TITANIUM SPHERE FOR ALVIN/AUTEC PRESSURE CAPSULE DESIGN CONSIDERATIONS.

by

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PRESSURE CAPSULE DESIGN CONSIDERATIONS

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(Encl (3) to ...)

ABSTRACT

In keeping with the general Deep Ocean Technology program objective of "developing the broad technological base", structural design considerations for replacing the existing HY-100 steel ALVIN/AUTEC pressure sphere with a titanium sphere are investigated. It is concluded that an 18,000 ft collapse depth and a 2000 pound payload increase is attainable utilizing 1.81 in thick, 100,000 psi yield strength titanium. Further cyclic, creep, and collapse tests of a second full scale sphere is required. The approximate cost of the structural phase of such a program is $969,000.

I. INTRODUCTION

Increasing the payload of ALVIN by approximately 2400 pounds would provide additional flexibility and utility in oceanographic operations. Accordingly, a proposal has been made to replace ALVIN's existing HY-100 pressure sphere with a titanium sphere. On 5 April 1968 a conference was held to discuss the ramifications of such a change, and as a result of this conference three ad-hoc groups were formed to prepare preliminary studies on certain aspects of the change - Titanium Alloy Selection, Vehicle Changes, and Pressure Capsule Design Considerations. It was requested that these studies be available within two weeks, (19 April 1968), so that they could be discussed in detail at the next ALVIN conference on 26 April 1968.

The results of the design consideration studies are presented herein. In order to ensure relevancy, the object of this study was defined by the contributing group as follows:

> To determine the feasibility of attaining an 18,000 ft collapse depth with a minimum increase of payload of 2000 pounds, for a Titanium sphere that would be compatible with ALVIN.

Members of the group contributing to this study were Mr. T. Kiernan (NSRDC), Mr. A. Sharp (WHOI), Mr. W. Ferrara (NAVSEC) and Mr. P. M. Palermo (NAVSEC).

GENERAL

Some of the more obvious advantages of replacing the existing HY-100 sphere with a Titanium sphere are:-

1. Increased payload for ALVIN for present operating depth of 6000 ft.
2. Ability to double the existing operating depth yet still increase payload over present system.
3. Opportunity to evaluate a large titanium structure in the deep ocean environment.
4. Opportunity to provide a "first-generation" test bed vehicle for possible D.O.T. applications.
5. Opportunity to provide DSSP with a first look at a manned Titanium structure in the environment, for possible DSSV applications.
6. Opportunity to systematically develop and evaluate the techniques/methodologies for certifying a category 2 or 3 material for deep submergence applications.

In order to exploit all of the possible advantages accruing from the replacement of the existing HY-100 sphere with a titanium sphere, two major structural change/alterations were considered desirable:-

- increased hull thickness from existing 1.33 in to approximately 1.75 in.
- increased forward viewing capacity - to permit the scientist/observer as well as the pilot to see forward.

The structural feasibility of the change to titanium and the two other changes mentioned above will be considered in the following paragraphs.

BASIC HULL STRENGTH

Considerable research on the strength of spherical shells has been conducted at the Naval Ship Research and Development Center (NSRDC). The culumination of this work has been the development of analysis for the prediction of the basic hull strength based upon the local geometry across a critical arc length. The development and verification of the NSRDC technique has been well documented in the open literature and will not be discussed herein. Suffice it to say that semi-empirical equations were developed for the elastic (P_3) and inelastic (P_E) buckling pressure of initially imperfect spheres, by taking advantage of the NSRDC finding that since collapse of a near perfect sphere is primarily a local phenomenon, slightly imperfect spheres can be treated by considering the local geometry over a critical arc length.

$$P_3' = 0.84\,E\left(\frac{h_a}{R_{10}}\right)^2$$

$$P_E' = 0.84\left[E_S E_T\right]^{1/2}\left(\frac{h_a}{R_{10}}\right)^2$$

$$\sigma_{AVG}' = \frac{P}{2}\,\frac{(R_{10})^2}{h_a R_1}$$

where

E is Youngs Modulus with subscripts s and t denoting secant and tangent,

ha is average thickness over a critical arc length

R_1 is local radius to midplane of the shell over a critical arc length,

and R_{10} is local radius to outside of the shell over a critical arc length.

The critical arc length (l_a) based on nominal geometrics is defined as

$$l_a = \frac{2.2\,[Rh]^{1/2}}{\left[0.75(1-\nu^2)\right]^{3/4}}$$

Taking advantage of the mass of experimental data available at NSRDC, curves were developed relating the ratio of P_G'/P_E' to P_{EXP}/P_E', for machined, stress-relived, and as fabricated hemispheres. With these curves available, it is possible to develop prediction type curves by first assuming collapse depths and thicknesses - thus solving for allowable deviations in sphericity, (Δ), this can then be plotted as a family of curves relating thickness or weight-to-displacement ratio (W/D) to Δ. By cross plotting from this family of curves it is possible to develop curves relating collapse depth to W/D ratio for a given or assumed Δ.

This same procedure was utilized herein for studying ALVIN. Fig 1 shows the empirical reduction factor curve based on HY-130 - HY-150 steels. (Strain hardening materials). The curves shown are the lower bound envelopes of experimental results from machined, stress relieved and non stress relieved models. It should be noted that the non stress relieved models were fabricated from pressed petals thus they contain a considerable number of seam welds and large areas of residual welding stresses. In Figures 2 and 3, are presented typical stress strain curves and plasticity factor curves, for titanium. Utilizing the curves of Figures 1, 2, and 3 the curve of Figures 4 can be developed (as described above) which relate Δ to W/D ratio for given collapse depths. Figure 4 is only one of a number of such curves that were developed for different collapse depth. Finally the curves of Figure 5 were developed by cross plotting from the curve of Figure 4, and the other similar curves for other collapse depths.

Since the ALVIN hull contains a single equatorial seam weld, as well as welds for the four view ports and hatch and since the hull will be hot formed in two hemispherical pieces, the as-fabricated hull should perform at least as well at the other as-fabricated hemispheres, and probably as well as the stress relieved hemispheres of Figure 1. Further it is possible, depending upon the titanium alloy selected, etc, that the hull will be stress relieved.

Thus the best engineering judgment of the strength of the Titanium hull for ALVIN, is that the failure should be defined somewhere between the limits of the stress relieved and the machined curve. (Fig 5). Further Figure 5 is based on an assumed Δ of 1/8 in. which is probably a conservative value. However, it was selected because it is felt that the distortions due to welding the titanium sphere will be greater than the measured distortions obtained from welded HY-100 spheres. Accordingly it is felt that the following minimum collapse pressures and W/D ratios should be attainable*:

Yield Strength psi	Collapse Depth Ft.	W/D-basic	W/D-corrected	Payload increase lbs
100,000	18,000	0.550	0.605	1975
110,000	18,000	0.524	0.576	2300
120,000	18,000	0.502	0.552	2550

*It should be noted that a similar technique was used to predict the collapse depth for the HY-100 ALVIN sphere. A depth of approximately 16,000 ft. was predicted based on a maximum measured Δ of 0.050 in.

Start

The basic W/D ratio is for the basic hull without penetrations. For the existing HY-100 ALVIN sphere, the inserts for the penetrations increased the basic W/D ratio by approximately 11 percent. Accordingly, the corrected W/D ratio shown above reflects a 11 percent increase on the basic W/D ratio. It is noted that optimization of the hull inserts will probably result in a slightly lighter structure than shown.

The predictions shown above indicate that from a structural standpoint it is possible to attain an 18,000 ft collapse depth with a payload increase within the general range of interest. Further, since the physical size of the hull (6'-10" O.D) and the predicted collapse depth are within the capabilities of existing facilities, verification of the predicted collapse depth for the Titanium sphere will be obtained from collapse tests of a full scale hull. Additional verification of the adequacy of the prediction curves will be obtained from tests of three titanium sphere models currently under construction, scheduled for testing in FY69.

RELIABILITY/SAFETY

The present HY-100 pressure capsule for ALVIN has a predicted collapse depth of approximately 16,000 ft. The HY-100 steel pressure hull material has been widely used in marine structures (including structural models with yield strengths in excess of 90,000 psi) and can be considered as a reliable well documented material. Thus for a given collapse depth, a deeper operating dpeth can be justified for the HY-100 sphere. Conversely a minimum of experimental data exists on the collapse strength of spherical titanium hulls. Thus prudence would require a more conservative approach in establishing an operating depth (based on collapse tests) for the titanium. The existing certification specifications require a minimum factor of 1.5 on collapse over operating depth - thus for the titanium sphere a factor somewhat greater than 1.5 seems desirable at this time. In this regard a goal of 18,000 ft as the collapse depth is feasible and should as a minimum permit operations to a depth of 9,000 ft. When more extensive operational and test data are generated and the degree of confidence in the titanium is increased, an increase of the operating depth can be considered.

VIEWING/VIEWPORT IMPROVEMENTS

There are a number of alternatives available concerning the viewport structure:-

1. Duplicate the existing viewport hull inserts for four windows
2. Optimize the viewport hull inserts for four windows
3. Provide two forward looking viewports, side by side, by decreasing the size of and moving laterally the existing forward looking viewport, optimize the remaining three window inserts
4. Optimize the viewport hull inserts for four windows, but utilize two of the electrical penetrations at the forward window as peep-holes with associated optical system for viewing, and growth possibility to utilize fiber optics in the future.

The two week time frame allowed for preparation of this report was not sufficient to permit structural analysis of the inserts in way of the viewports. However, based on past experience, optimization of the existing inserts is feasible and should be the minimum that is done. It is further recommended that the peep-hole with associated optics/fiber optics be installed in the new pressure hull. yes

Consideration must be given to the viewport materials and shape if deeper operating depths are contemplated for the rebuilt ALVIN. Cyclic,

impact and collapse studies are currently underway, under other programs, to assess window configurations (internal diameter to thickness ratios) for various operating depths. The results of these studies will be used as the bases for evaluating and/or redesigning the windows.

OTHER STRUCTURAL CHANGES

The insert at the access hatch can be optimized by utilizing the same procedure as developed for the view port inserts. The NSRDC has programmed Gifford's finite element analysis for these inserts. Unfortunately this analysis requires about one week set-up time for dividing the insert into the necessary elements, obtaining coordinates for the elements, etc, prior to solving the problem on the computer. However, when the Titanium sphere project is officially initiated this computer program will be utilized for optimization of all hull inserts.

Electrical penetrator fittings compatable with the AUTEC vehicle will be utilized. This entails providing opening for 23 fittings rather than the 12 now on ALVIN. This does not include, at this time, any necessary structural changes to the penetrators themselves to account for thicker inserts, deeper operating depths, etc.

Preliminary investigations indicate that the added deflections attendant with the use of titanium in the pressure sphere should not cause binding of the release mechanism. However some redesign may be necessary in the area of the penetration for the release mechanism shaft.

Check
put in
program
plan for
NSRDC hull Tests

Compatible materials
strength

deflection roughly 3 times
as much

TEST PROGRAM

It is conjectural whether the titanium alloy selected for ALVIN will be classed as a Category 2 or a Category 3 Material as specified by NAVSHIPS 0900-028-2010 (1 July 1967). Regardless of the category specified a model test to destruction is necessary, and the larger the model the more detailed the evaluation. Thus a full scale model would be highly desirable. Further a full scale model would partially satisfy the structural testing requirements of a Category 3 material. Therefore it is recommended that a full scale model be tested to destruction. (Existing test facilities are adequate for this test). Two prototype hulls should be constructed and the one with the worst dimensional tolerances (out-of sphericity, etc) should be selected for test. The results of this test should provide a minimum collapse pressure for the remaining sphere, and should also verify the design criteria. In addition to the collapse tests on the sphere, a proof test on the remaining sphere would also be required.

The preliminary tests program as presently envisioned would include cyclic, creep and hydrostatic collapse tests of the one pressure sphere, and a proof test to approximately 1.1 times the operating depth of the remaining sphere. A detailed test program will be developed at a future date.

COST ESTIMATE

The total cost estimate for building, testing and certifying a Titanium pressure sphere for ALVIN is approximately 1.8 million dollars. ?
This value was arrived at as follows:

Material (2 - spheres)	24,000 lbs at $6/lb.	144,000
Fabrication (2 spheres)	14,000 lbs at $50/lb	700,000
Instr, Test, Analysis, Report (Spheres)		125,000 ?
		$969,000

CONCLUSIONS

1. An 18,000 ft collapse depth with a minimum of 1975 pound payload increase is possible for a titanium sphere of the same outside dimensions as ALVIN. The following basic thicknesses are required for the yield strengths shown:

   a. 100,000 psi yield - 1.81 inches

   b. 110,000 psi yield - 1.72 inches

   c. 120,000 psi yield - 1.65 inches

2. The inserts for the view ports and hatch can be optimized from the existing for a further slight weight saving.

3. Additional forward viewing capabilities can be accommodated.

4. Additional electrical penetrators to be compatible with the AUTEC vehicles can be accommodated.

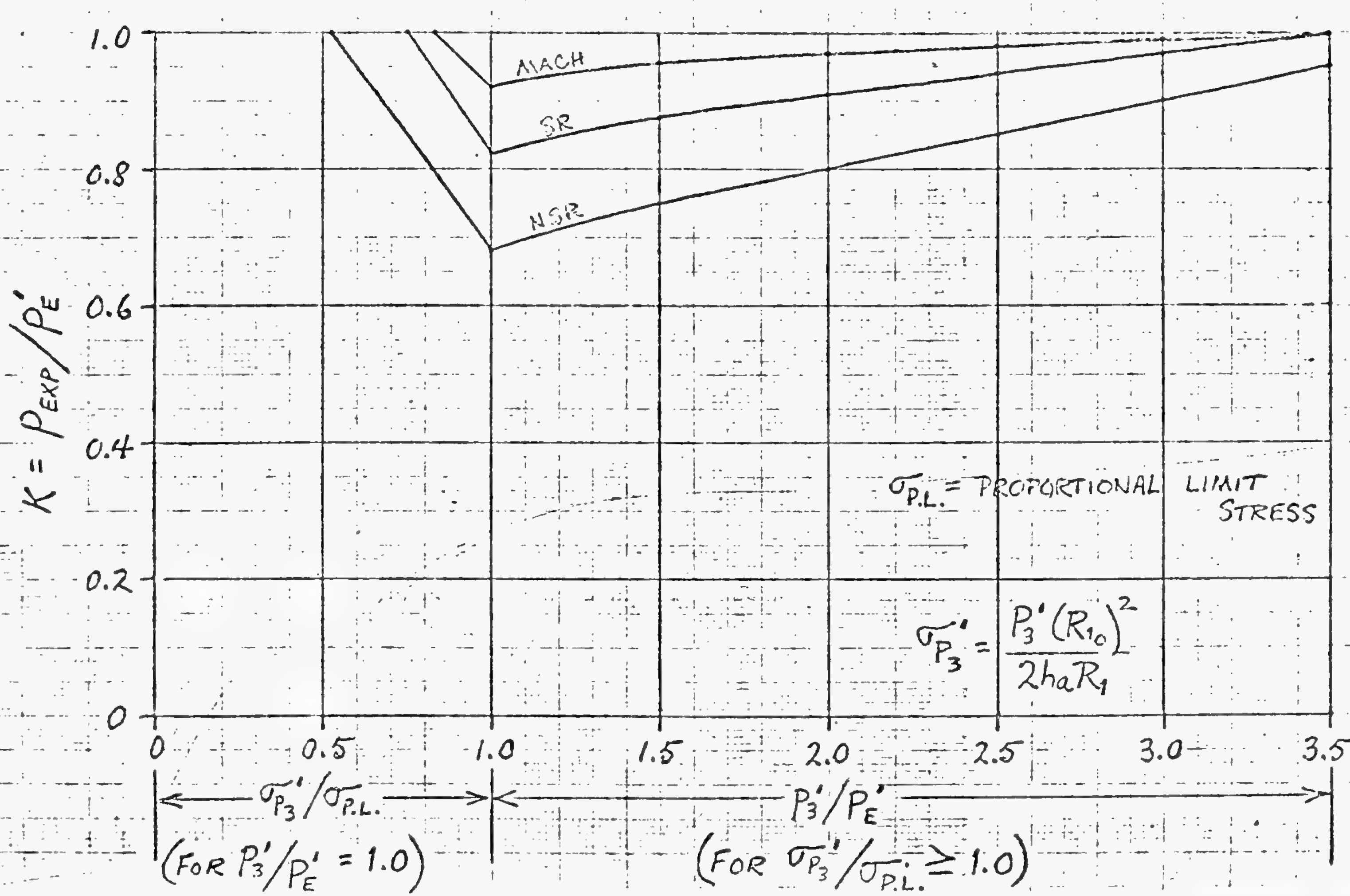
5. Binding of the hull release mechanism is not considered a problem.

6. Two prototype hulls should be constructed - one for cyclic, creep and collapse tests; the other for use in ALVIN/AUTEC.

RECOMMENDATION

In keeping with the Deep Ocean Technology program objective of "....developing the broad technological base...." A titanium sphere for ALVIN/AUTEC should be built and evaluated in the ocean environment. However it is essential that a duplicate full scale sphere be subjected to cyclic, creep, and collapse tests. These recommendations are based on structural design considerations only.

EXPERIMENTAL REDUCTION FACTOR CURVES
(HY 130-150 STEEL SPHERE SPECIMENS)



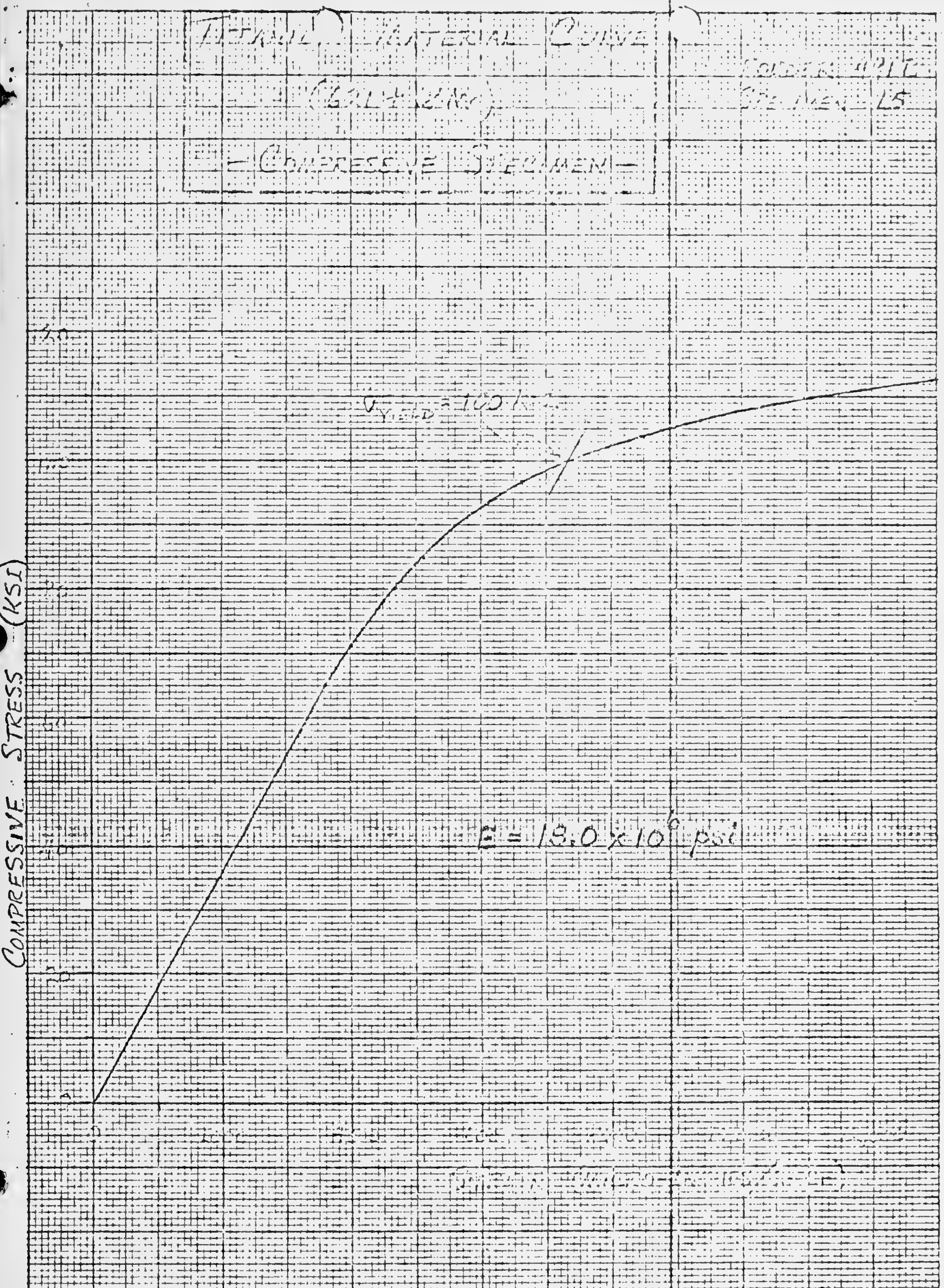

MATERIAL CURVE
- COMPRESSIVE SPECIMEN -
COMPRESSIVE STRESS (KSI)
E = 13.0 x 10^6 psi

FIGURE 2

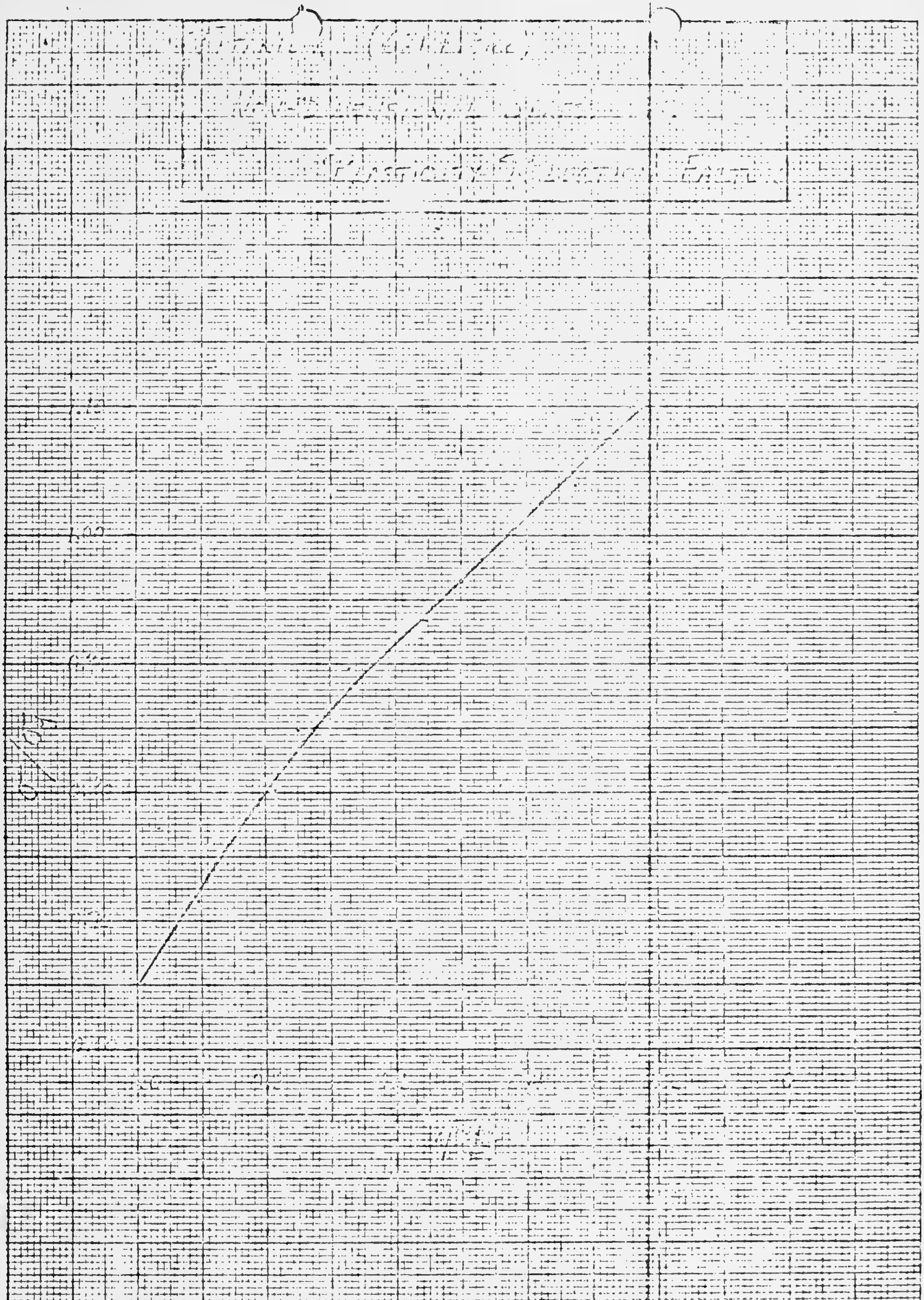


FIGURE 3

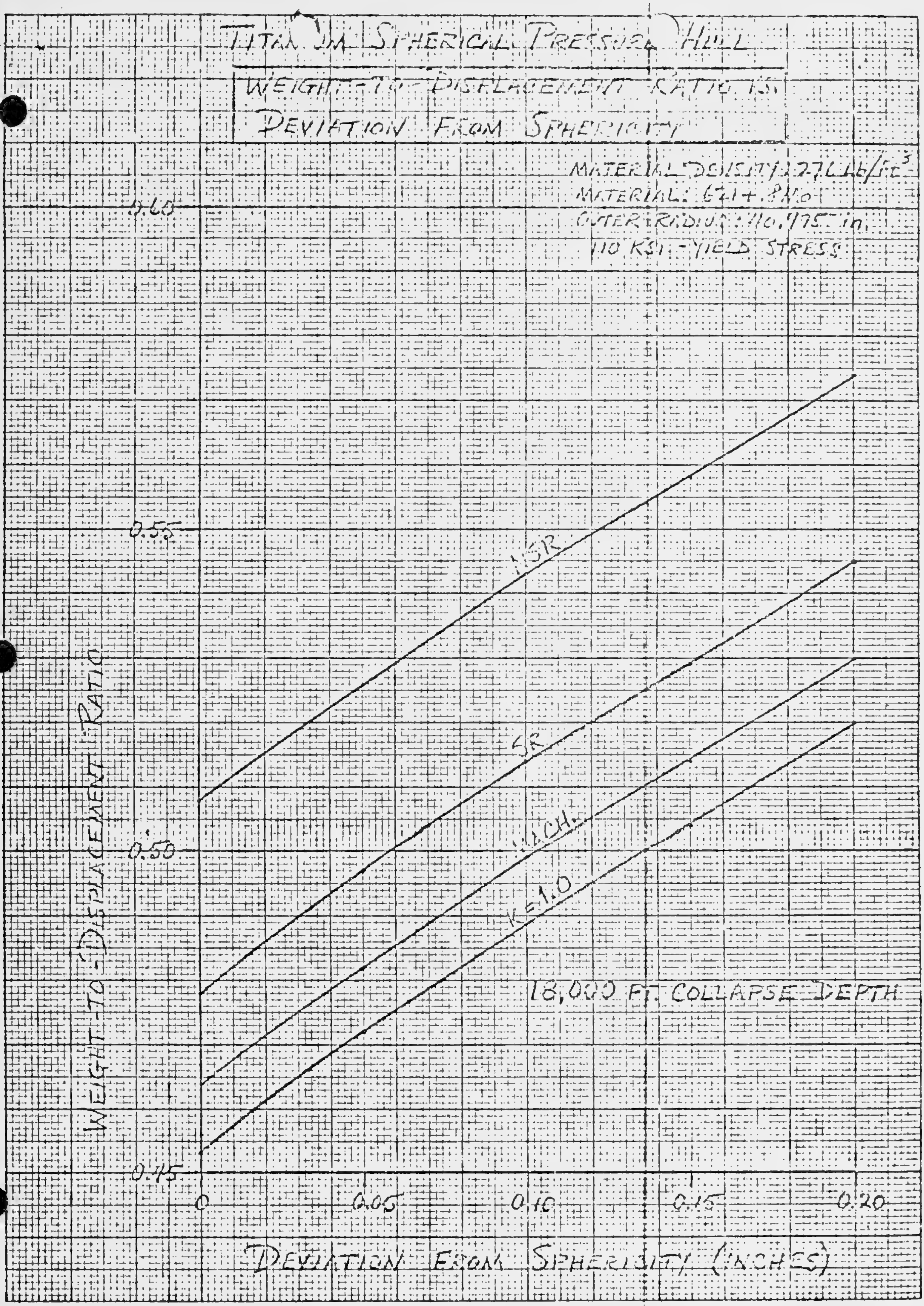

SPHERICAL PRESSURE HULL
WEIGHT-TO-DISPLACEMENT RATIO VS.
DEVIATION FROM SPHERICITY
MATERIAL DENSITY
110 KSI - YIELD STRESS
0.55
0.50
0.45
NSR
SR
18,000 FT. COLLAPSE DEPTH
0
0.05
0.10
0.15
0.20
WEIGHT-TO-DISPLACEMENT RATIO
DEVIATION FROM SPHERICITY (INCHES)

FIGURE 4.

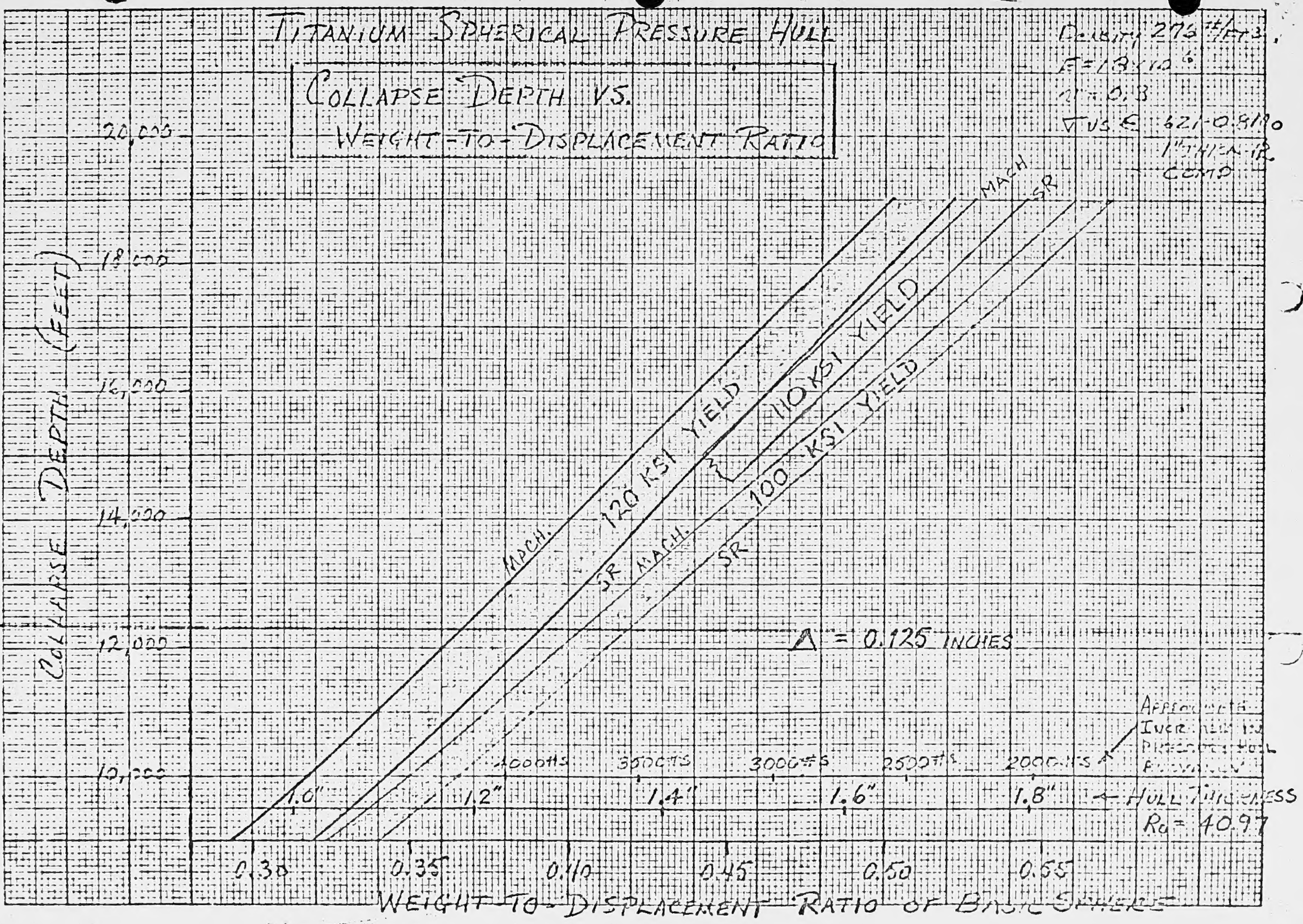

TITANIUM SPHERICAL PRESSURE HULL
COLLAPSE DEPTH VS.
WEIGHT-TO-DISPLACEMENT RATIO
20,000
18,000
16,000
14,000
12,000
10,000
COLLAPSE DEPTH (FEET)
MACH.
120 KSI YIELD
SR
MACH.
110 KSI YIELD
100 KSI YIELD
SR
MACH
SR
Δ = 0.125 INCHES
4000#S
3500#S
3000#S
2500#S
2000#S
1.0"
1.2"
1.4"
1.6"
1.8"
← HULL THICKNESS
Ro = 40.97
0.30
0.35
0.40
0.45
0.50
0.55
WEIGHT-TO-DISPLACEMENT RATIO OF BASIC SPHERE

FIGURE 5