76	49.23	20.81	10.56	6.11	3.89	2.67	1.95	1.48	1.17	.96	.80	.69	.60								
34	153.76	49.00	20.58	10.35	5.93	3.74	2.54	1.83	1.38	1.08	.87	.73	.62	.54	.47							
36	153.76	48.84	20.40	10.19	5.78	3.61	2.43	1.73	1.30	1.01	.81	.67	.56	.48	.42	.38						
42	153.76	48.84	20.09	9.88	5.50	3.36	2.21	1.54	1.13	.86	.68	.54	.45	.38	.33	.28	.25	.22	.20			
48	153.76	48.84	19.95	9.72	5.35	3.22	2.09	1.43	1.03	.77	.59	.47	.38	.32	.27	.23	.20	.18	.16	.14	.13	.12
54	153.76	48.84	19.95	9.65	5.27	3.14	2.01	1.36	.97	.71	.54	.43	.34	.28	.23	.20	.17	.15	.13	.12	.11	.10
60	153.76	48.84	19.95	9.61	5.22	3.10	1.97	1.32	.93	.68	.51	.40	.31	.26	.21	.18	.15	.13	.11	.10	.09	.08
66	153.76	48.84	19.95	9.61	5.20	3.07	1.94	1.29	.90	.65	.49	.38	.30	.24	.20	.16	.14	.12	.10	.09	.08	.07
72	153.76	48.84	19.95	9.61	5.20	3.05	1.92	1.27	.88	.64	.47	.36	.28	.23	.18	.15	.13	.11	.09	.08	.07	.06
78	153.76	48.84	19.95	9.61	5.20	3.04	1.91	1.26	.87	.63	.46	.35	.27	.22	.18	.14	.12	.10	.09	.08	.07	.06

TABLE 6-16. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 2 OZ. MAT - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	550.20																					
8	385.69	246.92																				
10	314.68	167.00	101.14																			
12	281.25	130.53	72.93	48.77																		
14	259.52	111.33	58.26	36.83	26.33																	
16	250.54	99.76	49.93	30.01	20.58	15.43																
18	243.44	92.57	44.45	25.78	17.07	12.40	9.63															
20	238.45	87.89	40.86	23.06	14.77	10.44	7.91	6.32														
22	235.87	84.76	38.41	21.10	13.20	9.10	6.75	5.28	4.32													
24	233.01	82.61	36.67	19.70	12.11	8.16	5.93	4.56	3.66	3.05												
26	233.01	81.13	35.43	18.69	11.26	7.49	5.33	4.03	3.19	2.62	2.21											
28	233.01	80.09	34.51	17.93	10.64	6.96	4.88	3.64	2.84	2.30	1.92	1.65										
30	233.01	79.36	33.84	17.36	10.16	6.55	4.56	3.34	2.58	2.06	1.70	1.44	1.25									
32	233.40	78.85	33.34	16.92	9.79	6.23	4.28	3.12	2.37	1.88	1.53	1.29	1.10	.96								
34	233.25	78.49	32.96	16.58	9.49	5.99	4.07	2.93	2.21	1.73	1.40	1.16	.99	.86	.76							
36	233.16	78.24	32.67	16.32	9.26	5.79	3.89	2.78	2.08	1.61	1.29	1.07	.90	.77	.68	.60						
42	233.04	78.24	32.18	15.82	8.81	5.39	3.54	2.47	1.81	1.37	1.08	.87	.72	.61	.52	.45	.40	.36	.33			
48	233.02	78.24	31.96	15.58	8.57	5.16	3.34	2.29	1.65	1.23	.95	.76	.62	.51	.43	.37	.32	.28	.25	.23	.21	.19
54	233.01	78.24	31.96	15.45	8.44	5.04	3.22	2.18	1.55	1.14	.87	.68	.55	.45	.38	.32	.27	.24	.21	.19	.17	.15
60	233.01	78.24	31.96	15.39	8.36	4.96	3.15	2.11	1.49	1.09	.82	.63	.50	.41	.34	.28	.24	.21	.18	.16	.14	.13
66	233.01	78.24	31.96	15.39	8.32	4.92	3.11	2.07	1.44	1.05	.78	.60	.47	.38	.31	.26	.22	.19	.16	.14	.13	.11
72	233.01	78.24	31.96	15.39	8.32	4.89	3.08	2.04	1.42	1.02	.76	.58	.45	.36	.29	.24	.20	.17	.15	.13	.11	.10
78	233.01	78.24	31.96	15.39	8.32	4.87	3.06	2.02	1.40	1.00	.74	.56	.44	.35	.28	.23	.19	.16	.14	.12	.10	.09

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	679.26																					
8	476.16	376.35																				
10	388.50	254.53	154.15																			
12	347.22	198.95	111.15	74.34																		
14	320.39	169.69	88.79	56.13	40.13																	
16	309.31	152.04	76.11	45.75	31.37	23.52																
18	300.54	141.09	67.75	39.30	26.02	18.89	14.68															
20	294.39	133.96	62.28	35.15	22.52	15.91	12.06	9.63														
22	291.20	129.18	58.54	32.15	20.12	13.88	10.28	8.05	6.58													
24	287.66	125.92	55.90	30.03	18.45	12.43	9.04	6.95	5.58	4.65												
26	287.66	123.65	54.00	28.49	17.17	11.42	8.13	6.15	4.86	3.99	3.37											
28	287.66	122.07	52.60	27.33	16.21	10.61	7.45	5.55	4.33	3.51	2.93	2.51										
30	287.66	120.96	51.58	26.46	15.48	9.98	6.94	5.09	3.93	3.14	2.59	2.20	1.90									
32	288.15	120.18	50.81	25.79	14.91	9.50	6.53	4.76	3.61	2.86	2.34	1.96	1.68	1.47								
34	287.96	119.63	50.23	25.28	14.47	9.12	6.20	4.47	3.36	2.64	2.13	1.77	1.51	1.31	1.15							
36	287.85	119.25	49.80	24.87	14.12	8.82	5.93	4.23	3.17	2.46	1.97	1.63	1.37	1.18	1.03	.92						
42	287.71	119.25	49.04	24.11	13.43	8.21	5.40	3.76	2.75	2.09	1.65	1.33	1.10	.93	.79	.69	.61	.55	.50			
48	287.67	119.25	48.71	23.74	13.06	7.87	5.09	3.49	2.51	1.88	1.45	1.15	.94	.78	.66	.56	.49	.43	.39	.35	.32	.29
54	287.67	119.25	48.71	23.55	12.86	7.67	4.91	3.33	2.36	1.74	1.33	1.04	.84	.69	.57	.49	.42	.36	.32	.29	.26	.23
60	287.66	119.25	48.71	23.46	12.75	7.56	4.80	3.22	2.27	1.65	1.25	.97	.77	.62	.52	.43	.37	.32	.28	.25	.22	.20
66	287.66	119.25	48.71	23.46	12.69	7.49	4.73	3.16	2.20	1.59	1.19	.92	.72	.58	.48	.40	.34	.29	.25	.22	.19	.17
72	287.66	119.25	48.71	23.46	12.69	7.45	4.69	3.11	2.16	1.55	1.16	.88	.69	.55	.45	.37	.31	.26	.23	.20	.17	.15
78	287.66	119.25	48.71	23.46	12.69	7.43	4.66	3.08	2.13	1.53	1.13	.86	.67	.53	.43	.35	.29	.25	.21	.18	.16	.14

TABLE 6-17. FIBERGLASS POLYESTER LAMINATES
RECTANGULAR PLATES - LATERALLY LOADED
ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH
25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED

PHYSICAL CONSTANTS:

$E_X = 1.81 \times 10^6$ PSI

$E_Y = 1.54 \times 10^6$ PSI

$G_{XY} = 0.45 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.19$

THICKNESS—H EQUALS 0.0625 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	.19																					
8	.12	.06																				
10	.09	.04	.02																			
12	.08	.03	.02	.01																		
14	.08	.03	.01	.01																		
16	.07	.03	.01	.01																		
18	.07	.02	.01	.01																		
20	.07	.02	.01	.01																		
22	.07	.02	.01	.01																		
24	.07	.02	.01	.01																		
26	.07	.02	.01																			
28	.07	.02	.01																			
30	.07	.02	.01																			
32	.07	.02	.01																			
34	.07	.02	.01																			
36	.07	.02	.01																			
42	.07	.02	.01																			
48	.07	.02	.01																			
54	.07	.02	.01																			
60	.07	.02	.01																			
66	.07	.02	.01																			
72	.07	.02	.01																			
78	.07	.02	.01																			

THICKNESS—H EQUALS 0.1250 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	3.05																					
8	1.85	.96																				
10	1.46	.64	.39																			
12	1.29	.51	.28	.19																		
14	1.21	.45	.23	.14	.10																	
16	1.17	.41	.20	.12	.08	.06																
18	1.16	.39	.18	.10	.07	.05	.04															
20	1.15	.38	.17	.09	.06	.04	.03	.02														
22	1.14	.37	.16	.09	.05	.04	.03	.02	.02													
24	1.14	.37	.16	.08	.05	.03	.02	.02	.01	.01												
26	1.13	.36	.15	.08	.05	.03	.02	.02	.01	.01												
28	1.13	.36	.15	.08	.04	.03	.02	.01	.01	.01												
30	1.13	.36	.15	.07	.04	.03	.02	.01	.01	.01												
32	1.13	.36	.15	.07	.04	.03	.02	.01	.01	.01												
34	1.13	.36	.15	.07	.04	.02	.02	.01	.01	.01												
36	1.13	.36	.15	.07	.04	.02	.02	.01	.01	.01												
42	1.13	.36	.15	.07	.04	.02	.01	.01	.01	.01												
48	1.13	.36	.15	.07	.04	.02	.01	.01	.01	.01												
54	1.13	.36	.15	.07	.04	.02	.01	.01	.01													
60	1.13	.36	.15	.07	.04	.02	.01	.01	.01													
66	1.13	.36	.15	.07	.04	.02	.01	.01	.01													
72	1.13	.36	.15	.07	.04	.02	.01	.01	.01													
78	1.16	.36	.15	.07	.04	.02	.01	.01	.01													

TABLE 6-17. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	15.42																					
8	9.36	4.88																				
10	7.41	3.24	2.00																			
12	6.55	2.58	1.41	.96																		
14	6.13	2.26	1.14	.71	.52																	
16	5.94	2.07	.99	.59	.40	.30																
18	5.87	1.97	.91	.51	.33	.24	.19															
20	5.81	1.90	.85	.46	.29	.20	.15	.12														
22	5.77	1.87	.81	.43	.26	.18	.13	.10	.09													
24	5.75	1.86	.79	.41	.24	.16	.12	.09	.07	.06												
26	5.73	1.84	.77	.39	.23	.15	.10	.08	.06	.05	.04											
28	5.72	1.83	.76	.38	.22	.14	.10	.07	.06	.04	.04	.03										
30	5.71	1.82	.76	.38	.21	.13	.09	.07	.05	.04	.03	.03	.02									
32	5.71	1.82	.76	.37	.21	.13	.09	.06	.05	.04	.03	.02	.02	.02								
34	5.71	1.81	.75	.37	.20	.13	.08	.06	.04	.03	.03	.02	.02	.02	.01							
36	5.71	1.81	.75	.37	.20	.12	.08	.06	.04	.03	.03	.02	.02	.02	.01	.01						
42	5.71	1.81	.74	.36	.20	.12	.08	.05	.04	.03	.02	.02	.01	.01	.01	.01						
48	5.71	1.81	.74	.36	.20	.12	.07	.05	.03	.03	.02	.02	.01	.01	.01	.01						
54	5.71	1.81	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
60	5.71	1.81	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
66	5.70	1.81	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
72	5.72	1.81	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
78	5.87	1.81	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01							

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	48.73																					
8	29.60	15.42																				
10	23.41	10.24	6.32																			
12	20.71	8.16	4.47	3.05																		
14	19.39	7.13	3.61	2.26	1.64																	
16	18.77	6.55	3.14	1.85	1.26	.96																
18	18.54	6.21	2.86	1.61	1.05	.76	.60															
20	18.36	6.01	2.68	1.46	.92	.64	.49	.39														
22	18.24	5.92	2.57	1.36	.83	.56	.41	.32	.27													
24	18.16	5.87	2.49	1.29	.77	.51	.37	.28	.23	.19												
26	18.11	5.82	2.44	1.25	.73	.47	.33	.25	.20	.16	.14											
28	18.08	5.79	2.42	1.21	.70	.45	.31	.23	.17	.14	.12	.10										
30	18.06	5.76	2.40	1.19	.68	.43	.29	.21	.16	.13	.10	.09	.08									
32	18.05	5.75	2.39	1.17	.66	.41	.27	.20	.15	.12	.09	.08	.07	.06								
34	18.05	5.73	2.38	1.16	.65	.40	.26	.19	.14	.11	.09	.07	.06	.05	.05							
36	18.04	5.72	2.37	1.16	.64	.39	.26	.18	.13	.10	.08	.07	.06	.05	.04	.04						
42	18.04	5.71	2.35	1.14	.63	.37	.24	.16	.12	.09	.07	.05	.04	.04	.03	.03	.02	.02	.02			
48	18.04	5.71	2.34	1.14	.62	.37	.23	.16	.11	.08	.06	.05	.04	.03	.03	.02	.02	.02	.02	.01	.01	.01
54	18.04	5.71	2.34	1.13	.61	.36	.23	.15	.11	.08	.06	.04	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01
60	18.04	5.71	2.34	1.13	.61	.36	.23	.15	.10	.07	.06	.04	.03	.03	.02	.02	.02	.01	.01	.01	.01	.01
66	18.03	5.71	2.34	1.13	.61	.36	.22	.15	.10	.07	.05	.04	.03	.03	.02	.02	.01	.01	.01	.01	.01	.01
72	18.08	5.71	2.34	1.13	.61	.36	.22	.15	.10	.07	.05	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01	.01
78	18.56	5.71	2.34	1.13	.61	.36	.22	.15	.10	.07	.05	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01	.01

TABLE 6-17. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS—H EQUALS 0.3125 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	118.98																					
8	72.27	37.65																				
10	57.14	25.01	15.43																			
12	50.57	19.93	10.91	7.44																		
14	47.33	17.40	8.81	5.51	4.02																	
16	45.82	16.00	7.67	4.52	3.08	2.35																
18	45.26	15.17	6.99	3.94	2.56	1.86	1.47															
20	44.83	14.67	6.55	3.57	2.24	1.56	1.19	.96														
22	44.53	14.45	6.27	3.33	2.03	1.37	1.01	.79	.66													
24	44.34	14.32	6.08	3.16	1.89	1.25	.89	.68	.55	.46												
26	44.22	14.22	5.95	3.04	1.78	1.15	.81	.61	.48	.39	.34											
28	44.14	14.13	5.90	2.96	1.71	1.09	.75	.55	.43	.34	.29	.25										
30	44.09	14.07	5.87	2.90	1.65	1.04	.71	.51	.39	.31	.25	.22	.19									
32	44.07	14.03	5.83	2.86	1.61	1.00	.67	.48	.36	.28	.23	.19	.17	.15								
34	44.06	14.00	5.80	2.84	1.58	.97	.65	.46	.34	.26	.21	.17	.15	.13	.12							
36	44.05	13.98	5.78	2.83	1.55	.95	.62	.44	.32	.25	.20	.16	.13	.12	.10	.09						
42	44.04	13.94	5.74	2.79	1.53	.91	.58	.40	.29	.21	.17	.13	.11	.09	.08	.07	.06	.05	.05			
48	44.04	13.94	5.72	2.77	1.51	.89	.57	.38	.27	.20	.15	.12	.09	.08	.07	.06	.05	.04	.04	.03	.03	.03
54	44.04	13.94	5.71	2.76	1.50	.89	.56	.37	.26	.19	.14	.11	.09	.07	.06	.05	.04	.04	.03	.03	.03	.02
60	44.03	13.94	5.71	2.76	1.49	.88	.55	.37	.25	.18	.13	.10	.08	.06	.05	.04	.04	.03	.03	.02	.02	.02
66	44.02	13.94	5.71	2.75	1.49	.88	.55	.36	.25	.18	.13	.10	.08	.06	.05	.04	.03	.03	.03	.02	.02	.02
72	44.13	13.93	5.71	2.75	1.49	.87	.55	.36	.25	.18	.13	.10	.08	.06	.05	.04	.03	.03	.02	.02	.02	.02
78	45.31	13.93	5.71	2.75	1.49	.87	.55	.36	.25	.18	.13	.10	.07	.06	.05	.04	.03	.03	.02	.02	.02	.01

THICKNESS—H EQUALS 0.3750 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	246.72																					
8	149.85	78.08																				
10	118.49	51.87	31.99																			
12	104.86	41.33	22.63	15.42																		
14	98.14	36.09	18.28	11.42	8.33																	
16	95.01	33.18	15.91	9.37	6.39	4.88																
18	93.85	31.46	14.49	8.16	5.31	3.85	3.05															
20	92.95	30.41	13.59	7.40	4.65	3.24	2.46	2.00														
22	92.34	29.96	13.00	6.90	4.21	2.85	2.09	1.64	1.37													
24	91.95	29.70	12.60	6.55	3.91	2.58	1.85	1.41	1.14	.96												
26	91.69	29.48	12.34	6.31	3.69	2.39	1.68	1.26	.99	.82	.70											
28	91.53	29.30	12.24	6.13	3.54	2.26	1.56	1.14	.88	.71	.60	.52										
30	91.44	29.18	12.16	6.01	3.42	2.15	1.46	1.06	.81	.64	.53	.45	.39									
32	91.38	29.09	12.09	5.94	3.33	2.07	1.39	.99	.75	.59	.48	.40	.34	.30								
34	91.36	29.03	12.03	5.90	3.27	2.01	1.34	.94	.70	.54	.44	.36	.31	.27	.24							
36	91.34	28.98	11.98	5.87	3.22	1.97	1.29	.91	.67	.51	.41	.33	.28	.24	.21	.19						
42	91.33	28.92	11.89	5.79	3.17	1.88	1.21	.83	.60	.45	.35	.28	.23	.19	.16	.14	.12	.11	.10			
48	91.33	28.90	11.86	5.75	3.13	1.86	1.17	.79	.56	.41	.31	.24	.20	.16	.14	.12	.10	.09	.08	.07	.07	.06
54	91.33	28.90	11.84	5.72	3.11	1.84	1.16	.77	.53	.39	.29	.23	.18	.14	.12	.10	.09	.07	.07	.06	.05	.05
60	91.30	28.90	11.84	5.71	3.09	1.82	1.15	.76	.52	.38	.28	.21	.17	.13	.11	.09	.08	.07	.06	.05	.04	.04
66	91.27	28.90	11.84	5.71	3.09	1.82	1.14	.75	.52	.37	.27	.21	.16	.13	.10	.09	.07	.06	.05	.05	.04	.04
72	91.50	28.90	11.84	5.71	3.08	1.81	1.14	.75	.51	.37	.27	.20	.16	.12	.10	.08	.07	.06	.05	.04	.04	.03
78	93.96	28.89	11.84	5.71	3.08	1.81	1.13	.75	.51	.36	.27	.20	.15	.12	.10	.08	.06	.05	.05	.04	.03	.03

TABLE 6-17. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.4375 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	423.63																					
8	277.62	144.65																				
10	219.53	96.10	59.27																			
12	194.27	76.57	41.92	28.57																		
14	181.82	66.86	33.86	21.17	15.43																	
16	176.03	61.47	29.47	17.35	11.84	9.04																
18	173.88	58.28	26.84	15.13	9.84	7.13	5.64															
20	172.21	56.34	25.18	13.72	8.61	6.00	4.56	3.70														
22	171.07	55.51	24.08	12.79	7.80	5.28	3.88	3.05	2.53													
24	170.34	55.02	23.35	12.14	7.24	4.78	3.43	2.62	2.11	1.79												
26	169.87	54.62	22.85	11.69	6.84	4.43	3.11	2.33	1.83	1.51	1.30											
28	169.57	54.29	22.67	11.36	6.55	4.18	2.88	2.12	1.64	1.32	1.11	.96										
30	169.40	54.07	22.53	11.13	6.34	3.99	2.71	1.96	1.49	1.19	.98	.83	.73									
32	169.30	53.90	22.40	11.00	6.18	3.84	2.58	1.84	1.38	1.08	.88	.74	.64	.57								
34	169.25	53.78	22.29	10.92	6.06	3.73	2.48	1.75	1.30	1.01	.81	.67	.57	.50	.44							
36	169.23	53.69	22.20	10.87	5.96	3.64	2.40	1.68	1.23	.95	.75	.62	.52	.45	.39	.35						
42	169.21	53.57	22.03	10.72	5.87	3.48	2.24	1.54	1.10	.83	.64	.51	.42	.35	.30	.26	.23	.21	.19			
48	169.21	53.54	21.96	10.65	5.80	3.44	2.17	1.46	1.03	.76	.58	.45	.36	.30	.25	.21	.19	.16	.15	.13	.12	.11
54	169.20	53.54	21.94	10.61	5.76	3.40	2.15	1.42	.99	.72	.54	.42	.33	.27	.22	.19	.16	.14	.12	.11	.10	.09
60	169.15	53.54	21.93	10.59	5.73	3.38	2.13	1.41	.97	.70	.52	.40	.31	.25	.20	.17	.14	.12	.11	.09	.08	.07
66	169.10	53.54	21.93	10.58	5.72	3.36	2.11	1.40	.96	.69	.50	.38	.30	.24	.19	.16	.13	.11	.10	.08	.07	.07
72	169.53	53.53	21.93	10.58	5.71	3.36	2.10	1.39	.95	.68	.50	.37	.29	.23	.18	.15	.12	.10	.09	.08	.07	.06
78	174.08	53.53	21.93	10.58	5.71	3.35	2.10	1.38	.95	.67	.49	.37	.28	.22	.18	.14	.12	.10	.08	.07	.06	.05

THICKNESS-H EQUALS 0.5000 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	577.60																					
8	373.11	246.76																				
10	314.51	163.93	101.11																			
12	279.40	130.63	71.51	48.74																		
14	262.32	114.07	57.77	36.11	26.32																	
16	260.05	104.86	50.28	29.60	20.20	15.42																
18	257.81	99.42	45.80	25.80	16.79	12.17	9.63															
20	256.71	96.12	42.95	23.41	14.69	10.24	7.77	6.32														
22	255.62	94.70	41.09	21.81	13.31	9.01	6.62	5.20	4.32													
24	254.54	93.85	39.84	20.71	12.36	8.16	5.85	4.47	3.61	3.05												
26	253.46	93.17	38.99	19.94	11.68	7.57	5.31	3.97	3.13	2.58	2.21											
28	253.46	92.62	38.68	19.39	11.18	7.13	4.92	3.61	2.79	2.26	1.90	1.65										
30	253.46	92.23	38.44	18.99	10.82	6.80	4.62	3.34	2.55	2.02	1.67	1.42	1.25									
32	253.46	91.95	38.21	18.77	10.54	6.55	4.40	3.14	2.36	1.85	1.50	1.26	1.09	.96								
34	253.46	91.74	38.03	18.63	10.33	6.36	4.23	2.99	2.22	1.72	1.38	1.14	.97	.85	.76							
36	253.46	91.60	37.87	18.54	10.18	6.21	4.09	2.86	2.10	1.61	1.28	1.05	.88	.76	.67	.60						
42	253.46	91.39	37.59	18.29	10.01	5.94	3.83	2.62	1.88	1.41	1.09	.87	.71	.60	.51	.44	.39	.36	.32			
48	253.46	91.34	37.47	18.16	9.89	5.87	3.71	2.49	1.76	1.29	.99	.77	.62	.51	.43	.36	.32	.28	.25	.23	.21	.19
54	253.46	91.33	37.43	18.09	9.82	5.80	3.66	2.43	1.69	1.23	.92	.71	.56	.46	.38	.32	.27	.24	.21	.18	.17	.15
60	252.40	91.33	37.41	18.06	9.78	5.76	3.63	2.40	1.66	1.19	.88	.68	.53	.42	.35	.29	.24	.21	.18	.16	.14	.13
66	252.40	91.33	37.41	18.05	9.76	5.74	3.60	2.38	1.64	1.17	.86	.65	.51	.40	.33	.27	.23	.19	.16	.14	.13	.11
72	253.46	91.33	37.41	18.04	9.75	5.72	3.59	2.37	1.63	1.16	.85	.64	.49	.39	.31	.26	.21	.18	.15	.13	.11	.10
78	257.81	91.31	37.41	18.04	9.74	5.72	3.58	2.36	1.62	1.15	.84	.63	.48	.38	.30	.25	.20	.17	.14	.12	.11	.09

TABLE 6-17. FIBERGLASS POLYESTER LAMINATES
RECTANGULAR PLATES - LATERALLY LOADED
ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH
25-27 OZ. WOVEN ROVING - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.5625 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	684.18																					
8	405.22	387.05																				
10	389.56	262.59	161.96																			
12	348.84	209.25	114.55	78.08																		
14	344.44	182.71	92.53	57.84	42.17																	
16	329.70	167.96	80.54	47.41	32.36	24.70																
18	327.54	159.26	73.35	41.33	26.90	19.49	15.42															
20	323.66	153.96	68.80	37.49	23.53	16.41	12.45	10.12														
22	323.66	151.69	65.81	34.94	21.32	14.43	10.60	8.32	6.92													
24	321.58	150.34	63.81	33.18	19.79	13.08	9.37	7.16	5.78	4.88												
26	321.58	149.25	62.45	31.94	18.70	12.12	8.50	6.36	5.01	4.13	3.55											
28	321.58	148.36	61.96	31.05	17.91	11.42	7.88	5.78	4.48	3.61	3.04	2.64										
30	319.87	147.74	61.58	30.41	17.32	10.90	7.41	5.36	4.08	3.24	2.68	2.28	2.00									
32	319.87	147.28	61.20	30.06	16.88	10.50	7.05	5.03	3.78	2.96	2.41	2.02	1.74	1.54								
34	319.87	146.95	60.91	29.85	16.55	10.19	6.77	4.78	3.55	2.75	2.21	1.83	1.56	1.36	1.21							
36	319.87	146.72	60.66	29.70	16.30	9.95	6.55	4.58	3.37	2.58	2.05	1.68	1.41	1.22	1.07	.96						
42	319.87	146.40	60.21	29.30	16.03	9.51	6.13	4.20	3.02	2.26	1.75	1.39	1.14	.96	.82	.71	.63	.57	.52			
48	319.87	146.31	60.02	29.09	15.84	9.40	5.94	3.99	2.82	2.07	1.58	1.24	.99	.82	.69	.58	.51	.45	.40	.36	.33	.30
54	319.87	146.30	59.95	28.98	15.73	9.30	5.87	3.89	2.71	1.97	1.48	1.14	.91	.73	.61	.51	.44	.38	.33	.30	.27	.24
60	319.87	146.30	59.93	28.93	15.66	9.23	5.81	3.85	2.65	1.90	1.41	1.08	.85	.68	.56	.46	.39	.33	.29	.25	.23	.20
66	319.87	146.30	59.92	28.91	15.63	9.19	5.77	3.81	2.63	1.87	1.37	1.04	.81	.65	.52	.43	.36	.31	.26	.23	.20	.18
72	321.58	146.29	59.92	28.90	15.61	9.17	5.75	3.79	2.61	1.86	1.36	1.02	.79	.62	.50	.41	.34	.29	.24	.21	.18	.16
78	327.54	146.27	59.92	28.90	15.60	9.16	5.73	3.77	2.59	1.84	1.35	1.01	.77	.61	.48	.39	.33	.27	.23	.20	.17	.15

THICKNESS-H EQUALS 0.6250 INCHES

LENGTH-B INCHES	WIDTH-A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	907.41																					
8	585.48	510.81																				
10	470.77	358.42	246.85																			
12	453.02	291.32	174.59	119.00																		
14	425.43	256.93	141.04	88.15	64.26																	
16	406.98	255.62	122.75	72.27	49.32	37.64																
18	403.70	241.44	111.80	63.00	40.99	29.71	23.51															
20	403.70	234.47	104.86	57.14	35.86	25.01	18.98	15.43														
22	400.47	228.75	100.31	53.25	32.49	21.99	16.16	12.69	10.54													
24	397.29	227.71	97.25	50.57	30.16	19.93	14.28	10.91	8.81	7.44												
26	397.29	225.66	95.19	48.68	28.51	18.47	12.96	9.69	7.64	6.30	5.41											
28	397.29	224.48	94.44	47.33	27.30	17.40	12.00	8.81	6.82	5.51	4.63	4.02										
30	397.29	224.48	93.86	46.35	26.40	16.61	11.29	8.16	6.22	4.94	4.08	3.48	3.04									
32	397.29	223.48	93.29	45.82	25.73	16.00	10.74	7.67	5.76	4.52	3.67	3.08	2.66	2.35								
34	393.65	223.48	92.83	45.49	25.23	15.53	10.32	7.29	5.41	4.19	3.37	2.79	2.37	2.07	1.85							
36	393.65	223.48	92.45	45.26	24.84	15.17	9.99	6.99	5.14	3.94	3.13	2.56	2.15	1.86	1.64	1.47						
42	393.65	222.48	91.78	44.66	24.43	14.49	9.35	6.40	4.60	3.44	2.66	2.13	1.74	1.46	1.25	1.09	.96	.87	.79			
48	393.65	222.48	91.49	44.34	24.14	14.32	9.05	6.08	4.30	3.16	2.41	1.88	1.51	1.25	1.05	.89	.77	.68	.61	.55	.50	.46
54	393.65	222.48	91.38	44.17	23.97	14.17	8.94	5.92	4.12	3.00	2.25	1.74	1.38	1.12	.92	.78	.66	.58	.51	.45	.40	.37
60	393.65	222.48	91.34	44.09	23.87	14.07	8.85	5.87	4.04	2.90	2.16	1.65	1.29	1.04	.85	.71	.60	.51	.44	.39	.34	.31
66	393.65	222.48	91.33	44.06	23.82	14.01	8.80	5.81	4.01	2.85	2.09	1.59	1.24	.98	.80	.66	.55	.47	.40	.35	.31	.27
72	397.29	222.48	91.33	44.05	23.79	13.98	8.76	5.78	3.97	2.83	2.07	1.55	1.20	.95	.76	.62	.52	.44	.37	.32	.28	.25
78	403.70	222.48	91.33	44.04	23.78	13.96	8.73	5.75	3.95	2.81	2.05	1.54	1.17	.92	.74	.60	.50	.42	.35	.30	.26	.23

TABLE 6-18. FIBERGLASS POLYESTER LAMINATES
RECTANGULAR PLATES - LATERALLY LOADED
ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH
10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED

PHYSICAL CONSTANTS:

$E_X = 1.96 \times 10^6$ PSI

$E_Y = 1.70 \times 10^6$ PSI

$G_{XY} = 0.52 \times 10^6$ PSI

$\sigma_{XY} = \sigma_{YX} = 0.20$

THICKNESS—H EQUALS 0.0625 INCHES

WIDTH—A INCHES

LENGTH—B INCHES	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	.18																					
8	.12	.06																				
10	.09	.04	.02																			
12	.08	.03	.02	.01																		
14	.08	.03	.01	.01	.01																	
16	.07	.03	.01	.01																		
18	.07	.02	.01	.01																		
20	.07	.02	.01	.01																		
22	.07	.02	.01	.01																		
24	.07	.02	.01	.01																		
26	.07	.02	.01																			
28	.07	.02	.01																			
30	.07	.02	.01																			
32	.07	.02	.01																			
34	.07	.02	.01																			
36	.07	.02	.01																			
42	.07	.02	.01																			
48	.07	.02	.01																			
54	.07	.02	.01																			
60	.07	.02	.01																			
66	.07	.02	.01																			
72	.07	.02	.01																			
78	.07	.02	.01																			

THICKNESS—H EQUALS 0.1250 INCHES

WIDTH—A INCHES

LENGTH—B INCHES	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	2.93																					
8	1.87	.93																				
10	1.48	.64	.38																			
12	1.31	.52	.28	.18																		
14	1.22	.45	.23	.14	.10																	
16	1.17	.41	.20	.12	.08	.06																
18	1.15	.39	.18	.10	.07	.05	.04															
20	1.14	.38	.17	.09	.06	.04	.03	.02														
22	1.13	.37	.16	.09	.05	.04	.03	.02	.02													
24	1.13	.36	.16	.08	.05	.03	.02	.02	.01	.01												
26	1.13	.36	.15	.08	.05	.03	.02	.02	.01	.01	.01											
28	1.12	.36	.15	.08	.04	.03	.02	.01	.01	.01	.01	.01										
30	1.12	.36	.15	.07	.04	.03	.02	.01	.01	.01	.01	.01										
32	1.12	.36	.15	.07	.04	.03	.02	.01	.01	.01	.01											
34	1.12	.36	.15	.07	.04	.03	.02	.01	.01	.01	.01											
36	1.12	.36	.15	.07	.04	.02	.02	.01	.01	.01	.01											
42	1.12	.36	.15	.07	.04	.02	.02	.01	.01	.01												
48	1.12	.36	.15	.07	.04	.02	.01	.01	.01	.01												
54	1.12	.35	.15	.07	.04	.02	.01	.01	.01													
60	1.12	.35	.15	.07	.04	.02	.01	.01	.01													
66	1.12	.35	.15	.07	.04	.02	.01	.01	.01													
72	1.12	.35	.15	.07	.04	.02	.01	.01	.01													
78	1.15	.35	.15	.07	.04	.02	.01	.01	.01													

TABLE 6-18. FIBERGLASS POLYESTER LAMINATES
RECTANGULAR PLATES - LATERALLY LOADED
ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH
10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS-H EQUALS 0.1875 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	14.85																					
8	9.44	4.70																				
10	7.49	3.26	1.92																			
12	6.61	2.61	1.41	.93																		
14	6.17	2.28	1.15	.71	.50																	
16	5.90	2.09	1.01	.59	.40	.29																
18	5.83	1.98	.91	.52	.33	.24	.18															
20	5.78	1.91	.86	.47	.29	.20	.15	.12														
22	5.74	1.66	.82	.44	.27	.18	.13	.10	.08													
24	5.72	1.85	.79	.41	.25	.16	.12	.09	.07	.06												
26	5.70	1.83	.77	.40	.23	.15	.11	.08	.06	.05	.04											
28	5.69	1.82	.76	.39	.22	.14	.10	.07	.06	.04	.04	.03										
30	5.69	1.82	.76	.38	.22	.14	.09	.07	.05	.04	.03	.03	.02									
32	5.68	1.81	.75	.37	.21	.13	.09	.06	.05	.04	.03	.02	.02	.02								
34	5.68	1.81	.75	.37	.21	.13	.08	.06	.04	.03	.03	.02	.02	.02	.01							
36	5.68	1.80	.75	.36	.20	.12	.08	.06	.04	.03	.03	.02	.02	.01	.01	.01						
42	5.68	1.80	.74	.36	.20	.12	.08	.05	.04	.03	.02	.02	.01	.01	.01	.01						
48	5.68	1.80	.74	.36	.19	.12	.07	.05	.04	.03	.02	.02	.01	.01	.01	.01						
54	5.68	1.80	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
60	5.68	1.80	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
66	5.67	1.80	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
72	5.66	1.80	.74	.36	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01	.01						
78	5.80	1.80	.74	.35	.19	.11	.07	.05	.03	.02	.02	.01	.01	.01	.01							

THICKNESS-H EQUALS 0.2500 INCHES

LENGTH-B INCHES	WIDTH-A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	46.93																					
8	29.85	14.85																				
10	23.68	10.29	6.08																			
12	20.90	8.26	4.47	2.93																		
14	19.49	7.21	3.65	2.25	1.58																	
16	18.65	6.61	3.18	1.87	1.25	.93																
18	18.44	6.25	2.89	1.63	1.06	.75	.58															
20	18.27	6.03	2.71	1.48	.93	.64	.48	.38														
22	18.16	5.88	2.59	1.38	.84	.57	.41	.32	.26													
24	18.08	5.83	2.50	1.31	.78	.52	.37	.28	.22	.18												
26	18.03	5.79	2.44	1.25	.74	.48	.34	.25	.20	.16	.13											
28	18.00	5.76	2.40	1.22	.70	.45	.31	.23	.18	.14	.12	.10										
30	17.98	5.74	2.39	1.19	.68	.43	.29	.21	.16	.13	.10	.09	.07									
32	17.97	5.72	2.38	1.17	.66	.41	.28	.20	.15	.12	.09	.08	.07	.06								
34	17.96	5.71	2.36	1.16	.65	.40	.27	.19	.14	.11	.09	.07	.06	.05	.05							
36	17.96	5.70	2.36	1.15	.64	.39	.26	.18	.13	.10	.08	.07	.06	.05	.04	.04						
42	17.95	5.68	2.34	1.14	.62	.37	.24	.16	.12	.09	.07	.06	.04	.04	.03	.03						
48	17.95	5.68	2.33	1.13	.61	.36	.23	.16	.11	.08	.06	.05	.04	.03	.03	.02	.02	.02	.02			
54	17.95	5.68	2.33	1.13	.61	.36	.23	.15	.11	.08	.06	.04	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01
60	17.94	5.68	2.33	1.12	.61	.36	.23	.15	.10	.07	.06	.04	.03	.03	.02	.02	.02	.01	.01	.01	.01	.01
66	17.92	5.68	2.33	1.12	.61	.36	.22	.15	.10	.07	.05	.04	.03	.03	.02	.02	.01	.01	.01	.01	.01	.01
72	17.90	5.68	2.33	1.12	.61	.36	.22	.15	.10	.07	.05	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01	.01
78	18.33	5.68	2.33	1.12	.61	.36	.22	.15	.10	.07	.05	.04	.03	.02	.02	.02	.01	.01	.01	.01	.01	.01

TABLE 6-18. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS—H EQUALS 0.3125 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	114.56																					
8	72.87	36.25																				
10	57.81	25.12	14.85																			
12	51.01	20.17	10.91	7.16																		
14	47.58	17.60	8.90	5.49	3.87																	
16	45.54	16.14	7.76	4.56	3.06	2.27																
18	45.02	15.26	7.06	3.98	2.58	1.84	1.42															
20	44.61	14.72	6.61	3.61	2.27	1.57	1.17	.93														
22	44.33	14.35	6.31	3.36	2.05	1.39	1.01	.78	.63													
24	44.14	14.25	6.11	3.19	1.91	1.26	.90	.68	.54	.45												
26	44.01	14.14	5.97	3.06	1.80	1.17	.82	.61	.48	.39	.32											
28	43.94	14.07	5.87	2.97	1.72	1.10	.76	.56	.43	.34	.28	.24										
30	43.89	14.01	5.83	2.91	1.66	1.05	.71	.52	.39	.31	.25	.21	.18									
32	43.86	13.96	5.80	2.85	1.62	1.01	.68	.49	.36	.28	.23	.19	.16	.14								
34	43.85	13.93	5.77	2.83	1.58	.98	.65	.46	.34	.26	.21	.17	.15	.13	.11							
36	43.84	13.91	5.75	2.81	1.56	.95	.63	.44	.32	.25	.20	.16	.13	.12	.10	.09						
42	43.83	13.88	5.71	2.78	1.52	.90	.59	.40	.29	.22	.17	.13	.11	.09	.08	.07	.06	.05	.05			
48	43.83	13.87	5.69	2.76	1.50	.89	.56	.38	.27	.20	.15	.12	.10	.08	.07	.06	.05	.04	.04	.03	.03	.03
54	43.83	13.87	5.68	2.75	1.49	.88	.56	.37	.26	.19	.14	.11	.09	.07	.06	.05	.04	.04	.03	.03	.03	.02
60	43.81	13.87	5.68	2.74	1.49	.88	.55	.36	.25	.18	.14	.10	.08	.07	.05	.04	.04	.03	.03	.02	.02	.02
66	43.74	13.87	5.68	2.74	1.48	.87	.55	.36	.25	.18	.13	.10	.08	.06	.05	.04	.03	.03	.03	.02	.02	.02
72	43.70	13.87	5.68	2.74	1.48	.87	.54	.36	.25	.18	.13	.10	.08	.06	.05	.04	.03	.03	.02	.02	.02	.02
78	44.75	13.86	5.68	2.74	1.48	.87	.54	.36	.25	.17	.13	.10	.07	.06	.05	.04	.03	.03	.02	.02	.02	.01

THICKNESS—H EQUALS 0.3750 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	237.57																					
8	151.11	75.17																				
10	119.88	52.08	30.79																			
12	105.78	41.82	22.62	14.86																		
14	98.67	36.50	18.46	11.39	8.02																	
16	94.44	33.47	16.10	9.45	6.35	4.70																
18	93.36	31.65	14.64	8.26	5.34	3.82	2.93															
20	92.51	30.53	13.71	7.49	4.70	3.26	2.43	1.92														
22	91.92	29.75	13.09	6.97	4.26	2.88	2.10	1.62	1.32													
24	91.52	29.54	12.66	6.61	3.95	2.61	1.87	1.41	1.12	.93												
26	91.27	29.33	12.37	6.35	3.73	2.42	1.70	1.26	.99	.80	.67											
28	91.11	29.17	12.17	6.17	3.57	2.28	1.57	1.15	.89	.71	.59	.50										
30	91.01	29.05	12.10	6.03	3.45	2.17	1.48	1.07	.81	.64	.53	.44	.38									
32	90.96	28.96	12.03	5.90	3.35	2.09	1.41	1.01	.76	.59	.48	.40	.34	.29								
34	90.93	28.89	11.97	5.87	3.28	2.03	1.35	.96	.71	.55	.44	.36	.30	.26	.23							
36	90.91	28.85	11.93	5.83	3.23	1.98	1.31	.92	.67	.52	.41	.33	.28	.24	.21	.18						
42	90.90	28.78	11.84	5.76	3.15	1.87	1.22	.84	.60	.45	.35	.28	.23	.19	.16	.14	.12	.11	.10			
48	90.89	28.76	11.80	5.72	3.11	1.85	1.17	.79	.56	.41	.31	.25	.20	.16	.14	.12	.10	.09	.08	.07	.06	.06
54	90.88	28.76	11.79	5.70	3.09	1.83	1.15	.76	.54	.39	.29	.23	.18	.15	.12	.10	.09	.08	.07	.06	.05	.05
60	90.84	28.76	11.78	5.69	3.08	1.82	1.14	.76	.52	.38	.28	.22	.17	.14	.11	.09	.08	.07	.06	.05	.04	.04
66	90.70	28.76	11.78	5.68	3.07	1.81	1.13	.75	.52	.37	.27	.21	.16	.13	.10	.09	.07	.06	.05	.05	.04	.04
72	90.61	28.76	11.78	5.68	3.07	1.80	1.13	.75	.51	.36	.27	.20	.16	.12	.10	.08	.07	.06	.05	.04	.04	.03
78	92.81	28.75	11.78	5.68	3.07	1.80	1.13	.74	.51	.36	.26	.20	.15	.12	.10	.08	.06	.05	.05	.04	.03	.03

TABLE 6-18. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS—H EQUALS 0.4375 INCHES

LENGTH—B INCHES	WIDTH—A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	437.72																					
8	279.95	139.27																				
10	222.10	96.49	57.05																			
12	195.97	77.48	41.91	27.53																		
14	182.80	67.62	34.21	21.10	14.85																	
16	174.96	62.01	29.82	17.50	11.76	8.70																
18	172.97	58.65	27.13	15.31	9.90	7.07	5.44															
20	171.39	56.57	25.40	13.88	8.70	6.03	4.51	3.57														
22	170.29	55.11	24.24	12.92	7.89	5.33	3.89	3.01	2.44													
24	169.56	54.73	23.46	12.25	7.32	4.84	3.46	2.62	2.08	1.72												
26	169.08	54.34	22.92	11.77	6.91	4.49	3.15	2.34	1.83	1.49	1.25											
28	168.79	54.05	22.55	11.43	6.61	4.23	2.92	2.14	1.65	1.32	1.09	.93										
30	168.61	53.82	22.42	11.17	6.39	4.03	2.74	1.98	1.51	1.19	.97	.82	.70									
32	168.51	53.65	22.28	10.94	6.21	3.87	2.61	1.86	1.40	1.09	.88	.74	.63	.54								
34	168.45	53.53	22.18	10.88	6.08	3.76	2.50	1.77	1.32	1.02	.81	.67	.56	.49	.43							
36	168.42	53.45	22.09	10.81	5.98	3.66	2.42	1.70	1.25	.96	.76	.62	.52	.44	.38	.34						
42	168.40	53.32	21.93	10.68	5.83	3.46	2.26	1.55	1.11	.83	.65	.52	.42	.35	.30	.26	.23	.20	.18			
48	168.40	53.29	21.86	10.60	5.77	3.42	2.16	1.47	1.04	.77	.58	.46	.37	.30	.25	.22	.19	.16	.15	.13	.12	.11
54	168.38	53.28	21.84	10.56	5.73	3.39	2.14	1.42	.99	.72	.54	.42	.33	.27	.22	.19	.16	.14	.12	.11	.10	.09
60	168.29	53.28	21.83	10.54	5.71	3.36	2.12	1.40	.96	.70	.52	.40	.31	.25	.21	.17	.14	.12	.11	.09	.08	.07
66	168.04	53.28	21.82	10.53	5.69	3.35	2.10	1.39	.96	.68	.50	.38	.30	.24	.19	.16	.13	.11	.10	.06	.07	.07
72	167.87	53.28	21.82	10.53	5.69	3.34	2.09	1.38	.95	.68	.49	.37	.29	.23	.18	.15	.13	.11	.09	.08	.07	.06
78	171.94	53.26	21.82	10.53	5.68	3.33	2.09	1.37	.94	.67	.49	.37	.28	.22	.18	.15	.12	.10	.09	.07	.06	.06

THICKNESS—H EQUALS 0.5000 INCHES

LENGTH—B INCHES	WIDTH—A INCHES 6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	574.81																					
8	383.21	237.59																				
10	322.38	164.61	97.32																			
12	286.06	132.17	71.50	46.96																		
14	267.24	115.35	58.36	36.00	25.34																	
16	261.50	105.79	50.88	29.86	20.07	14.85																
18	260.38	100.05	46.29	26.11	16.89	12.06	9.28															
20	259.28	96.50	43.33	23.68	14.85	10.29	7.69	6.09														
22	258.18	94.02	41.36	22.04	13.47	9.09	6.63	5.13	4.16													
24	257.09	93.37	40.03	20.90	12.50	8.26	5.90	4.47	3.55	2.93												
26	256.01	92.71	39.11	20.08	11.80	7.66	5.37	4.00	3.12	2.54	2.13											
28	256.01	92.20	38.47	19.49	11.28	7.21	4.98	3.65	2.81	2.25	1.86	1.58										
30	256.01	91.81	38.24	19.06	10.89	6.87	4.68	3.38	2.57	2.03	1.66	1.40	1.20									
32	256.01	91.52	38.02	18.66	10.60	6.61	4.45	3.18	2.39	1.86	1.51	1.25	1.07	.93								
34	256.01	91.32	37.84	18.55	10.38	6.41	4.27	3.02	2.24	1.73	1.39	1.14	.96	.83	.73							
36	254.94	91.18	37.69	18.44	10.21	6.25	4.13	2.89	2.13	1.63	1.29	1.06	.88	.75	.66	.58						
42	254.94	90.97	37.42	18.21	9.96	5.91	3.85	2.64	1.90	1.42	1.10	.88	.72	.60	.51	.44	.39	.35	.31			
48	254.94	90.91	37.30	18.08	9.84	5.83	3.69	2.50	1.77	1.31	1.00	.78	.63	.52	.43	.37	.32	.28	.25	.22	.20	.18
54	254.94	90.90	37.25	18.01	9.77	5.78	3.64	2.42	1.70	1.23	.93	.72	.57	.46	.38	.32	.28	.24	.21	.18	.16	.15
60	254.94	90.90	37.24	17.98	9.73	5.74	3.61	2.39	1.65	1.19	.89	.68	.53	.43	.35	.29	.25	.21	.18	.16	.14	.13
66	254.94	90.89	37.23	17.96	9.71	5.71	3.59	2.37	1.63	1.16	.86	.65	.51	.41	.33	.27	.23	.19	.17	.14	.13	.11
72	254.94	90.88	37.23	17.96	9.70	5.70	3.57	2.36	1.62	1.15	.84	.64	.49	.39	.31	.26	.21	.18	.15	.13	.12	.10
78	257.09	90.86	37.23	17.96	9.70	5.69	3.56	2.35	1.61	1.14	.84	.63	.48	.38	.30	.25	.20	.17	.15	.12	.11	.09

TABLE 6-18. FIBERGLASS POLYESTER LAMINATES RECTANGULAR PLATES - LATERALLY LOADED ULTIMATE UNIFORM LOAD - POUNDS PER SQUARE INCH 10 OZ. CLOTH - ALL EDGES SIMPLY SUPPORTED (Cont'd)

THICKNESS—H EQUALS 0.5625 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	686.15																					
8	496.98	380.57																				
10	401.38	263.68	155.89																			
12	356.32	211.71	114.53	75.22																		
14	351.79	184.77	93.48	57.66	40.59																	
16	332.22	169.45	81.49	47.83	32.15	23.78																
18	330.07	160.26	74.14	41.82	27.06	19.32	14.86															
20	326.18	154.57	69.40	37.94	23.79	16.48	12.32	9.75														
22	326.18	150.61	66.25	35.31	21.57	14.57	10.62	8.22	6.66													
24	326.18	149.56	64.11	33.47	20.02	13.23	9.45	7.16	5.69	4.70												
26	324.44	148.50	62.65	32.16	18.89	12.26	8.60	6.40	5.00	4.06	3.41											
28	324.44	147.69	61.61	31.22	16.07	11.55	7.97	5.84	4.50	3.60	2.98	2.54										
30	324.44	147.06	61.26	30.53	17.45	11.01	7.49	5.42	4.12	3.25	2.66	2.24	1.92									
32	324.44	146.60	60.89	29.88	16.98	10.59	7.13	5.09	3.82	2.99	2.42	2.01	1.71	1.49								
34	324.44	146.26	60.60	29.72	16.63	10.27	6.84	4.84	3.59	2.78	2.22	1.83	1.54	1.33	1.17							
36	322.38	146.05	60.38	29.54	16.35	10.02	6.61	4.63	3.41	2.61	2.07	1.69	1.41	1.21	1.05	.93						
42	322.38	145.71	59.94	29.17	15.95	9.46	6.17	4.23	3.04	2.28	1.77	1.41	1.15	.97	.82	.71	.63	.56	.50			
48	322.38	145.62	59.75	28.96	15.77	9.35	5.90	4.01	2.84	2.09	1.59	1.25	1.01	.83	.69	.59	.51	.45	.40	.36	.32	.29
54	322.38	145.60	59.67	28.85	15.66	9.25	5.83	3.87	2.72	1.98	1.49	1.15	.92	.74	.61	.52	.44	.38	.33	.30	.26	.24
60	322.38	145.60	59.64	28.80	15.59	9.19	5.78	3.83	2.64	1.91	1.42	1.09	.86	.69	.56	.47	.40	.34	.29	.26	.23	.20
66	322.38	145.59	59.64	28.77	15.56	9.15	5.74	3.80	2.61	1.86	1.38	1.05	.82	.65	.53	.44	.36	.31	.27	.23	.20	.18
72	322.38	145.58	59.64	28.76	15.54	9.13	5.72	3.77	2.59	1.85	1.35	1.02	.79	.63	.50	.41	.34	.29	.25	.21	.19	.16
78	326.18	145.54	59.64	28.76	15.53	9.11	5.70	3.76	2.58	1.83	1.34	1.00	.77	.61	.49	.40	.33	.27	.23	.20	.17	.15

THICKNESS—H EQUALS 0.6250 INCHES

LENGTH—B INCHES	WIDTH—A INCHES																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
6	885.61																					
8	602.08	502.72																				
10	482.81	363.54	237.60																			
12	464.41	298.97	174.57	114.64																		
14	431.52	263.54	142.47	87.89	61.86																	
16	409.48	258.27	124.20	72.89	48.99	36.25																
18	406.20	244.26	113.00	63.75	41.24	29.45	22.65															
20	406.20	235.60	105.78	57.82	36.25	25.12	18.77	14.85														
22	402.98	229.55	100.98	53.81	32.88	22.20	16.19	12.52	10.15													
24	402.98	227.95	97.72	51.02	30.51	20.17	14.40	10.91	8.68	7.16												
26	399.28	226.34	95.48	49.02	28.80	18.69	13.11	9.76	7.63	6.19	5.20											
28	399.28	225.10	93.91	47.58	27.54	17.60	12.15	8.91	6.86	5.49	4.55	3.87										
30	399.28	224.14	93.36	46.54	26.59	16.77	11.42	8.26	6.28	4.96	4.06	3.41	2.93									
32	399.28	223.45	92.81	45.54	25.88	16.14	10.86	7.76	5.83	4.55	3.68	3.06	2.61	2.27								
34	399.28	222.95	92.37	45.29	25.34	15.65	10.42	7.37	5.48	4.23	3.39	2.79	2.35	2.03	1.78							
36	399.28	222.61	92.02	45.03	24.93	15.26	10.08	7.06	5.20	3.98	3.16	2.58	2.15	1.84	1.60	1.42						
42	399.28	222.09	91.35	44.46	24.30	14.43	9.40	6.45	4.64	3.48	2.69	2.15	1.76	1.47	1.25	1.09	.95	.85	.76			
48	399.28	221.95	91.06	44.14	24.03	14.25	9.00	6.11	4.33	3.19	2.43	1.91	1.53	1.26	1.06	.90	.78	.68	.60	.54	.49	.45
54	399.28	221.92	90.95	43.97	23.86	14.10	8.89	5.90	4.14	3.01	2.27	1.76	1.39	1.13	.94	.79	.67	.58	.51	.45	.40	.36
60	399.28	221.92	90.91	43.89	23.76	14.01	8.81	5.84	4.02	2.91	2.17	1.66	1.31	1.05	.86	.71	.60	.52	.45	.39	.35	.31
66	399.28	221.91	90.90	43.85	23.71	13.95	8.76	5.79	3.99	2.83	2.10	1.60	1.25	.99	.81	.66	.56	.47	.41	.35	.31	.27
72	396.16	221.89	90.90	43.84	23.68	13.91	8.72	5.75	3.95	2.81	2.06	1.56	1.21	.95	.77	.63	.52	.44	.38	.32	.28	.25
78	399.28	221.82	90.90	43.83	23.67	13.89	8.69	5.73	3.93	2.79	2.04	1.53	1.18	.93	.74	.61	.50	.42	.36	.30	.26	.23

DESIGN EXAMPLE 6-24. UNIFORMLY LOADED SIMPLY SUPPORTED CLOTH LAMINATE PANEL

A 24 in. wide by 48 in. long plate is to sustain a head of salt water of 2-1/2 ft, Fig. 6-48. If the plate is a simply supported 10 oz. cloth reinforced polyester laminate, find the thickness required for a factor of safety of 2.

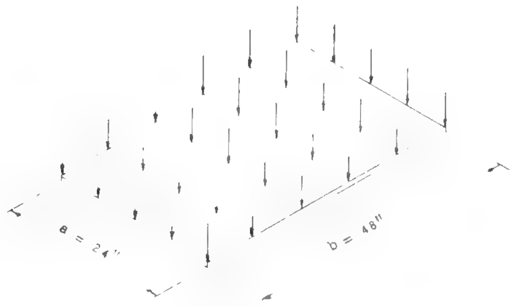


Fig. 6-48. Uniformly Loaded Plate with Edges Simply Supported

The water load on the plate is:

$$p = \frac{2.5 \times 64.4}{144} = 1.12 \text{ psi}$$

For a factor of safety of 2, the ultimate load the plate must support is:

$$P_u = 2 \times 1.12 = 2.24 \text{ psi}$$

From Table 6-18

For a 9/16 in. thick plate : $P_u = 2.09$ psi

For a 5/8 in. thick plate : $P_u = 3.19$ psi

Therefore, the 5/8 in. thick plate is required.

DESIGN EXAMPLE 6-25. ULTIMATE UNIFORM LOAD FOR SIMPLY SUPPORTED WOVEN ROVING LAMINATE PANEL

A laminate is 10 in. wide by 36 in. long by 3/8 in. thick and is made of woven roving reinforced polyester resin.

What ultimate uniform load can the plate support if the edges are simply supported similar to Fig. 6-48?

From Table 6-17 the ultimate uniform load that this plate can support is equal to 11.98 psi or 1725 psf.

Case 2. Plates with Clamped Edges Under Uniform Loads

The deflection equation for plates with clamped edges under uniform loads is (18):

$$w = A\left\{ x(x-a)\eta(\eta-\beta) + \sum_n \frac{a_n}{H_n(\beta)} \left[\sin\delta_n(\eta-\beta)\sinh\gamma_n\eta + \sin\delta_n\eta \sinh\gamma_n(\eta-\beta)\right] \sin\lambda_n X + \sum_m \frac{b_m}{K_m(a)}\left[\sin c_m(x-a)\sinh d_m x + \sin c_m x \sinh d_m(x-a)\right]\sin\sigma_m\eta \right\} \quad (6.61)$$

where:

$$\sigma_m = \frac{m\pi}{\beta} \qquad d_m = \sigma_m\rho \qquad c_m = \sigma_n\sigma$$

$$H_n(\beta) = \gamma_n \sin\delta_n\beta + \delta_n \sinh\gamma_n\beta$$

$$K_m(a) = d_m \sin c_m a + c_m \sinh d_m a$$

$$b_m = \frac{8a}{\beta\sigma_m^3} - \frac{8\sigma_m}{\beta}\sum_n \frac{\lambda_n\gamma_n F_n(\beta)}{(\delta_n^2 + \sigma_m^2 + \gamma_n^2)^2 - 4\delta_n^2\sigma_m^2} a_n$$

$$a_n = \frac{8\beta}{a\lambda_n^3} - \frac{8\lambda_n}{a}\sum_m \frac{\sigma_m d_m G_m(a)}{(c_m^2 + \lambda_n^2 + d_m^2)^2 - 4c_m^2\lambda_n^2} b_m$$

$$F_n(\beta) = \frac{\cos\delta_n\beta + \cosh\gamma_n\beta}{\left(\frac{\rho}{\sigma}\right)\sin\delta_n\beta + \sinh\gamma_n\beta}$$

$$G_m(a) = \frac{\cos c_m a + \cosh d_m a}{\left(\frac{\rho}{\sigma}\right)\sin c_m a + \sinh d_m a}$$

Symbols not defined are as previously noted.

From this general deflection equation 6.61, the following basic plate moment equations and the equation for the deflection at the center of the plate have been derived:

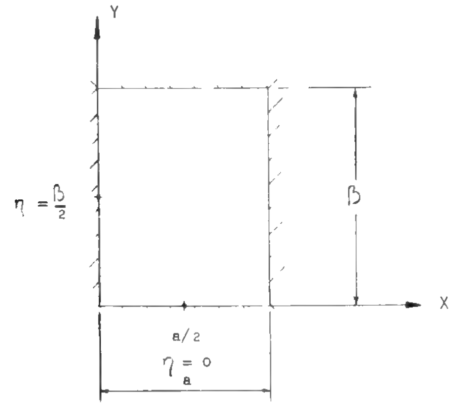


Fig. 6-49. Uniformly Loaded Plates with Clamped Edges

Referring to Fig. 6-49, for

$$X = 0 \qquad \eta = \frac{\beta}{2}$$

$$m_x = -D_1 \left\{ A \left[-\frac{\beta^2}{2} + \frac{2bcd}{K} \sin\sigma \frac{\beta}{2} \left(\cos ca + \cosh da \right) \right] \right\} \tag{6.62}$$

$$m_y = -D_2 \left\{ \sigma_2 A \left[-\frac{\beta^2}{2} + \frac{2bcd}{K} \sin\sigma \frac{\beta}{2} \left(\cos ca + \cosh da \right) \right] \right\} \tag{6.63}$$

Deflection at center of plate:

$$w = 2A \left\{ \frac{a^2\beta^2}{32} - \frac{a}{H} \sin\frac{\delta\beta}{2} \sin\frac{\gamma\beta}{2} \sin\frac{\lambda a}{2} - \frac{b}{K} \sin\frac{ca}{2} \sinh\frac{da}{2} \sin\frac{\sigma\beta}{2} \right\} \tag{6.64}$$

Referring to Fig. 6-49, then for:

$$X = \frac{a}{2} \text{ and } \eta = 0$$

$$m_x = -D_1 \left\{ \sigma_1 \varepsilon^2 A \left[-\frac{a^2}{2} + \frac{2\gamma\delta a \sin\lambda a/2}{H} \left(\cos\delta\beta + \cosh\gamma\beta \right) \right] \right\} \tag{6.62a}$$

$$m_y = -D_2 \left\{ \varepsilon^2 A \left[-\frac{a^2}{2} + \frac{2\gamma\delta a \sin\lambda a/2}{H} \left(\cos\delta\beta + \cosh\gamma\beta \right) \right] \right\} \tag{6.63a}$$

$$m_y = \sigma_1 m_x \tag{6.63b}$$

From the above equations the ultimate uniform loads for laminates with clamped edges may be determined. As previously stated, load tables for this condition have not been developed.

Since there are so many possible combinations of reinforcements that may be used in laminates, equations with accompanying graphs and tables of necessary constants developed for orthotropic materials and applied to plywood (5) and isotropic materials (19) are presented to obtain the unit loads and bending moments for both simply supported and clamped edges. Tables 6-19 and 6-20 have been developed for simply supported plates only.

Fiberglass reinforced laminates are assumed to behave similar to plywood panels and the following equations apply (5):

Case 1. Simply Supported Plates Under Uniform Loads

For a uniformly loaded panel with all edges simply supported and for a small deflection, the deflection at the center of the panel is:

$$w = 0.155\, K_1 \frac{pa^4}{E_1 h^3} \tag{6.64}$$

where

K_1 = a constant from Fig. 6-50a

a = the short side of the panel

Other symbols as previously defined.

and the unit load is:

$$p = \frac{w\ E_1 h^3}{0.155\ K_1\ a^4} \tag{6.65}$$

To obtain K_1 from Fig. 6-50a the following constant must be determined:

$$\frac{b}{a}\left[\frac{E_1}{E_2}\right]^{\frac{1}{4}} \tag{6.66}$$

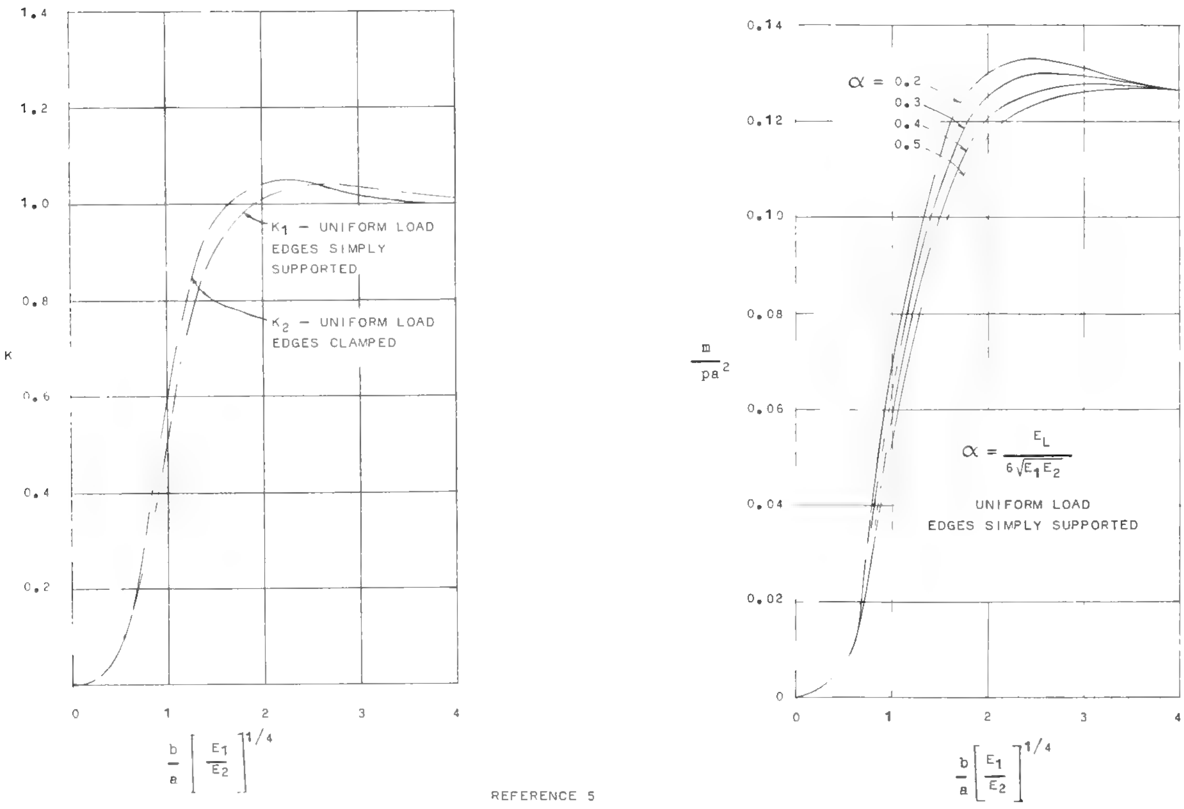
The maximum bending moment at the center of the span is obtained from the graph, Fig. 6-50b:

$$\frac{m}{pa^2} = \text{value from graph} \tag{6.67}$$

and $m = pa^2$ (value from graph)

To obtain the value of $\frac{m}{pa^2}$ above from Fig. 6-50b the constant α must be determined:

$$\alpha = \frac{E_L}{6\sqrt{E_1 E_2}} \tag{6.68}$$



REFERENCE 5

a. CONSTANTS FOR DEFLECTION

b. BENDING MOMENT AT CENTER OF PANEL

Fig. 6-50. Curves of Deflection and Bending Moment Constants for Flat Rectangular Panels - Small Deflections

Case 2. Plates with Clamped Edges Under Uniform Loads

For a uniformly loaded panel with all edges clamped and for a small deflection, the deflection equation is:

$$w = 0.031\ K_2 \frac{pa^4}{E_1 h^3} \qquad (6.69)$$

where K_2 = a constant from Fig. 6-50a similar to K_1, for simply supported plates.

and

$$p = \frac{wE_1h^3}{0.031K_2a^4} \qquad (6.70)$$

To apply the method of analyzing laterally loaded rectangular plates of isotropic materials (19) to fiberglass reinforced laminates, it was necessary to determine additional constants which are given in Tables 6-19 and 6-20. Table 6-19 gives constants for isotropic materials with Poisson's ratios of 0.20, 0.30 and 0.37. These ratio values correspond to the ratio values of cloth and woven roving laminates, steel and mat laminates respectively. For the orthotropic characteristics of cloth and woven roving laminates the constants in Table 6-19 are not directly applicable and the correction factors presented in Table 6-20 must also be applied. In establishing Table 6-20, the warp direction of the reinforcement has been assumed parallel to the short side of the panel. Correction factors for shear force constants have not been determined.

The following equations and Tables 6-19 and 6-20 are applicable only to Case 1 and give approximate values.

Case 1. Simply Supported Plates Under Uniform Loads

Deflection at the center of the panel:

Isotropic		Orthotropic	
$w = \frac{\alpha pa^4}{12EI}$	(6.71)	$w = K_\alpha \times \frac{\alpha pa^4}{12EI}$	(6.71a)
	Unit load:		
$p = \frac{12wEI}{\alpha a^4}$	(6.72)	$p = \frac{12wEI}{K_\alpha \alpha a^4}$	(6.72a)
	Maximum bending moments:		
$m_x = \beta_x pa^2$	(6.73)	$m_x = K_x \beta_x pa^2$	(6.73a)
$m_y = \beta_y pa^2$	(6.74)	$m_y = K_y \beta_y pa^2$	(6.74a)

TABLE 6-19. DEFLECTION, BENDING MOMENT AND SHEAR FORCE CONSTANTS FOR UNIFORMLY LOADED SIMPLY SUPPORTED FLAT RECTANGULAR PANELS OF ISOTROPIC MATERIALS

	Bending Moment $m_{Max} = \beta pa^2$						Deflection at Center of Plate $W_{Max} = \frac{\alpha pa^4}{12 EI}$			Shear Force at Center of Side b $V_{Max} = \delta pa$		
	βx			βy			α			δ		
b/a \ σ	0.20	0.30	0.37	0.20	0.30	0.37	0.20	0.30	0.37	.20	.30	.37
1.0	.044	.048	.051	.044	.048	.051	.0467	.0443	.0420	.431	.420	.412
1.1	.052	.055	.057	.044	.049	.052	.0559	.0530	.0503	.450	.440	.432
1.2	.059	.063	.065	.044	.050	.053	.0650	.0616	.0584	.465	.455	.447
1.3	.066	.069	.071	.044	.050	.054	.0735	.0697	.0661	.477	.468	.461
1.4	.072	.075	.077	.044	.051	.055	.0812	.0770	.0730	.486	.478	.471
1.5	.078	.081	.083	.043	.050	.055	.0889	.0843	.0800	.494	.486	.479
1.6	.083	.086	.088	.042	.049	.055	.0956	.0906	.0859	.498	.491	.485
1.7	.088	.091	.093	.041	.049	.055	.1017	.0964	.0914	.503	.496	.491
1.8	.093	.095	.097	.040	.048	.55	.1073	.1017	.0965	.505	.499	.494
1.9	.097	.099	.101	.038	.047	.54	.1122	.1064	.1009	.508	.502	.498
2.0	.100	.102	.103	.037	.046	.053	.1167	.1106	.1049	.509	.503	.499
2.2	.106	.107	.108	.035	.044	.051	.1242	.1177	.1116	.510	.505	.501
2.4	.110	.111	.112	.033	.043	.050	.1300	.1232	.1169	.510	.506	.503
2.6	.113	.114	.115	.031	.041	.049	.1346	.1276	.1210	.510	.506	.503
2.8	.116	.117	.118	.030	.41	.049	.1381	.1309	.1242	.509	.506	.504
3.0	.118	.119	.120	.029	.040	.048	.1409	.1336	.1267	.507	.505	.504
∞	.125	.125	.125	.025	.038	.046	.1500	.1422	.1349	.500	.500	.500

TABLE 6-20. CORRECTION FACTORS FOR DEFLECTION AND BENDING MOMENT CONSTANTS FOR UNIFORMLY LOADED SIMPLY SUPPORTED FLAT RECTANGULAR PANELS OF ORTHOTROPIC MATERIALS

b/a	10 Oz. Cloth $\frac{E_x}{E_y} = 1.153 \quad \sigma = 0.20$			25-27 Oz. Woven Roving $\frac{E_x}{E_y} = 1.175 \quad \sigma = 0.19$		
	Bending Moment		Deflection	Bending Moment		Deflection
	K_x	K_y	K_α	K_x	K_y	K_α
1.0	1.091	0.955	1.049	1.227	1.045	1.173
1.1	1.119	0.966	1.086	1.236	1.040	1.191
1.2	1.134	0.977	1.100	1.237	1.030	1.199
1.3	1.141	0.977	1.111	1.224	1.015	1.195
1.4	1.141	0.977	1.115	1.208	0.997	1.186
1.5	1.137	0.977	1.112	1.192	0.977	1.175
1.6	1.129	0.976	1.109	1.177	0.955	1.163
1.7	1.120	0.976	1.105	1.162	0.935	1.151
1.8	1.109	0.975	1.099	1.148	0.918	1.139
1.9	1.099	0.974	1.094	1.134	0.914	1.129
2.0	1.091	0.973	1.088	1.121	0.906	1.119
2.2	1.076	0.971	1.077	1.097	0.899	1.099
2.4	1.065	0.970	1.067	1.079	0.902	1.081
2.6	1.054	0.969	1.056	1.065	0.910	1.064
2.8	1.044	0.967	1.045	1.052	0.920	1.049
3.0	1.034	0.966	1.034	1.042	0.931	1.036
∞	1.000	1.000	1.000	1.000	1.000	1.000

Shear force at center of side b:

Isotropic		Orthotropic
$V_{max} = \delta pa$	(6.75)	

where

α = deflection constant (Table 6-19)

β_x and β_y = bending moment constants in X and Y directions (Table 6-19)

δ = shear force constant (Table 6-19)

K_α , K_x and K_y = correction factors for deflection and bending moments in orthotropic plates

Other symbols as previously defined.

DESIGN EXAMPLE 6-26. ULTIMATE UNIFORM LOAD FOR WOVEN ROVING LAMINATE PANEL WITH SIMPLY SUPPORTED AND CLAMPED EDGES

Given a woven roving polyester laminate 12 in. wide by 24 in. long by 1/4 in. thick. Find the ultimate unit load p, bending moment m_x and bending stress f_b for the laminate when simply supported and with clamped edges.

Case 1. Simply Supported Edges

a. Value obtained from Table 6-17

$p = 1.29$ psi

$m_x = 22.00$ in.-lbs. (not given in this text)

$f_b = 2070$ psi

b. Using the orthotropic method (5) for the unit load, p:

$E_1 = E_x = 1.81 \times 10^6$

$E_2 = E_y = 1.54 \times 10^6$

$w = \frac{h}{2} = \frac{0.25}{2} = 0.125$ in. maximum allowable deflection

$$\frac{b}{a}\left[\frac{E_1}{E_2}\right]^{\frac{1}{4}} = \frac{24}{12}\left[\frac{1.81 \times 10^6}{1.54 \times 10^6}\right]^{\frac{1}{4}} = 2 \times 1.04 = 2.08 \qquad (6.66)$$

From Fig. 6-50a, for a $\frac{b}{a}\left[\frac{E_1}{E_2}\right]^{\frac{1}{4}}$ value of 2.08 the value of K_1 is 1.02

$$\text{and } w = \frac{0.155 \times 1.02 \times p \times 12^4}{1.81 \times 10^6 \times 0.25^3} = \frac{0.250}{2} = 0.125 \text{ in.} \qquad (6.64)$$

$$\text{and } p = \frac{0.125 \times 1.81 \times 10^6 \times 0.25^3}{0.155 \times 1.02 \times 12^4} = 1.10 \text{ psi} \qquad (6.65)$$

For the bending moment, m_x: (6.68)

$$\alpha = \frac{E_L}{6\sqrt{E_1E_2}} = \frac{1.81 \times 10^6}{6\sqrt{1.81 \times 10^6 \times 1.54 \times 10^6}} = 0.181$$

From the graph of Fig. 6-50b:

$$\frac{m_x}{pa^2} = 0.1255$$

$$m_x = 0.1255 \times 1.10 \times 12^2 = 19.88 \text{ in.-lbs.} \qquad (6.67)$$

For the bending stress:

Stress due to m_x:

$$f_{bx} = \frac{m_x}{Z} \qquad (6.31)$$

$$Z = \frac{bh^2}{6} = 1 \times \frac{0.25^2}{6} = .0104 \text{ in.}^3 \text{ for a 1 in. unit width} \qquad (6.32)$$

$$f_{bx} = \frac{19.88}{0.0104} = 1912 \text{ psi}$$

c. Using the modified isotropic method for the unit load p:

$\sigma_x = \sigma_y = 0.19$

$E = E_x$; E_x and E_y as previously given

$\frac{b}{a} = \frac{24}{12} = 2.0$

From Table 6-19 for $\sigma = 0.20$:

$$\alpha = 0.1167$$

From Table 6-20 for woven roving:

$$K_\alpha = 1.119$$

and $$p = \frac{12 \times 0.125 \times 1.81 \times 10^6 \times (1 \times 0.25^3)/12}{1.119 \times 0.1167 \times 12^4} = 1.30 \text{ psi} \qquad (6.72a)$$

For the bending moment, m_x

From Table 6-19 for $\sigma = 0.20$, $\beta_x = 0.100$

From Table 6-20 for woven roving, $K_x = 1.121$

and $$m_x = 1.121 \times 0.100 \times 1.30 \times 12^2 = 20.98 \text{ in.-lbs.} \qquad (6.73a)$$

For the bending stress:

Similar to the orthotropic method (5) above; $f_{bx} = 2017$ psi

Summary of results:

	Load Table 6-17	Orthotropic Method (5)	Modified Isotropic Method
p, psi	1.29	1.10	1.30
m_x, in.-lbs.	22.00	19.88	20.98
f_{bx}, psi	2070	1912	2017

The above results are in good agreement and any of the methods of analysis discussed is considered applicable.

Case 2. Clamped Edges

Using the orthotropic method (5):

From Fig. 6-50a, for a value of $\frac{b}{a}\left[\frac{E_1}{E_2}\right]^{\frac{1}{4}} = 2.08$, the value of $K_2 = 1.04$.

and the unit load is:

$$p = \frac{0.125 \times 1.81 \times 10^6 \times 0.25^3}{0.031 \times 1.04 \times 12^4} = 5.30 \text{ psi} \qquad (6.70)$$

Plates with Large Deflections: When the deflection of a laterally loaded plate equals several times its thickness, the formulas developed for plates with small deflections cannot be used. March (18, 20) has developed expressions which can be used to give approximate values for load, deflection, bending stress and direct stress. Only the conditions for a uniformly loaded plate with simply supported and clamped edges are presented in this text. Fig. 6-47 and the symbols previously defined are applicable to this discussion.

Case 1. Simply Supported Plates Under Uniform Loads

For a plate that is uniformly loaded and whose edges are simply supported, the following formulas can be used to determine approximate values of the various factors of the plate:

Maximum bending stress:

$$f_b \cong \frac{\alpha E_x h w}{\lambda a^2} \qquad (6.76)$$

Mean direct stress:

$$f_a = \frac{E_1}{3\lambda}\,\frac{h^2\eta^2}{a^2} \cong \frac{2.572\ E_x w^2}{\lambda a^2} \qquad (6.77)$$

Total maximum stress:

$$f_{total} = f_b + f_a$$

Uniform load:

$$p = \frac{E_x h^4}{a^4}\left[\frac{6.4E_1 w}{\lambda E_x h} + \frac{20.6\ E_a w^3}{\lambda E_x h^3}\right] \qquad (6.78)$$

$$p = \frac{h^3}{\lambda a^4}\left[6.4E_1 w + \frac{20.6\ E_a w^3}{h^2}\right] \qquad (6.78a)$$

where

$$\eta = 2.778\left[\frac{E_a}{E_1}\right]^{\frac{1}{2}}\frac{w}{h} \qquad (6.79)$$

$$\alpha = 4\left[\frac{\frac{1}{\eta^2} \times \frac{\cosh \eta - 1}{\cosh \eta}}{\frac{1}{\eta^2}\left(1 - 2\left\{\frac{\cosh \eta - 1}{\eta^2 \cosh \eta}\right\}\right)}\right] \qquad (6.80)$$

and

E_a = modulus in tension parallel to the x-axis, E_{tx}

E_1 = modulus in bending parallel to the x-axis, E_{bx}

The value of α can be chosen from Fig. 6-51a.

The above expressions are applicable when the ratio $\frac{\beta}{a} = \frac{b}{a}\left[\frac{E_1}{E_2}\right]^{\frac{1}{4}} \geqq 1.75$.

Case 2. Plates with Clamped Edges Under Uniform Load

For a plate with clamped edges and uniformly loaded the following formulas have been derived:

Uniform load:

$$p = \frac{h^3}{\lambda a^4}\left[32\ E_1 w + \frac{23\ E_a w^3}{h^2}\right] \qquad (6.81)$$

Maximum bending stress:

$$f_b = \alpha\,\frac{E_x}{\lambda}\left[\frac{h}{a}\right]^2\frac{w}{h} \cong \frac{E_x h}{\lambda a^2}\left[16\ E_x w + \frac{2.98 E_x E_a w^3}{E_1}\right] \qquad (6.82)$$

Mean direct stress:

$$f_a = \frac{E_1}{3\lambda}\,\frac{h^2}{a^2}\,\eta^2 \qquad (6.83)$$

Total maximum stress:

$$f_{Total} = f_b + f_a$$

$$\text{where } \eta = \frac{w}{h}\left[\frac{E_a}{E_1}\right]^{\frac{1}{2}} \times \frac{1}{0.366} \qquad (6.84)$$

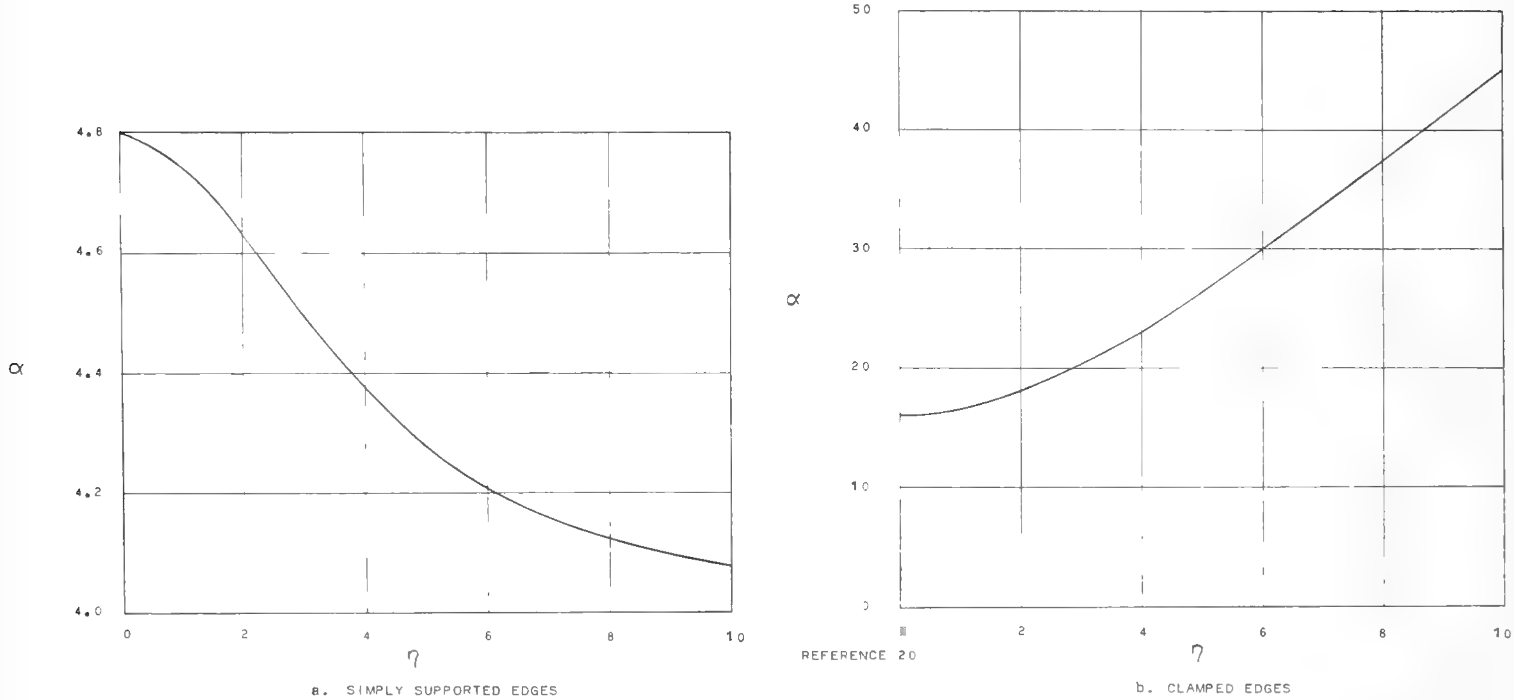
$$\alpha = 4 \left[\frac{\dfrac{\cosh \eta - 1}{\cosh \eta}}{1 - 2 \left(\dfrac{\cosh \eta - 1}{\eta^2 \cosh \eta} \right)} \right] \qquad (6.85)$$

The value of α can be obtained from Fig. 6-51b.

The above expressions are applicable when the ratio of

$$\frac{\beta}{a} = \frac{b}{a} \left[\frac{E_1}{E_2} \right]^{\frac{1}{4}} \geq 1.5.$$

In the solving of problems with the above equations it is suggested that the unit load, p, be known or assumed for a specific laminate and the deflection, w, computed. Knowing w, the values of η and α can be established. Finally the bending and direct stresses can be determined.



a. SIMPLY SUPPORTED EDGES

b. CLAMPED EDGES

Fig. 6-51. Coefficient α as a Function of η for Uniformly Loaded Flat Rectangular Panels

SANDWICH CONSTRUCTION

A structural sandwich may be defined as a combination of strong, high density, thin facings with a relatively weak, low density thick core. The obvious purpose of such an arrangement is to increase the rigidity and strength of a thin plate with a minimum increase in weight.

The theoretical analysis of sandwich construction, particularly sandwich construction with orthotropic materials is a lengthy process and the theory is far from complete. The theoretical analysis which has been done has generally resulted in expressions which are very cumbersome and tedious to evaluate. In addition, some of the necessary elastic properties of the different core materials which vary with density have not been completely established. For these reasons, alternate conservative methods of analysis which sacrifice accuracy for speed and ease in design are generally used and are recommended for most marine applications.

Sandwich construction is generally used for flat or curved panels subject to flexure and edgewise compression.

Flexure

The flexural analysis of sandwich construction includes the determination of the stresses in the facings and core materials and the deflection of the panel. When considering a one-way panel the analysis is similar to the analysis for a one-way composite plate or beam as previously discussed. The flexural properties of some of the core materials, such as foamed plastics or honeycombs are quite low and may be ignored in the analysis. Some core materials such as balsa wood have appreciable flexural moduli of elasticity, particularly when the grain of the wood is parallel to the plane of the panel and may be considered effective.

As an example, consider a 1 in. wide strip of a sandwich panel having a 1 in. thick core of 4 lb. density balsa wood and 1/8 in. thick facings of 10 ounce cloth-polyester laminate. Ignoring the effect of the core, the flexural rigidity of the sandwich from equation 6.16 is, $EI = 0.1270 \times 10^6$ in.-lbs. Including the effect of the balsa core, the flexural rigidity becomes, $EI = 0.1397 \times 10^6$, which is an increase of approximately 10 per cent. When the core is considered effective, the allowable tensile or compressive stress should not be exceeded at the outermost fiber of the core.

Simple One-Way Panels: In the determination of the deflection of one-way sandwich panels, the effect of the shear deformation of the low density core may be appreciable and should be considered. Shear deformation effect has been previously discussed for laminates and beam sections.

As an example of this effect, the approximate deflection of a simple cantilever sandwich beam section with a concentrated load at the unsupported end, Fig. 6-52, has been investigated (12, 21) and the resulting expression in a simplified form is:

$$d = \frac{PL^3}{3EI}\left[1 + \frac{h^2 e}{4L^2}\right] \tag{6.86}$$

$$2e = \frac{E_{xf}}{G_f}\left[2 - 3\left(\frac{c}{h}\right) + \left(\frac{c}{h}\right)^3\right] + \frac{E_{xc}}{G_c}\left[3r\left(\frac{c}{h}\right) - 3r\left(\frac{c}{h}\right)^3 + 2\left(\frac{c}{h}\right)^3\right] \tag{6.87}$$

where $$r = \frac{E_{xf}}{E_{xc}} \tag{6.88}$$

P, EI and G are as previously defined.

Other symbols as indicated in Fig. 6-52.

A comparison of the deflection obtained by this expression and that obtained by various other approximate methods is presented in Design Example 6-27.

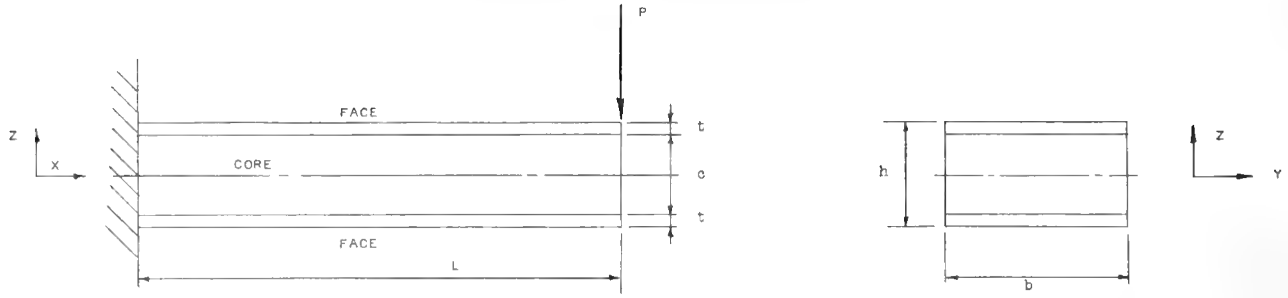


Fig. 6-52. Cantilever Sandwich Beam

DESIGN EXAMPLE 6-27. DEFLECTION OF CANTILEVER SANDWICH BEAM

Consider a 1 in. wide strip of the cantilever sandwich beam as indicated in Fig. 6-52 to have a length of 10 in. and to support a load of 10 lbs. at its free end. The beam is constructed of the materials indicated below. Determine the deflection at the free end.

FACINGS:

10 ounce cloth laminate

Thickness $t = \frac{1}{8}$ in.

$E_{xf} = 1.60 \times 10^6$ psi (Table 5-10)

$G_f = 0.52 \times 10^6$ psi (Table 5-14)

CORE:

Balsa wood - 4 lb. density. Grain direction placed parallel to span of beam.

Thickness, c = 1 in.

$E_{xc} = 0.152 \times 10^6$ psi (Reference 23)

$G_c = 0.008 \times 10^6$ psi (Reference 23)

1. Deflection with equations 6.86 through 6.88 previously discussed.

$$r = \frac{E_{xf}}{E_{xc}} = \frac{1.60 \times 10^6}{0.152 \times 10^6} = 10.53 \qquad (6.88)$$

$$c = 1 \text{ in.}, \ h = 1.25 \text{ in.}, \ \frac{c}{h} = 0.80$$

$$2e = \frac{1.60 \times 10^6}{0.52 \times 10^6}\left[2 - 3\left(0.80 + 0.80\right)^3\right] \qquad (6.87)$$

$$+ \frac{0.152 \times 10^6}{0.008 \times 10^6}\left[3 \times 10.53\left(0.80\right) - 3 \times 10.53\left(0.80\right)^3 + 2\left(0.80\right)^3\right]$$

$$e = 96.36$$

$$EI = \sum E_i I_i = E_{xc}\frac{bc^3}{12} + E_{xf}\left[2 \times \frac{bt^3}{12} + 2 \times bt \times \left(\frac{t + c}{2}\right)^2\right] \qquad (6.16)$$

$$= 0.1397 \times 10^6$$

$$d = \frac{PL^3}{3EI}\left[1 + \frac{h^2 e}{4L^2}\right] = \frac{10 \times 10^3}{3 \times 0.1397 \times 10^6}\left[1 + \frac{1.25^2 \times 96.36}{4 \times 10^2}\right] \qquad (6.86)$$

$$= 0.0329 \text{ in.}$$

2. Deflection due to bending of the facings only, ignoring shear deflection and the effect of the core:

$$E_f I_f = E_{xf}\left[2 \times \frac{bt^3}{12} + 2 \times bt \times \left(\frac{t + c}{2}\right)^2\right] \tag{6.16}$$

$$= 0.1270 \times 10^6$$

$$d = \frac{PL^3}{3E_f I_f} = 0.0262 \text{ in.}$$

This is considerably less than the more accurate method above. (6.89)

3. Deflection due to bending and shear of the facings, ignoring the effect of the core:

$$E_f I_f = 0.1270 \times 10^6$$

$$G_f A_f = 0.52 \times 10^6 \times 2 \times 1 \times .25 = 0.13 \times 10^6$$

$$d = \frac{PL^3}{3E_f I_f} + \frac{PL}{G_f A_f} \tag{6.90}$$

$$= 0.0262 + 0.0008 = 0.0270 \text{ in.}$$

4. Deflection due to bending and shear considering the facings and core acting together:

$$EI = \sum E_i I_i = E_{xc}\frac{bc^3}{12} + E_{xf}\left[2 \times \frac{bt^3}{12} + 2 \times bt \times \left(\frac{t + c}{2}\right)^2\right] \tag{6.16}$$

$$= 0.1397 \times 10^6$$

$$GA = \sum G_i A_i = G_c \times bc + G_f \times 2bt = 0.138 \times 10^6 \tag{6.91}$$

$$d = \frac{PL^3}{3EI} + \frac{PL}{GA} \tag{6.90}$$

$$= .0239 + 0.0007 = .0246 \text{ in.}$$

5. Deflection as the sum of the bending deflection of the facings only and the shear deflection of the core only:

$$E_f I_f = E_{xf}\left[2 \times \frac{bt^3}{12} + 2 \times bt \times \left(\frac{t + c}{2}\right)^2\right] \tag{6.16}$$

$$G_c A_c = G_c bc$$

$$d = \frac{PL^3}{3E_f I_f} + \frac{PL}{G_c A_c} \tag{6.90}$$

$$= 0.0262 + .0125$$

$$= 0.0387 \text{ in.}$$

Alternatively, since the flexural modulus of the balsa wood is large, the bending deflection above may be modified to include its effect. The resulting deflection is then:

$$d = 0.0239 + 0.0125 = 0.0364 \text{ in.}$$

The results of the analysis used in Design Example 6-27 indicate that the simplified analysis, No. 5, which includes the flexural deflection, with or without the core, and the shear deflection of the core only, assuming uniform shear distribution, gives a conservative deflection when compared with the more accurate analysis, No. 1. The difference is approximately 10 per cent for the simplified analysis and is considered acceptable.

Although the comparative analysis has been made for a simple cantilever beam loaded at the end, it is believed that similar comparative deflections will occur for other beam loading and support conditions. Therefore it is recommended that the simplified analysis, No. 5 be used in obtaining an approximate deflection for simple one-way panels. This proposed method is presently used in tests to determine the shear moduli of core materials (22). In this test the core material is combined with very thin faces to minimize their effect on the shear deflection.

The analysis of the flexural stresses in a one-way sandwich panel or beam is similar to the analysis for a composite laminate previously discussed. Design Example 6-28 indicates the procedure used computing the stresses in the various components of a sandwich section.

DESIGN EXAMPLE 6-28. STRESSES IN A CANTILEVER SANDWICH BEAM

For the sandwich beam given in Design Example 6-27, calculate the flexural and shear stresses in the facings and core.

Bending Moment, $M = PL = 100$ in.-lbs.

Shear $V = P = 10$ lbs.

Bending stress at any point, y in the cross-section

$$f_{bi} = \frac{M}{Z} = \frac{MEyy}{EI} \qquad (6.36)$$

where $EI = \sum E_i I_i$ = Stiffness factor of the entire section (6.16)

Tensile or compressive stress in the facings:

$$f_{tf} = f_{cf} = \frac{100 \times 1.60 \times 10^6 \times .625}{0.1397 \times 10^6} = 716 \text{ psi}$$

Tensile or compressive stress in the core:

$$f_{tc} = f_{cc} = \frac{100 \times 0.52 \times 10^6 \times .50}{0.1397 \times 10^6} = 186 \text{ psi}$$

The maximum shear stress is: $f_s = \frac{VQ'}{EIb}$ (6.37)

where V, EI, b and Q' are as previously defined.

Shear stress at the interface between the laminate and the balsa core:

$$f_s = \frac{10 \times 1.60 \times 10^6 \times 1 \times .125 \times .5625}{1 \times 0.1397 \times 10^6}$$

$$= 8.1 \text{ psi}$$

Shear stress at the neutral axis in the balsa core

$$f_s = \frac{10 \times \left[1.60 \times 10^6 \times 1 \times .125 \times .5625 \;+\; 0.52 \times 10^6 \times 1 \times .5 \times .25 \right]}{1 \times 0.1397 \times 10^6}$$

$= 12.71$ psi

As an alternative method, consider all the shear stress carried by the core only. Then the maximum shear stress at the center of the core is:

$$f_s = \frac{3}{2}\frac{V}{b_c t_c} \tag{6.33}$$

$$= \frac{3}{2}\frac{10}{1 \times 1} = 15 \text{ psi}$$

This approximate method gives a conservative estimate of the shear stress and is considered applicable.

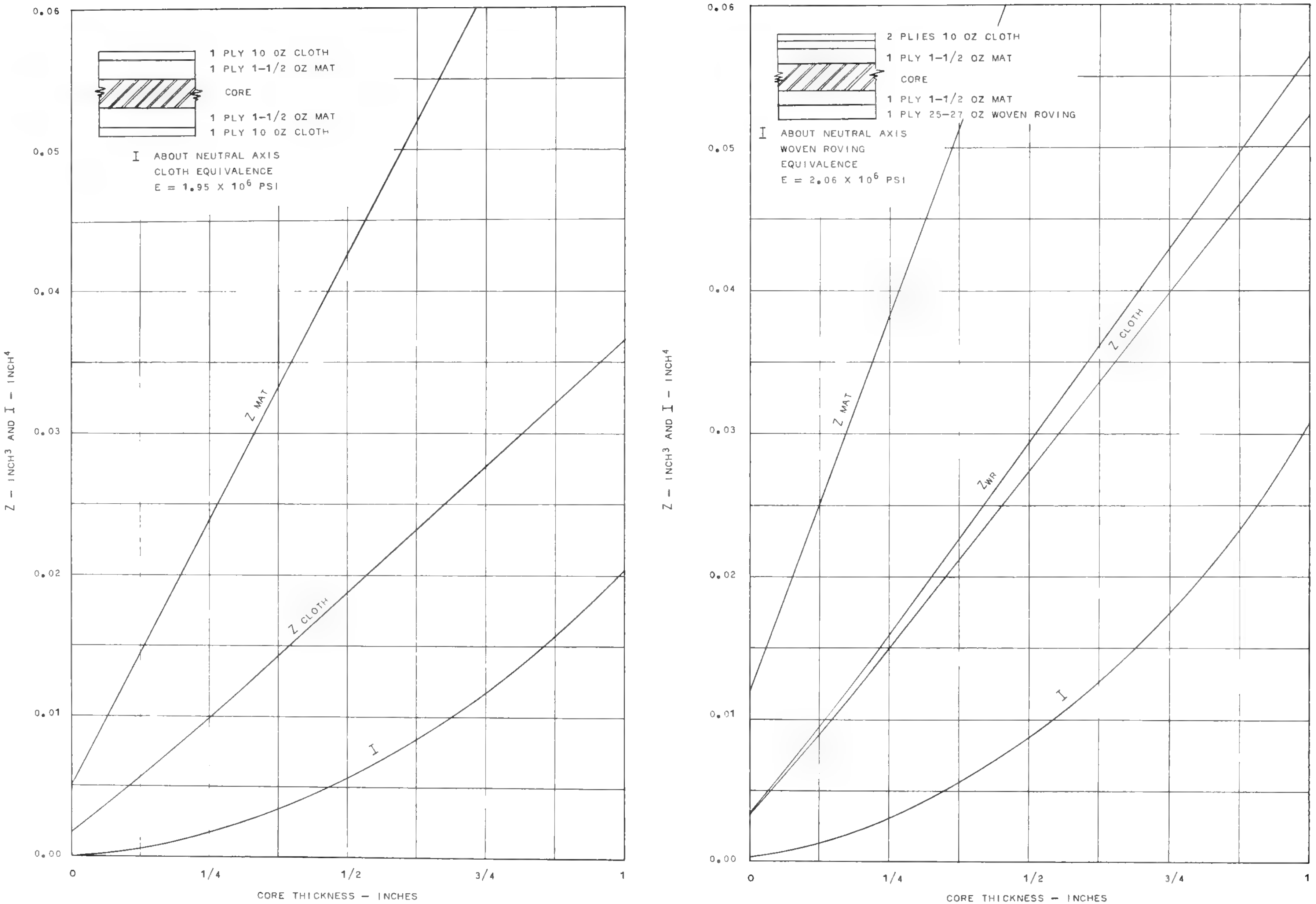
Fig. 6-53 gives the section moduli and moments of inertia about the neutral axis for a 1 in. wide strip for two types of sandwich constructions. In both cases the core is regarded as ineffective in determining the above properties. The section moduli values are corrected to give stress values directly, similar to the values given for the single laminates. The moment of inertia, I, for the Type A sandwich is based on cloth equivalence and may be used with a modulus of elasticity of 1.95×10^6 psi. The moment of inertia, I, for the Type B sandwich is based on woven roving equivalence, and may be used with a modulus of elasticity of 2.06×10^6 psi.

Flat Rectangular Panels: Methods of analysis of laterally loaded sandwich panels have been developed (12, 24), but all conditions of loading and edge supports have not been fully investigated for orthotropic sandwich panels. The behavior of a simply supported uniformly loaded orthotropic sandwich panel (24) is presented since it is applicable to the sandwich panels with cloth and woven roving fiberglass laminate facings presented in Fig. 6-53.

Referring to Fig. 6-47 for flat plates, the lengths of the edges of the panel are denoted as a and b and are parallel to the directions of the x and y axes which are the warp and fill directions of the laminates and core. The formulas given are applicable only to panels with small deflections that do not introduce direct stresses to the panel.

For a uniformly loaded simply supported panel, the deflection at the center of the panel:

$$w = \frac{16}{\pi^6} \times \frac{a^2 b^2 p}{\sqrt{D_x D_y} + \left[K_f + K_m \right]} \tag{6.92}$$



a. TYPE A SANDWICH

b. TYPE B SANDWICH

Fig. 6-53. Sandwich Construction with Fiberglass-Polyester Laminate Faces - Section Modulus, Z, and Moment of Inertia, I for a 1 In. Wide Strip - Core Considered Ineffective and the bending moments at the center of the panel for a 1 in. strip are:

$$M_x = \frac{16}{\pi^4} pa^2 \frac{B_1 + \left(B_2 - 2B_3\right)\frac{a^2}{b^2} + V_x B_3 \frac{a^2}{b^2}\left[\left(B_2 - 2B_3\right)\frac{a^2}{b^2} - B_1\right]}{B_1 + 2B_2 \frac{a^2}{b^2} + \frac{a^4}{B_1 b^4}}$$

$$\frac{+ V_y \left[B_1 B_3 + \left(1 - B^2{}_2 + 3B_2B_3 - 2B^2{}_3\right)\frac{a^2}{b^2}\right]}{+ \left(V_y + V_x \frac{a^2}{b^2}\right)\left[\left(1 - B_2{}^2\right)\frac{a^2}{b^2} + B_3\left(B_1 + 2B_2 \frac{a^2}{b^2} + \frac{a^4}{B_1 b^4}\right)\right]} \qquad (6.93)$$

$$M_y = \frac{16}{\pi^4} pa^2 \frac{B_2 - 2B_3 + \frac{a^2}{B_1 b_2} + V_x \frac{a^2}{b^2}\left[\frac{B_3}{B_1}\frac{a^2}{b^2} + 1 - B_2{}^2 + 3B_2B_3 - 2B_3{}^2\right]}{B_1 + 2B_2 \frac{a^2}{b^2} + \frac{a^4}{B_1 b^4}}$$

$$\frac{+ V_y B_3 \left[B_2 - 2B_3 + \frac{a^2}{B_1 b^2}\right]}{+ \left(V_y + V_x \frac{a^2}{b^2}\right)\left[\left(1 - B_2{}^2\right)\frac{a^2}{b^2} + B_3\left(B_1 + 2B_2 \frac{a^2}{b^2} + \frac{a^4}{B_1 b^4}\right)\right]} \qquad (6.94)$$

Where:

$$D_x = \frac{E_{xf}}{12\lambda_f}\left[h^3 - \rho_x c^3 - \frac{3\rho_x c^3 \left(t_1 - t_2\right)^2}{1 - \rho_y \frac{c}{h}}\right]$$

$$\lambda_f = 1 - \sigma_{xyf} \quad \sigma_{yxf}$$

$$\lambda_c = 1 - \sigma_{xyc} \quad \sigma_{yxc}$$

$$\rho_x = 1 - \frac{E_{xc}\lambda_f}{E_{xf}\lambda_c}$$

$$D_y = \frac{E_{yf}}{12\lambda_f}\left[h^3 - \rho_y c^3 - \frac{3\rho_y c \left(t_1 - t_2\right)^2}{1 - \rho_y \frac{c}{h}}\right]$$

$$\rho_y = 1 - \frac{E_{yc}\lambda_f}{E_{yf}\lambda_c}$$

$$D_{xy} = \frac{G_{xyf}}{12}\left(h^3 - c^3\right)$$

$$U_{xz} = cG_{xyc}$$

$$U_{yz} = cG_{yxc}$$

$$K_f = \frac{E_{xf}}{\lambda_f} \frac{t_1^3 + t_2^3}{12\sqrt{D_x D_y}} \left[B_1 C_1 + 2B_2 C_2 + \frac{C_3}{B_1} \right]$$

$$K_m = \frac{B_1 C_1 + 2B_2 C_2 + \frac{B_3}{B_1} + A\left[\frac{V_x}{C_4} + V_y\right]}{1 + \left[B_1 C_1 + B_3 C_2\right]\frac{V_x}{C_4} + \left[\frac{C_3}{B_1} + B_3 C_2\right] V_y + \frac{V_x V_y}{C_4} A}$$

Values of K_f and K_m above are applicable for deflection when $n = 1$ and the length to width ratio:

$$\frac{b}{a}\left[\frac{D_x}{D_y}\right]^{\frac{1}{4}}$$

is within a range of 0.71 to 1.4.

Also when the core is considered effective, $K_f = 0$

$$V_x = \frac{\pi^2}{a^2} \frac{\sqrt{D_x D_y}}{U_{xz}}$$

$$V_y = \frac{\pi^2}{a^2} \frac{\sqrt{D_x D_y}}{U_{yz}}$$

$$B_1 = \sqrt{\frac{D_x}{D_y}}$$

$$B_2 = \frac{D_x \sigma_{yxf} + 2D_{xy}}{\sqrt{D_x D_y}}$$

$$B_3 = \frac{D_{xy}}{\sqrt{D_x D_y}}$$

$$C_1 = C_4 = \frac{b^2}{n^2 a^2}; \quad C_2 = 1; \quad C_3 = \frac{n^2 a^2}{b^2}$$

where n = number of half-waves and equal to 1 in the equations for K_f and K_m above.

$$A = C_1 C_3 - B_2^2 C_2^2 + B_3 C_2 \left(B_1 C_1 + 2B_2 C_2 + \frac{C_3}{B_1}\right)$$

These equations have been applied to a sandwich panel in order to compare the results with those obtained by simpler methods. The panel was taken as 24 in. by 24 in., composed of a 1 in. thick core, and 1/8 in. thick facings. The facings were considered to be of 10 ounce fiberglass cloth-polyester laminate. Two different core materials were evaluated; balsa wood of 4 lbs. per cu. ft. density and an isotropic low modulus material similar to a foamed resin. The material properties assumed are given below:

Facings - 10 ounce cloth - polyester laminate

$E_{xf} = 1.60 \times 10^6$ psi (Table 5-10)

$E_{yf} = 1.52 \times 10^6$ psi

$\sigma_{xyf} = 0.20$ (Average of Tables 5-8 and 5-12)

$\sigma_{yxf} = 0.20$

$G_{xyf} = 0.52 \times 10^6$ psi (Table 5-14)

Core - 4 lb. density balsa (Reference 23)

$E_{xc} = 0.152 \times 10^6$ psi

$E_{yc} = 0.0023 \times 10^6$ psi

$\sigma_{xyc} = 0.488$

$\sigma_{yxc} = 0.009$

$G_{xyc} = 0.008 \times 10^6$ psi

Core - low modulus isotropic (Reference 23)

$E_{xc} = E_{yc} = 0.005 \times 10^6$ psi

$\sigma_{xyc} = \sigma_{yxc} = 0.20$

$G_c = 0.002 \times 10^6$ psi

Two alternative methods of analysis have been evaluated; the first considering the facings only effective and using the usual panel formula corrected for orthotropicity of the facing, Tables 6-19 and 6-20, the second considering a 1 in. wide strip of the panel as a beam in accordance with the simplified method of analysis (No. 5) previously discussed.

The results of the investigation of the deflection and the bending moments are summarized below.

Summary of Panel Deflections

Method of Analysis	Deflection	
	Balsa Core	Foamed Plastic Core
Exact	0.0033 in.	0.0038 in.
Normal Panel Formulas	0.00102 in.	0.00102 in.
Simple Beam	0.0043 in.	0.0048 in.

Summary of Panel Bending Moments

Method of Analysis	Bending Moment			
	Balsa Core		Foamed Plastic Core	
	M_x	M_y	M_x	M_y
Exact	5.24 in.-lbs.	2.31 in.-lbs.	4.27 in.-lbs.	4.06 in.-lbs.
Normal Panel Formulas	2.76 in.-lbs.	2.62 in.-lbs.	2.76 in.-lbs.	2.62 in.-lbs.
Simple Beam	7.20 in.-lbs.	7.20 in.-lbs.	7.20 in.-lbs.	7.20 in.-lbs.

A study of the summary indicates that the use of normal plate panel formulas for sandwich panels results in non-conservative values for both deflection and bending moment. This is due to the effect of the very low shear moduli of the core materials. It is interesting to note the effect of core orthotropicity on the bending moment as evidenced by the balsa wood. The use of the simplified method of analysis gives conservative results and can be used in lieu of the exact method which is cumbersome and tedious to evaluate.

Edgewise Compression

Sandwich panels loaded in edgewise compression may fail in one of two ways; by instability of the facings and by column instability of the entire sandwich as a unit. The critical stress for a particular sandwich section is the lower of the two stresses.

The critical facing buckling stress, below which rippling of the facing will not occur, may be conservatively predicted from the formula (13, 25).

$$F_{cr} = \frac{1}{2}\sqrt[3]{E_f E_{zc} G_{xzc}} \qquad (6.95)$$

where: E_f is the flexural modulus of the facing material in the direction of load.

E_{zc} is the tensile or compressive modulus of the core material in the direction perpendicular to the plane of the sandwich.

G_{xzc} is the shear rigidity of the core material associated with the direction of the load and the perpendicular to the plane of the sandwich.

The critical facing buckling stress for buckling of the panel as a unit is given by (24, 26):

$$F_{yfcr} = E_{yf}\left[\frac{\pi^2\sqrt{D_x D_y}}{a^2 H_y}\right] K \qquad (6.96)$$

Where the x axis is taken parallel to side a, the y axis parallel to side b, and the load is uniformly distributed along side a.

$$K = K_f + K_m$$

K_f and K_m are obtained from the equations previously given.

$$H_y = E_{yf}\left[h-c\right] + E_{yc}\, C$$

For the case of all edges simply supported the C values used in evaluating K_m and K_f are:

$$C_1 = C_4 = \frac{b^2}{n^2a^2}\,; \quad C_2 = 1; \; C_3 = \frac{n^2a^2}{b^2}$$

In using equation 6.96 it is necessary to use a minimum value for K. This is obtained by substituting n = 1, 2, 3, etc. successively in the formulae for K_f and K_m and determining which value of n produces the minimum K.

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APPENDIX A

TEST PROGRAM FIBERGLASS POLYESTER LAMINATES

TEST PROCEDURES

The following test procedures are modifications of existing procedures or were especially devised for this test program, by the participating laboratories:

Shear Strength - Parallel

The test for shear strength parallel to the laminate was modified from ASTM-D-732 or LP-406-b method 1041.

Strips of the laminate under test were cut to the same width as the laminate's thickness. The samples were then tested in the Johnson Double Shear Jig with the side edge of the laminate up at a position rotated 90 degrees from the test position used for perpendicular shear.

Poisson's Ratio in Compression

The longitudinal and lateral deformation of the compression samples were followed simultaneously by SR4-X extensometers developed by Plastics Research Laboratory, Massachusetts Institute of Technology. The simultaneous data was plotted automatically on an X-Y recorder.

Poisson's Ratio in Tension

The longitudinal deformation of the tensile specimen is recorded by a microformer type extensometer and automatically plotted on a load deflection recorder.

The lateral deformation was followed by an SR-4 extensometer provided by Plastics Research Laboratory, Massachusetts Institute of Technology with the data plotted automatically on a separate load deflection recorder.

Calculation of Compressive and Tensile Poisson's Ratios

The data for lateral deformation was plotted versus the simultaneous longitudinal deformation on rectilinear graph paper. The slope of the plotted graph is equal to Poisson's Ratio.

APPENDIX B

TEST PROGRAM - FIBERGLASS POLYESTER LAMINATES STATISTICAL ANALYSIS OF TEST DATA

By Mr. C. Daniel
Consulting Engineering Statistician

This Appendix is presented for statisticians and gives an explanation of the procedures used in obtaining the results, and a discussion of some of the problems encountered in analyzing the test data.

The following types of laminates were evaluated:

M1 - Mat - 2 ounces per square foot

M2 - Woven Roving - 25-27 ounces per square yard

M3 - Cloth - 10 ounces per square yard

M4 - Mat with 1 ply of 10 ounce cloth on each face

M5 - Woven Roving with 1 ply of 10 ounce cloth on each face

Original Design and its Modifications

The plan first proposed was a Graeco-Latin Cube, sometimes also called a quarter replicate of a 4^4 factorial experiment. The four factors were: Material, Fabricator, Thickness and Testing Laboratory.

To this plan were later added:

Four thicknesses of material M1 to form a sequence of five thicknesses for this material.

16 duplicate panels arranged in a Graeco-Latin square.

Duplicate specimens in every panel for every property.

Discussion of Original Design

The general plan used (quarter replicate of a 4^4) was well adapted to estimate differences among materials, among fabricators, etc. It was not well adapted to measuring the differing variabilities of the several materials.

The testing of duplicate panels was not properly randomized. Thus the use of the panel-to-panel observed variability as a measure of error in the analysis of variance is excluded.

The use of duplicate specimens was largely unnecessary for the estimation of the smallest component of variance. The interactions with angle (within a panel) generally check the specimen standard deviation quite closely with ample degrees of freedom. When the two do not check, the angle interaction estimate is preferable.

Methods of Analysis

Inspection of the data indicated that, with a few obvious and correctible exceptions, the differences among test laboratories were negligible. The balanced part of the data could then be viewed as a full single replicate of a "4^3" experiment, with four materials, four fabricators and four thicknesses. But it was known beforehand that the several types of material would not have the same random variation, nor would they respond in the same way to the several factors.

The five materials used were grouped into three sets. M1 and M4, mat and cloth faced mat were put in one group; M2 and M5, woven roving and cloth faced woven roving, were put in another group; and finally M3, 10 ounce cloth, was put by itself in the third group. The two pairs behaved sufficiently alike to justify this grouping.

Secondly, the largely isotropic M1 and M4 measurements for all three angles were analyzed together. Although M2 and M5 were by no means isotropic, it was possible to analyze the 0 degrees and 90 degrees data together in all cases. For some properties the 45 degrees data could be included in the same analysis.

For M1 and M4, then, we have a split-plot analysis, with angle and its interactions as sub-plot variables. Similarly for M2 and M5. A typical example is given below.

If the error distribution is normal, the cumulative distribution of the specimen ranges should be the "half-normal" distribution. The empirical cumulative distribution (called "ecd" hereafter) should then fit a straight line on a half-normal grid. Such a plot was made for every set of duplicate specimen ranges. In some cases all ranges fell nicely on a straight line. In most cases, however, a small proportion of excessive values, not fitting the pattern set by the rest, was found. The number of such coupon mavericks is shown in the columns headed "c" and in lines "e", in the Table of Standard Deviations, Table B-1. These values were excluded from later analysis. As an example the plot for M1 and M4 tensile strength specimen ranges is shown in Fig. B-1.

A similar half-normal plot was made for the panel ranges in each grouping with similar conclusions. But since there were so few duplicate comparable panels, it is not often possible to speak of the pattern set or of the assured reliability of the corresponding distribution. The results are shown in the columns headed "d" in the Table of Standard Deviations, Table B-1. Fig. B-2 is an example of such an "ecd".

As a numerical example the analysis of tensile strengths for materials M1 and M4 for all three angles is given below.

> First a full MxFxTxA table, with two materials, four fabricators, four thicknesses, three angles and with all subtotals and differences was made up.
>
> From the table above, the analysis of variance, shown in Table B-2 was computed. All computations were written down, and the FxT and MxFxT discrepancies were all computed for inspection. (For several other properties some bad values were discovered from these discrepance tables).
>
> There were clear material and fabricator differences and there was an MxA interaction. The latter was expected, being due to the anisotropy of the M4 cloth faced mat compared to the isotropy of the M1 mat. The conclusions must reflect these differences.

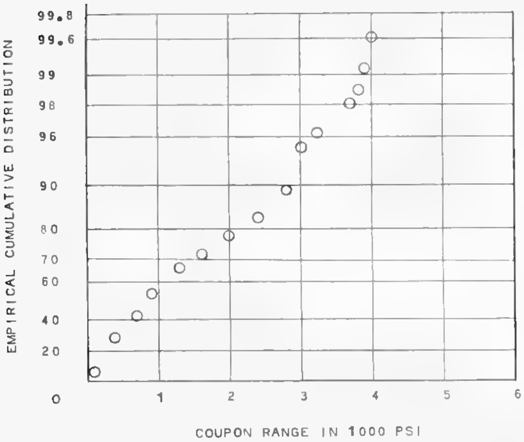

Fig. B-1. Tensile Strength, Coupon Range for Mat (M1) and Cloth Faced Mat (M4) Laminates - All Angles Included

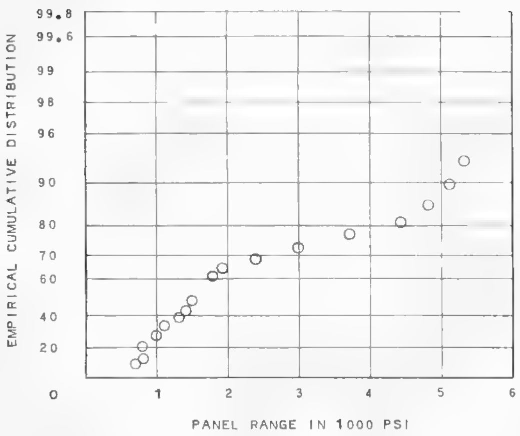

Fig. B-2. Tensile Strength, Panel Ranges for Mat (M1) and Cloth Faced Mat (M4) Laminates - All Angles Included

Thus in the body of this report, different values are shown for the two materials and a different pattern is shown with angle for each material. Finally, the fabricators must be distinguished from each other since one was able to produce material with a 3.6 ksi consistently greater tensile strength than the other three fabricators.

The best estimate we can get of the error standard deviation among panels made at different times will be obtained by pooling mean squares for MF, MT, FT and MFT if these are all of comparable magnitude. Such is the case here. The combined Mean Square, with 24 degrees of freedom, is 10.6. This Mean Square estimates $3\sigma_p^2 + \sigma_A^2 + \sigma_c^2/2$. We take as an estimate of panel variance, then, 10.6/3 or 3.53, remembering that this does include some within-panel variability (in the present case about 0.33 from 0.98/3). The corresponding standard deviation is 1.9.

Having checked on the near normality of the data (by the ecd plots of the specimens, of the panels, and of the discrepancies computed in the analysis of variance) it appeared safe to use published tolerance factors to estimate ranges below means; (called L.T.R. for Lower Tolerance Ranges, in the tables of this report). These values, subtracted from the averages estimated in each cell of the tables, give the Lower Tolerance Limits (L.T.L.) shown. All tolerance limits are computed at the 95 per cent level of confidence. They are also the limits that are expected to be lower than 95 per cent of the population that corresponds. The multipliers used were published by G. Lieberman, in the Journal of Industrial Quality Control for April 1958. For the present example, at 95 per cent confidence, and for 95 per cent coverage, with 24 degrees of freedom, the factor is found to be 2.30 and the lower tolerance range is therefore 2.30 x 1.9 or 4.4.

Similar operations were carried through for fourteen properties and for three groups of materials. With only a few exceptions, the data were readily interpretable. The exceptions were in the data on compressive Poisson's ratio and in some of the per cent water absorption figures. The irregularity of the data on these two properties, at least for some of the materials, greatly diminishes the value of these sets.

TABLE B-1. ESTIMATED STANDARD DEVIATIONS

Property		MATERIALS																
		M1 and M4				M2 and M5							M3					
		0°, 45° & 90°				0° & 90°				45°			0° & 90°				45°	
		c	a	d	p	c	a	d	p	c	d	p	c	a	d	p	d	p
Tensile	s	0.95	0.98	0.80	1.9	1.7	1.7	2.5	1.9	0.82	1.1	1.0	1.0	2.7	1.0	2.2	0.7	1.25
Strength	n	148	48	23	24	72	24	8	21	36	4	32	60	9	8	9	4	9
	e	0	0	5	2	7	0	0	0	0	0	0	4	0	0	0	0	0
Flexural	s	1.85	1.78	1.00	2.88	1.85	2.98	2.50	4.42	1.2	2.50	4.42	2.0	1.8	0.6	2.0	0.6	2.0
Strength	n	108	47	22	24	70	48	12	24	36	12	24	60	30	12	9	12	9
	e	0	0	4	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Compressive	s	1.30	1.33	1.00	3.54	1.2	1.40	1.9	4.36	0.4	0.4	2.33	0.91		1.78	2.0		
Strength	n	170	48	24	24	72	24	8	24	36	4	24	60		18	9		
	e	2	0	2	0	4	0	0	0	1	0	0	4		0	0		
Shear	s	0.40	0.88	0.6	0.82	0.65	0.62	0.3	0.84	0.40			0.24		0.25	1.75		
Strength	n	168	48	24	24	72	48	12	24	36			60		12	9		
Perpendicular	e	3	0	0	0	1	0	2	0	2			0		0	0		
						0°, 45° & 90°							0°, 45° & 90°					
Shear	s	0.60	0.54	0.45	0.89	0.55	0.59	0.35	0.86				0.45	0.71	0.45	0.88		
Strength	n	168	48	21	24	72	48	12	24				60	18	12	9		
Parallel	e	2	0	1	0	1	0	2	0				1	0	2	0		
Tensile	s	0.13	0.13	0.07	0.73	0.15	1	0.22	0.22				0.20		0.17	0.24		
Modulus	n	168	48	24	20	108		12	24				60		12	9		
	e	12	0	3	1	10		0	4				4		2	0		
Flexural	s	0.045	0.065	0.07	0.12	0.10	0.20	0.11	0.26				0.085	0.10	0.08	0.11		
Modulus	n	167	60	22	21	108	48	12	24				60	18	12	9		
	e	7	0	0	0	2	0	1	0				1	0	2	0		
Compressive	s	8	9	8	26	8	14	12	26				6	10	12	9		
Modulus	n	132	34	15	12	79	34	9	17				41	12	2	6		
Per Cent	e	25	0	0	0	6	0	0	0				6	0	1	1		
Tensile	s	10.4	16	7	23	9	44	15	35				9	32	12	120		
Poisson's Ratio	n	168	34	24	24	101	48	12	12				55	30	12	9		
Per Cent	e	8	0	2	0	6	0	0	0				4	0	1	0		
Compressive	s	12	18	4	18	14		8	56							46		
Poisson's Ratio	n	133	40	15	23	59		8	24							10		
Per Cent	e	2	0	0	0	9		1	7							2		
Specific	s	0.006	.009	0.013	0.029	0.013	0.012	0.016	0.05				0.055		0.035	0.05		
Gravity	n	108	48	25	20	108	62	12	23				60		12	15		
	e	3	0	2	2	2	0	0	1				1		2	0		
Per Cent	s	1.0	1.03	1.6	2.4	1.1	0.92	1.0	2.8				0.045	0.46	0.4	0.69		
Glass by	n	168	62	24	21	108	62	12	18				60	30	12	9		
Weight	e	3	0	1	0	1	0	1	0				4	0	0	0		
Per Cent	s	0.6	0.64	1.0	1.8	1.1	0.59	1.3	2.7				0.4	1.02	0.4	0.78		
Glass by	n	168	48	24	24	108	48	12	21				60	18	12	9		
Volume	e	2	0	0	0	1	0	0	0				3	0	0	0		
Per Cent Water	s	6	1	1	21								15			38		
Absorption	n	34			10								32			9		
30 Days	e	0			0								0			0		

s - estimated standard deviation

c - from duplicate coupons

a - from angle-interactions, i. e. within panel

d - from duplicate panels

p - from panel-interactions, after removal of occasional, excessive values

n - number of degrees of freedom for each estimate

e - number of values judged excessive

TABLE B-2. SPECIMEN ANALYSIS OF VARIANCE FOR TENSILE STRENGTH OF MAT (M1) AND CLOTH FACED MAT (M4) LAMINATES; ALL ANGLES INCLUDED

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Expected Values of Mean Squares
Materials (M)	1	34.	34.*	$48\sigma'^2_M + 3\sigma^2_p + \sigma^2_A + \sigma^2_c/2$
Fabricator (F)	3	252.	84.*	$24\sigma'^2_F + 3\sigma^2_p + \sigma^2_A + \sigma^2_c/2$
Thicknesses (T)	3	61.	20.	$24\sigma'^2_T + 3\sigma^2_p + \sigma^2_A + \sigma^2_c/2$
Angles (A)	2	5.	2.5	$32\sigma'^2_A + \sigma^2_A + \sigma^2_c/2$
M x F	3	53.	18.	$12\sigma'^2_{MF} + 3\sigma^2_p + \sigma^2_A + \sigma^2_c/2$
M x T	3	13.	4.	$12\sigma'^2_{MT} + 3\sigma^2_p + \sigma^2_A + \sigma^2_c/2$
M x A	2	63.	32.*	$16\sigma'^2_{MA} + \sigma^2_A + \sigma^2_c/2$
F x T	9	78.	8.6	$6\sigma'^2_{FT} + 3\sigma^2_p + \sigma^2_A + \sigma^2_c/2$
F x A	6	4.	1.	$8\sigma'^2_{FA} + \sigma^2_A + \sigma^2_c/2$
T x A	6	4.	1	$8\sigma'^2_{TA} + \sigma^2_A + \sigma^2_c/2$
M x F x T	9	110.	12.2	$3\sigma'^2_{MFT} + 3\sigma^2_p + \sigma^2_A + \sigma^2_c/2$
Residual	48	47.	0.98	$\sigma^2_A + \sigma^2_c/2$
Total	95	724.		

* All angles

Discussion of Method of Analysis

Omission of some valid data: Only the balanced data ignoring test laboratories was included in the analyses variance. A more ambitious program might have tried to use standard least-squares methods (multiple regression, including all two-factor interactions) on the complete and unbalanced set of data. However the considerable number of bad values turned up in the balanced analyses warns that mere insistence on including all data does not in itself guarantee greater validity. Since the spotting of bad values is much more difficult in unbalanced data, it is not considered likely that much information was lost by omitting the panels that were added later to the balanced plan. (These were the four panels of M1 added to form a complete sequence of thicknesses, and the sixteen panels added for "duplicates"). These omitted data were not entirely wasted, since the computed Lower Tolerance Limits were compared with the lowest values in all the relevant data. In most cases no values lay below the computed L.T.L. In some cases several values lay below, usually coming from related panels. These values were judged bad, and therefore rejected.

Rejection of some duplicate data: Certain pieces of data were rejected on the grounds that they did not fit the pattern clearly formed by the remaining pieces. This practice, while it gave neater conclusions, is especially questionable since judgments on future variability are to be made. Unless enough data is taken in future qualifying tests by fabricators, so that similar rejection of out-of-pattern pieces can be made, then even wider limits of tolerance will have to be used. Less than ten panels of each type and thickness of material from a new and untried fabricator should not be considered. Schedules for producing such test panels should be prepared with statistical caution.

Omission of test laboratories as a factor: Except for a mistake in one test laboratory's measurements of specific gravity, no serious differences among laboratories were noted. However a full analysis including test laboratories was not made. If there were any serious laboratory differences, they would show in the analyses of variance made as MFT interactions. Whenever MFT appeared larger than MF, MT or FT, a search was made to see if the larger discrepancies were attributable to systematic laboratory differences. No such attributions were made. There is of course always the chance that MFT was in fact inflated by its confounding with the laboratories and that at the same time MF, MT and FT were large for other reasons. If this unfortunate combination of circumstances was obtained in any case, we would miss all four, and would report a gross over-estimate of the panel error.

Inappropriateness of Lieberman's Tolerance Limit Table: This table is exact when the error distribution is normal, and when a simple mean value and its associated standard deviation are to be used. This case is different since we usually have a mean value established by a regression-equation, but with variance a known multiple of the error variance. Professor Henry Scheffe has worked out the exact distribution required. It turns out to be a case of the "non-central t-distribution." Because of the spotty tabulation of this distribution in the literature, two checks of the exact distribution were made and compared with the values corresponding from Liebermans' Table. The differences were negligible and so the easier tabulation was used in all other cases.

Conclusions

One of the commonest conclusions from a large statistical study is that a great deal of care must be used in planning future extensions. This conclusion holds here. Much has been learned about the systematic differences among fabricators and among materials. Much more needs to be learned about the cause and cure of the random variability of the materials, especially among duplicate panels produced by the same fabricator.

Considering the clear evidence presented by these data of systematic and important differences between fabricators all of whom are experienced in handling these materials, it will be important to develop qualifying tests for fabricators. If this is not done, the fabricators with better panels will be discriminated against.

Index

23175