R 691

Technical Report

SITE SURVEYING FOR OCEAN FLOOR CONSTRUCTION

August 1970

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND

NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

SITE SURVEYING FOR OCEAN FLOOR CONSTRUCTION

Technical Report R-691

56-010

by

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ABSTRACT

The increase in interest by the Navy and other organizations in placement of structures on the seafloor necessitates establishing site parameters relevant to such construction, and equipment for measuring these parameters. Included in this report are the site parameters significant to designing, constructing, operating, and maintaining a seafloor structure; an outline of the site survey procedure; the equipment available for conducting these site surveys; and data handling and reduction techniques. Also included are recommendations for research required prior to placement of structures and equipment.

CONTENTS

INTRODUCTION

The objectives of this study were to determine and summarize the requirements and the methods for selecting and surveying an ocean site for on-bottom installations. In accordance with the objectives, the various parameters significant to designing, constructing, operating, and maintaining a bottom installation were established. Simultaneously, a study to determine the state-of-the-art methods and equipment to assess the values of these parameters in site survey operations was conducted.

The purpose of this report is to present the findings from this study and also to supplement earlier reports[1,2,3] by the Naval Civil Engineering Laboratory (NCEL) in the area of ocean construction and site surveys. This report discusses parameters significant to engineering site surveys and the procedures and state-of-the-art techniques available to assess the values of these parameters.

Since this report is written with the assumption that the reader has an understanding of the concepts of site surveying, specific step-by-step descriptions will not be included. The more significant aspects of site surveying for ocean floor structures will be covered.

Site surveying capabilities for engineering applications in the ocean are currently deficient. Site surveys conducted for general oceanographic and geological studies do not demand the precision required in civil engineering. Positioning in the ocean is one deficient area, and the remoteness of the bottom relative to a surface vessel compounds this problem. As a consequence, horizontal control is inadequate to survey areas of 500 feet by 500 feet with sufficient precision that a structure can later be founded on a relatively level area 50 feet by 50 feet within the surveyed area.

The problem of site surveying for engineering applications will be partially solved by the development of precise positioning techniques. The other aspect of the problem is the measurement techniques required to assess the values of the site survey parameters. Possibly an absolute system of on-bottom horizontal control from which data points can be referred will ultimately be required for positioning. (An absolute system refers to one which is integrated with the absolute coordinates of the earth.) As an intermediate goal, it is desired to have horizontal controls accurate to

±5 feet with reference to the closest international geodetic network location point. With such a system used in conjunction with a submersible survey vehicle, the many inaccuracies, doubts, and questionable data obtained by conventional surface systems can be eliminated.

SITE PARAMETERS

Although many data about a particular location are required in site survey operations, only the parameters of major importance to designing, constructing, operating, and maintaining a bottom structure have been considered in this study.

The following are considered to be the significant site factors for ocean bottom installations:

Foundation Engineering Data

- Shear strengths
- Consolidation characteristics
- Index properties (density, void ratio, grain size distribution, etc.)
- Sediment thickness
- Compaction characteristics

Geological Oceanographic Parameters

- Bottom topography
- Subbottom structure (faults, joints, discontinuities, bedding, depth to bedrock)
- Sediment type
- Seismic activity
- Sediment transport (mass movements, turbidity currents, scour and fill)

Physical and Chemical Oceanographic Parameters

- Currents and tides
- Temperature
- Salinity
- Sound velocity
- Light transmissibility

Dissolved oxygen

pH

Hydrogen sulfide

Biological Oceanographic Parameters

Presence of fouling organisms

Presence of plankton

Presence of marine bacteria (both aerobic and anaerobic)

Surface Phenomena

Climate

Sea states

Foundation Engineering Data

Data on shear strength, consolidation characteristics, index properties, sediment thickness, and compaction characteristics are required for the design of the foundation for the proposed bottom installation. With these measured data the foundation and the structure can be designed.

For structural foundations, interpretation of these measured parameters must answer the question: Will the sediment support the structural loads without producing failure of the sediment mass and without objectionable total and differential settlement? Information on several important foundation engineering considerations is required to answer this question: (1) the type and physical properties of the sediment, (2) the type of structural foundation, and (3) location in the sediment column of this foundation. The above question is certainly not the only question that requires answering in any foundation engineering problem. The data collected for answering the above question, however, is the same type required to answer other particular foundation engineering problems, for example, slope stability. (The design and analysis of foundation systems, for example, spread footings, mats, rafts, and piles, are a subject of another research area and will not be covered here.)

Although ultimate bearing capacity of seafloor sediment is of prime interest to researchers, its meaning is often misunderstood. The ultimate bearing capacity of sediments is not a singular value analogous, for example, to the yield strength of a particular type of structural steel (for example, 30,000 psi.) The ultimate bearing capacity of any given sediment is a function of cohesion, angle of internal friction, density, footing size and shape, depth in the sediment, and other sediment properties. As indicated above, in the design of footings, settlement considerations are integrated with considerations for ultimate supporting capability of the sediment.

Several ultimate bearing capacity and settlement computation techniques exist. The ultimate bearing capacity is usually calculated by Terzaghi's equations.[4] For long footings at or below the sediment surface under general shear conditions, the ultimate bearing capacity equation has the form

$$q_u = c N_c + \gamma b \frac{N_\gamma}{2} + \gamma d N_q$$

where q_u = ultimate bearing capacity

c = cohesion

γ = sediment unit weight

b = footing width

d = effective overburden depth

N_c, N_γ, N_q = dimensionless bearing capacity factors

By various modifications of this equation, expressions for the local shear case for long footings, for round footings, and for square footings are derived to fit the particular problem being analyzed.

A method of computing settlement for fairly large footings on cohesive, normally consolidated material is presented by Hough[5] and is accomplished by solution of the equations

$$\Delta H_i = H \frac{CI}{1 + e} \log\left(1 + \frac{\Delta p}{p}\right)$$

$$TS = \sum_{i=1}^{n} \Delta H_i$$

where ΔH_i = change in layer thickness

H = layer thickness

CI = compression index

e = void ratio

Δp = stress change

p = initial stress

TS = total settlement

n = number of layers

It should be noted that if only the above equations are used, a gross simplification is being made of the complex problem of design and analysis of a foundation system. In a structure of significant importance, such as in a manned structure, other considerations and more exacting design methods are required. For example, shear and plastic deformations of the sediment contributing to the settlement of the structure should be considered. As another example, the rigidity of the structure and foundation elements has a direct influence on the settlement behavior. An analysis to take this factor into account is very complex but may be necessary where the safety of personnel is of prime importance. As a further example, in granular sediments vibration effects can cause compaction of the sediments to a relative density of 75%, and this could result in considerable settlement and/or damage to the structure if the sediments are initially loose.

For noncohesive sediments, the serious problem exists of not being able to obtain a suitable sample for laboratory testing. Because of the remoteness of the bottom beyond diver depths, the required in-situ density and other values cannot be measured accurately. Thus, to be on the conservative side, it would be safer to assume local shear failure conditions rather than general shear failure conditions as illustrated by Figure 1, which was developed by Vesić[6] for terrestrial sands. Punching shear will most likely not be encountered, since the footing size will be relatively large to minimize settlement.

The sediment thickness and bedding characteristics must be known for each proposed site. If point-bearing piles are to be used, the depth to bedrock is required. Bedding characteristics are also required if friction piles are to be utilized. The various strata need to be delineated to insure that no weak beds exist which might be the seat of settlement or through which a failure plane could develop. Information on sediment thickness and bedding is also required in bearing capacity and settlement analysis as discussed in previous paragraphs.

Data on the compaction characteristics of the sediments are also required. (The definition of compaction as used here is making the sediments more dense by some artificial means.) In many cases, the site will be acceptable in respects other than bearing capacity and settlement. To improve these characteristics, compaction of the sediment may have to be undertaken. Although the techniques of the compaction of marine sediments have not been developed, compaction appears feasible and will be required, particularly when a location has been preselected in which the sediments will have to be modified for the site to be acceptable.

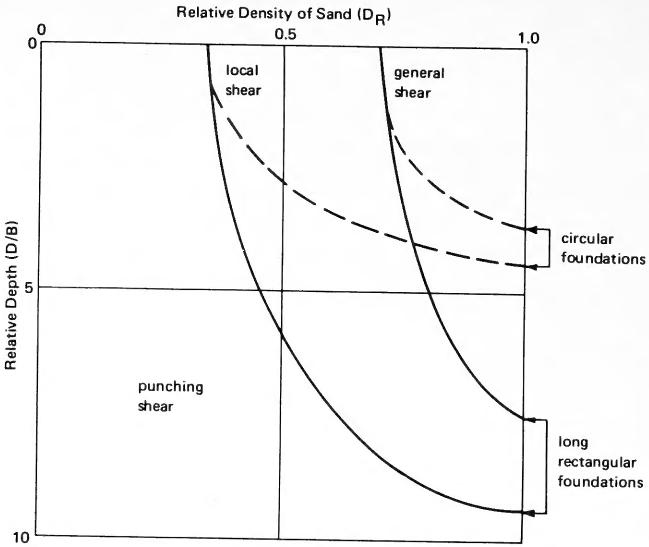

Figure 1. Types of failure at different relative depth (D/B) of foundations in sand. (From A. B. Vesić.[6] © Highway Research Board. Used by permission.)

Geological Oceanographic Parameters

Assessment of the geological oceanographic parameters for each site is required for evaluation of the stability of the site. For example, the bottom topography could reveal important features that indicate high currents, slide debris, slide scarps, or tension cracks which are significant to the stability of the structure.

The subbottom geological structure must be defined in the evaluation of the stability of a given site. Such features as faults, joints, discontinuities, strata, and depth to bedrock must be properly recognized to make an adequate evaluation of the site. As the number of these structural features increases, the problem of predicting foundation behavior becomes increasingly more difficult and less accurate. In general, the subbottom features at each site must be evaluated individually. For example, in the case of slopes with bedding with various dips, the slope with the beds dipping in the direction of the slope and with the beds intersecting the sediment surface are usually less stable than slopes with beds dipping opposite to the slope. The geological structure should therefore be considered in careful detail.

The sediment type and composition are required for each site to gain a more complete picture of the stability of the site. The classification of the sediment as sand, silt, clay, or a combination of these indicates, to a degree, the probable behavior of the sediment under the proposed structural loading. In sands, settlement will occur with little or no lag time as the structural load is applied. In clays, settlement is a function of the consolidation characteristics, and lag time may therefore be considerable. In sands, depending on relative densities, spontaneous liquefaction could occur and result in excessive settlements which could cause structural failures. In clays, thixotropic properties may be significant if sediments are disturbed during installation or operation of the structure.

The constituents of the sediment are also very important to stability, as is illustrated by the following examples. In coarse-grain sediments with shells from plankton and other biological growths, the crushing of the tiny cells in these growths will cause settlements which may be excessive. In clays, the presence of expansive clays such as montmorillonite or nonexpansive clays such as illite may be significant. Also, the presence of montmorillonite in as small a quantity as 5 to 10% changes the behavior of a clay radically. Thus, the constituents of the sediment must be determined to make a proper evaluation of the site.

Since earthquakes are usually associated with faults and their behavior, the local and regional fault zones of each site should be established. In addition, the frequency and magnitude of past earthquakes occurring in the area should be noted and accounted for in design. Research should also be conducted on the effects of earthquake forces, particularly at the interfaces of density changes (that is, at sediment–water, rock–sediment, and rock–water interfaces). This research may reveal new parameters that may require measurement in site surveys.

Sediment transport, as referred to in this report, includes transport of sediments by gravity forces and by currents. Sediment transport by gravity forces in the seafloor environment may include landslides, creep movement, and flow slides. Sediment may be moved in the water in several ways including by scour and fill-type water currents and by turbidity currents. All of these sediment movements may cause destruction or serious damage to the structure and interfere with the operational objective of the installation. Thus, site surveys must be of sufficient accuracy and scope to adequately collect data to assess the presence or possible occurrence of these sediment movement phenomena. An example of the necessity of a precise comprehensive survey is suggested by the far-reaching influence of turbidity currents as indicated by the deposits along submarine canyons.

Physical and Chemical Oceanographic Parameters

For design of the bottom structure and analysis of its maintenance and functional requirements, measurements must be made for currents, temperature, salinity, dissolved oxygen, pH, and hydrogen sulfide. The patterns of the water currents at each site are required for design and stability analysis of the structure to be placed on the seafloor. The magnitudes, direction, and average duration of the currents are required to design for lateral loadings on the structure and on foundation elements. Currents would generally tend to displace laterally and overturn the structure and create scour and fill problems. Thus, an assessment of the currents must be made for each site.

Data on the other physical and chemical oceanographic parameters including temperature, salinity, dissolved oxygen, pH, and hydrogen sulfide are required for designing the bottom structure and for making a proper evaluation of its maintenance and operational requirements. The foremost reason for measuring these properties is to evaluate the corrosion potential of the particular site. Knowledge of these properties together with various in-situ test data [7,8] will aid in the design of corrosion-resistant structures for longer maintenance-free installations. Since corrosion decreases the safety factor of the structural members, it is important that these site parameters be measured so that a proper design can be achieved.

The measurement of these parameters is also required to make an assessment of the suitability of the site for the intended purpose of the bottom structure. For example, if the intended purpose of the structure is to conduct research on sound velocity characteristics, the site with the best physical properties to conduct this study can be selected. If aquaculture studies are the prime objective of the bottom structure, the site with the environment most conducive to the successful conduct of these experiments would be desired. In addition, the water temperature and salinity at respective pressures are used in the correction of the depth determined by a sonar technique in the bathymetric surveys.

Biological Oceanographic Parameters

Biological characteristics influence marine fouling and destruction, visibility, and sound transmission at a given location. It has been shown by various researchers (for example, Muraoka [9-15]) that fouling and destructive effects of structural components due to biological activity would definitely be a problem at water depths to 6,000 feet and, possibly, deeper. Attachment of large quantities of fouling organisms on structural components would be a problem in the upper few hundred feet of water. These fouling effects decrease with depth; however, marine borers and microorganisms are still present to cause destruction of materials associated with the structure at greater depths.

The activities of these marine organisms could have many serious consequences. For example, if lumber, manila and cotton ropes, and other materials which are susceptible to destruction by marine borers and other organisms are used, failure of these elements could result in a hazardous situation.

Biological growths in critical areas of the structure could cause problems leading to reduction in the useful life of the established structure even though the structural elements were not damaged. For example, marine growths on viewports of the structure and on the front transparent housing of television and still cameras could interfere with operations and experiments. As a further example, biological growths in the intake and exhaust pipes for seawater would detrimentally affect the performance of such systems.

The presence of planktonic foraminifera and other biological inhabitants of the water column interferes with sound and light transmission. The presence or absence of these inhabitants greatly affects visibility, expecially in deep waters where artificial lights are required. Sound transmission is also affected by these water-borne plants and animals. The deep scattering layer which occasionally appears on echograms from surface-conducted bathymetric surveys is an example of this effect.

Marine bacteria of both the aerobic and anaerobic types when present in the environment of the structure could detrimentally affect the structure and component parts. Although the bacteria are small, in large quantities they can create wide-spread damage as the following examples illustrate. Sulfate-reducing bacteria in an anaerobic environment produce hydrogen sulfide, known to be a corrosion agent. Aerobic bacteria cause organic material to decompose. Bacteria are also the source of primary films, which initiate fouling on materials.

Thus, the measurement of biological parameters in site survey operations is necessary to make an adequate assessment of the suitability of a site with respect to biological fouling and other effects.

Surface Phenomena

Data on surface phenomena, including climatological characteristics, sea states, surface currents, and tides are required for evaluation of specific sites. Since surface support will be used in the installation, maintenance, resupply, and possibly emergency rescue associated with the bottom structure, the effects of these surface phenomena must be known.

If a surface power source is used, surface effects will be highly significant. With these measured data, the proper anchor configuration or dynamic positioning technique could be designed. These data would also aid in designing a specialized platform for surface-support applications.

SITE SURVEY REQUIREMENTS

Before any surveys are conducted, the site requirements for each specific structure must be defined to establish the proper scope of the survey. The following are the major items which should be defined: purpose of the installation, operational requirements, size of structure, location of structure (on or in bottom), and degree of precision required in the survey.

The purpose of the installation has to be known so that the proper site parameters are measured in a degree commensurate with the importance of the structure. For example, the measurement of the foundation-supporting characteristics for an unmanned Submersible Test Unit (STU) (Figure 2) will be far less extensive than for a manned underwater structure (a model of which is shown in Figure 3). If the bottom structure is for biological studies, a site considered to be a dead area similar to some basins off of Southern California may not be acceptable. Thus, the purpose of the bottom structure determines the extent and the type of survey parameters to be measured.

The operational requirements of the bottom structure influence the selection of proposed sites for survey. For example, the use of surface support power sources for a manned station on the seafloor requires that the surface vessel be in relatively quiet and shielded waters (safety considerations). If the bottom installation is a telemetering station, it would be desirable to locate this structure on a topographic high where it can be monitored over the widest area. On the other hand, if the bottom structure is for defense purposes, it may be desirable to conceal this structure in a depressed area on the seafloor or possibly in the bottom sediments or rock. Thus, the operational requirements of the structure should be defined so that the appropriate survey can be conducted.

The size of the structure has a direct bearing on the extent and depth of the foundation engineering survey. With respect to Boussinesq's theory [17] of stress distribution in an elastic, homogeneous, isotropic, and semi-infinite medium, it is noted that the "bulb of influence" becomes larger and extends deeper as the footing size increases. The effect of this increase in footing size is illustrated in Figure 4 in which isobars of equal stress intensity are plotted. For the same structure unit loading, it is seen that a given stress isobar is larger and extends deeper into the sediment column for the larger footing. The effect of this increase in size of a given isobar for the same structure unit loading is to increase the total settlement. Figure 4 also illustrates the importance of investigating deeper into the sediment column for larger structures to insure that no weak layer exists which may influence the stability of the structure. Thus, the size of the structure must be defined in order that the appropriate survey be conducted.

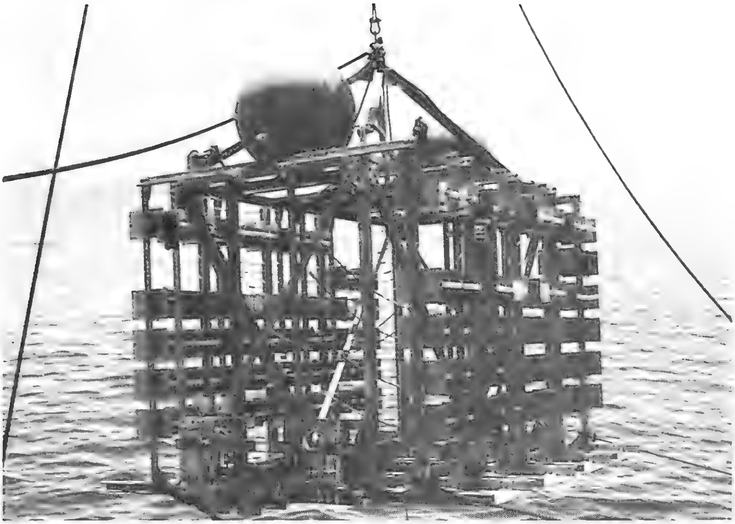

Figure 2. Submersible Test Unit (STU) used by NCEL for studying the effects of the deep-ocean environment on construction materials.

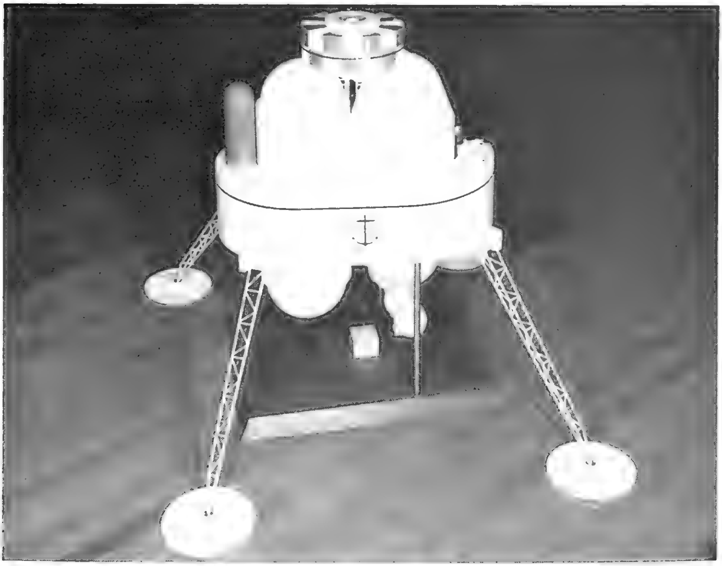

Figure 3. Model of a manned underwater structure developed by General Dynamics.[16]

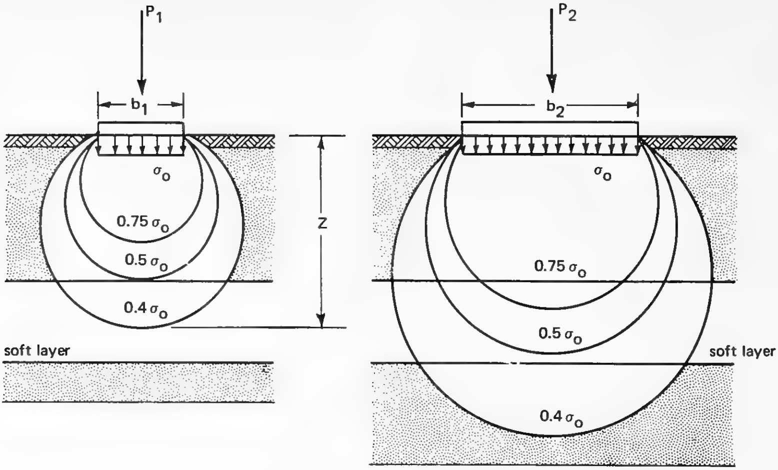

Figure 4. Effect of footing size on stress distribution in a layered soil system. (From SOIL MECHANICS by A. R. Jumikis,[17] Copyright © 1962, by Litton Educational Publishing, Inc., by permission of Van Nostrand Reinhold Company.)

The location of the structure on or in the sediment will govern the depth to which the survey will be required to extend and the type of parameters that need to be measured. Depending on the depth requirements, alternative techniques may have to be utilized to assess the foundation parameters. For example, for a small structure of relatively minor importance, the NCEL in-situ vane shear device could be utilized for strength measurements. On the other hand, if a 1,000-foot-long by 100-foot-diameter cylindrical structure is to be founded on the seafloor, vane shear type data would not be adequate. In other cases, the depth to bedrock may be required to be known. The location in the sediment column of the structure also influences the parameters to be measured. For example, lateral loading on the structure due to currents may be less important for structures *in* the bottom sediments than for structures *on* the sediment surface. On the other hand, lateral loading due to the sediment weight is of prime importance for a structure in the sediments. Thus the location of the structure in or on the bottom will influence the survey depth and the type of parameters that must be measured.

In general, the degree of precision of the survey is governed by the relative importance of the structure. For example, the precision required for the survey for a manned bottom installation will be far greater than for an unmanned Submersible Test Unit (STU), as discussed previously. Since the degree of precision governs the survey technique and procedures, this requirement must be defined prior to conducting the survey. As an example, a bathymetric survey conducted with the LORAC positioning system and a Precision Depth Recorder (PDR) may be satisfactory for a STU, but would be inadequate for a manned bottom complex. A different survey technique would be required for the latter installation, possibly one using submersibles.

SITE SURVEY PROCEDURE

The procedure for surveying a site is divided into two major categories or phases; the preliminary survey phase, and the detail survey phase. The extent to which each survey phase is conducted depends on the purpose of the installation, the operational requirements, the size of the structure, and the degree of importance of the structure. In general, each phase is conducted with a degree of thoroughness which is dependent on the particular installation. It is possible that for a specific structure the existing information will be adequate to evaluate and select the site, thus obviating the necessity for further investigations. In other cases, the existing data may be incomplete, requiring only specific information from the detail survey phase. Figure 5 diagrammatically shows the various possible routes that may result in the process of selecting a site. The general site survey procedure, which includes both the preliminary and detail survey phases, will be discussed in this section.

In certain cases, a site may be preselected, that is, the stipulation is made to place the particular structure at a specific location. For example, it may be stipulated that the structure shall be placed off of San Clemente Island in the vicinity of NOTS Pier. In this case, the previously discussed site survey and selection procedure does not apply. Here, the existing data are evaluated and if necessary, a detail survey is conducted. Regardless of what is found in the evaluation of the existing data or in the detail survey phase, the site "must be made to work" for the structure—the structural design must be accommodated to the constraints of the site. In the previously discussed procedure, the site that would work best for the particular structure is selected after all the data have been evaluated.

Preliminary Survey

The preliminary survey phase consists of searching for existing information, personal contacts, and reconnaissance surveys. In the search for existing information, data on the site parameters including foundation engineering, geological

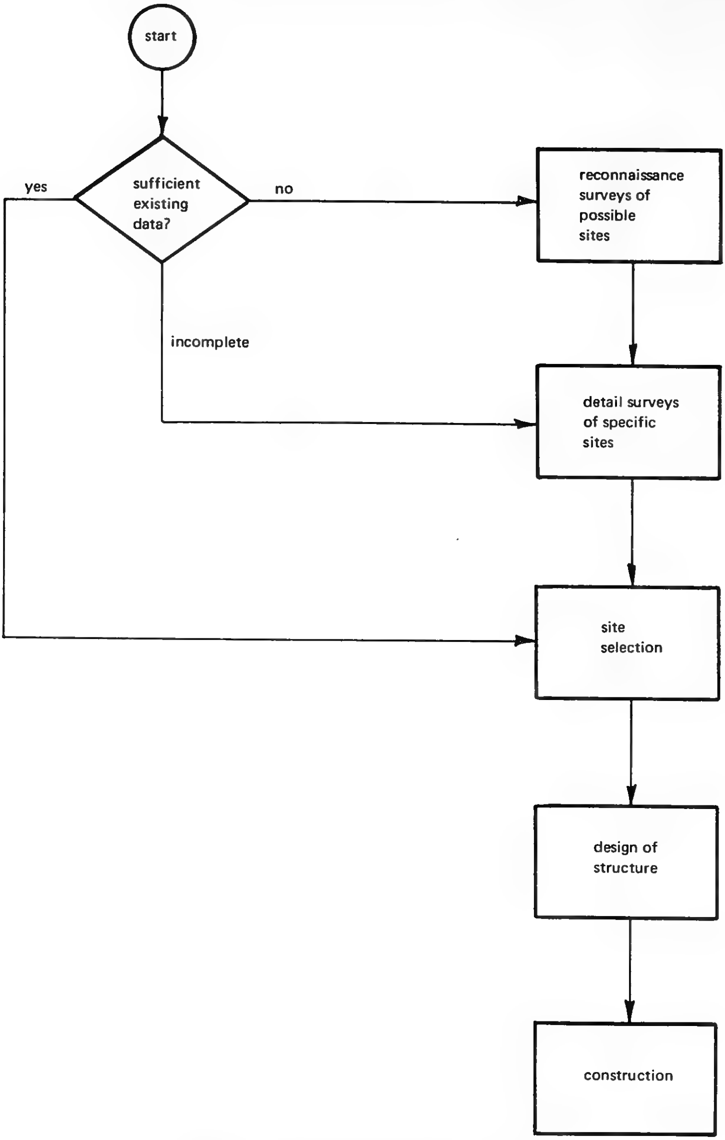

Figure 5. Site survey and selection procedure.

oceanographic, physical oceanographic, chemical oceanographic, biological oceanographic, and surface phenomena are investigated. To facilitate the initial search for information, Tables A-1 to A-8 of Appendix A have been prepared. These tables list possible sources of specific information in these categories.

Table A-1 is a listing of possible sources of bathymetric charts. From these charts, candidate sites can be chosen according to the requirements of the particular structure—for example, placement in a relatively flat location or placement on a topographic high. Another reason for investigating existing bathymetric charts is to determine if these bathymetric charts are sufficiently accurate for the requirements of the structure or if additional data are required from the detail survey phase.

Table A-2 lists possible sources for underwater photographs that could be used in the preliminary survey phase. The purpose of locating and studying available photographs is to determine if particular sites contemplated for a structure are suitable and if additional photographs are required from the detail survey phase. A number of conclusions can be reached by studying these existing photographs. For example, as shown in Figure 6, it is seen that considerable biological activity is taking place at the sediment surface, thereby disturbing the upper layers of the sediments. Placing, leveling, and stabilizing a structure on rock outcrops such as that shown in Figure 7 would be very difficult; thus it may be desirable to avoid these areas initially. The lack of sediments on the rock outcrop of Figure 8 could be indicative of high currents in the area. If it is suspected that certain local seafloor areas such as estuarine outlets (that is, Mississippi River) possess a uniform gradation from clear water to consolidated sediments (that is, clear water, milky, turbid, colloidal, etc.), photographs could verify or may show that this is not a problem, as is shown in Figure 9 for an area off San Diego. Other important features such as tension cracks and slide debris may possibly be recorded on existing photographs. Thus, depending on the particular structure to be founded on the seafloor and its site requirements, existing photographs can be advantageously interpreted.

Sediment samples for geological and engineering properties have been taken from various ocean-floor sites. Particular information on specific sites will be valuable in the preliminary survey phase. Possible sources of this particular information are listed in Table A-3. Although much information on these properties is being published, the majority of the data have received only limited dissemination. It is necessary that these data be searched out to determine if additional data are required for these properties in the detail survey phase.

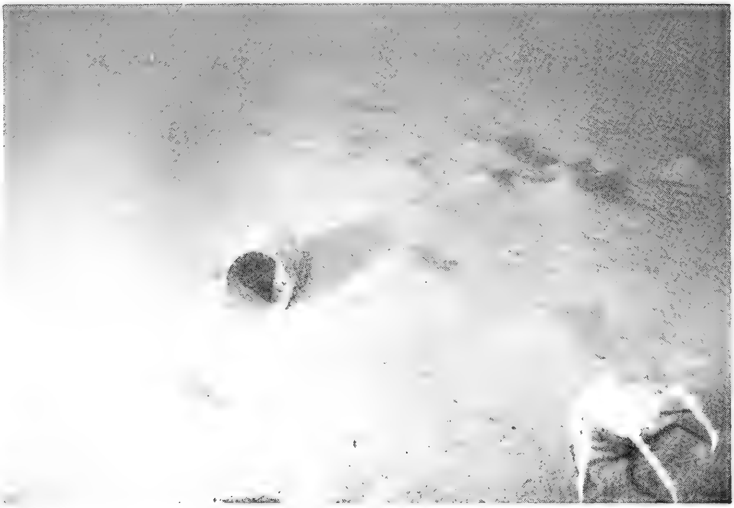

Figure 6. Disturbance of upper sediment layers by burrowing animals observed off the Coronado Banks.

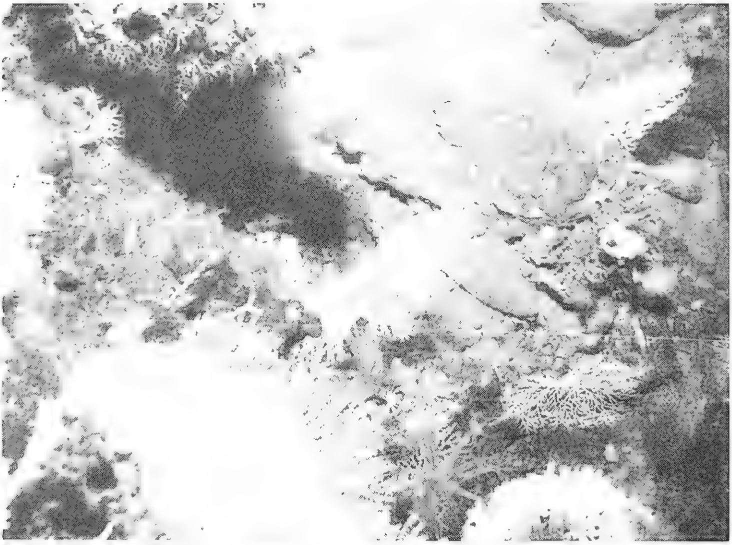

Figure 7. Rock outcrop and marine life on San Juan Seamount off the California coast.

Figure 8. Underwater rock outcrop with no overlying sediments except coarse grained deposits in interstitial areas (San Juan Seamount).

Figure 9. The presence of a discrete separation between sediment and water is shown in this photograph of the seafloor off the Coronado Bank.

To aid in the search and location of the data pertinent to a specific site under investigation, a listing of possible sources of oceanographic data has been prepared and is presented as Table A-4. Information, such as that shown in Figure 10, is collected as background information for various experiments. Often, these data are not published. In many cases, the existing data are sufficient for placement of a particular structure. In other cases, only supplemental measurements may be required in the detail survey phase.

Much information of scientific interest in the areas of geological and biological characteristics can be found in various publications. Data obtained for oil exploration or other engineering-oriented services, however, are usually not published. As an example of published information, during the period June-July 1967, Geotech[18] conducted a continuous seismic reflection survey from Trinidad to South Africa over a route totaling 7,000 miles. It is probable that if the profile includes areas of interest for a particular structure, the records could be purchased. Existing geological and biological data may also be available for other specific areas of interest. To facilitate the search for this data, Table A-5 for geological properties and Table A-6 for biological properties have been prepared.

Weather information is collected daily at various locations throughout the world and is generally available. The data on surface effects resulting from the influences of the weather, however, may not be readily available. To facilitate the search for this information on weather and surface effects, a listing of possible sources for these data has been prepared and is presented as Table A-7.

Contained in Table A-8 is a listing of possible sources for information on earthquakes and earthquake effects. Information such as shown in Figure 11, which is a plot of earthquake epicenters occurring in the Southern California offshore area, is available for various oceanic regions. This information, in addition to being required for design of the structure, could be one of the controlling factors in the selection of candidate sites. Since it is not possible to gain epicenter location and other data on earthquake effects in the detail survey phase, it is necessary to rely chiefly on available historial information. Thus, the search for this information must be made in the preliminary survey phase.

Investigation of existing information is essential. In general, the purpose of locating these existing data is twofold: (1) to determine if existing data are adequate for selecting a site and placement of the structure, and (2) if not, to determine which parameters require assessment in the detail survey phase.

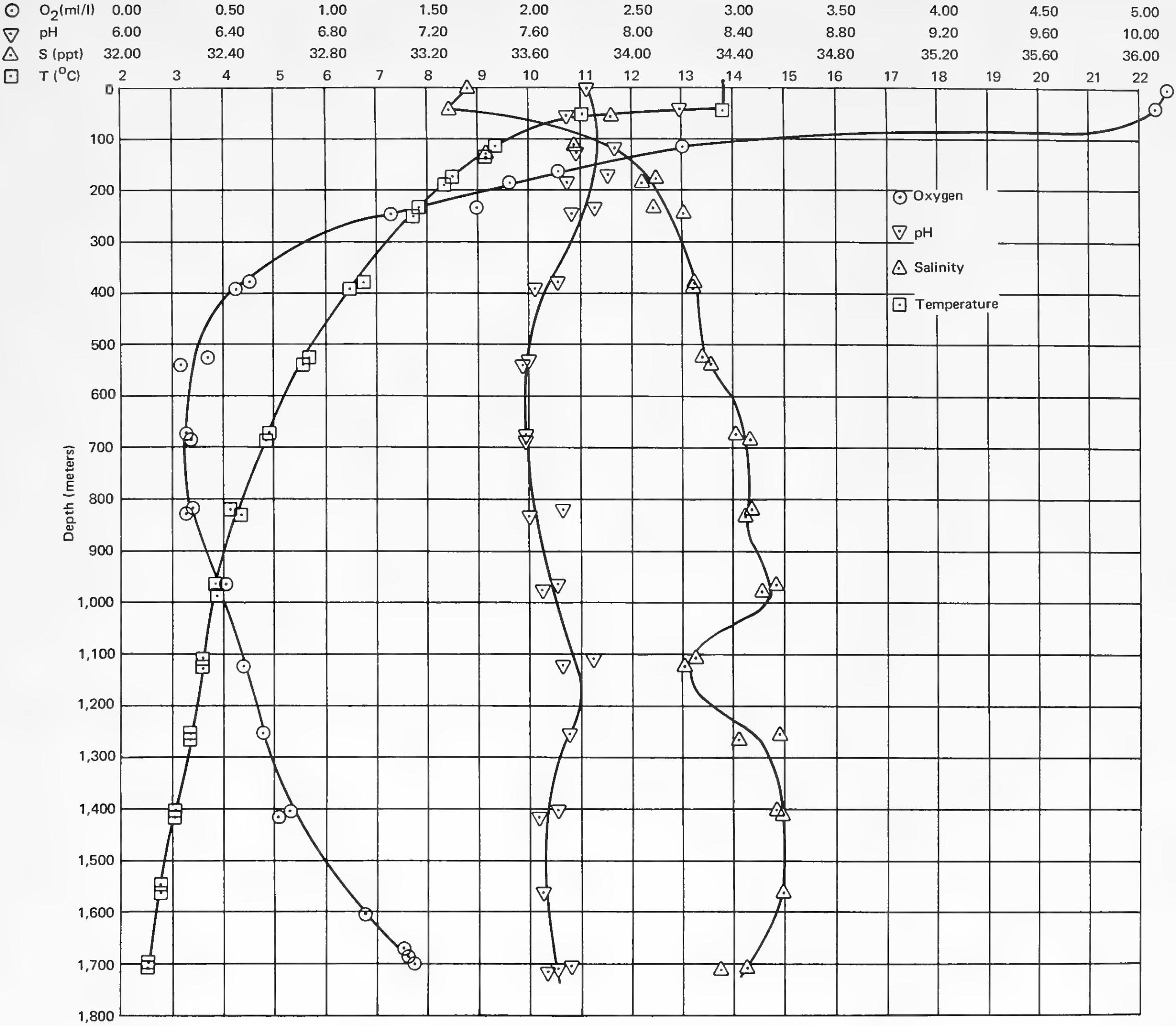

Figure 10. Example of existing oceanographic data. (From NCEL STU I series test site on June 20, 1967, at 33°44′N-120°45′W in water depth of 1,736 meters.)

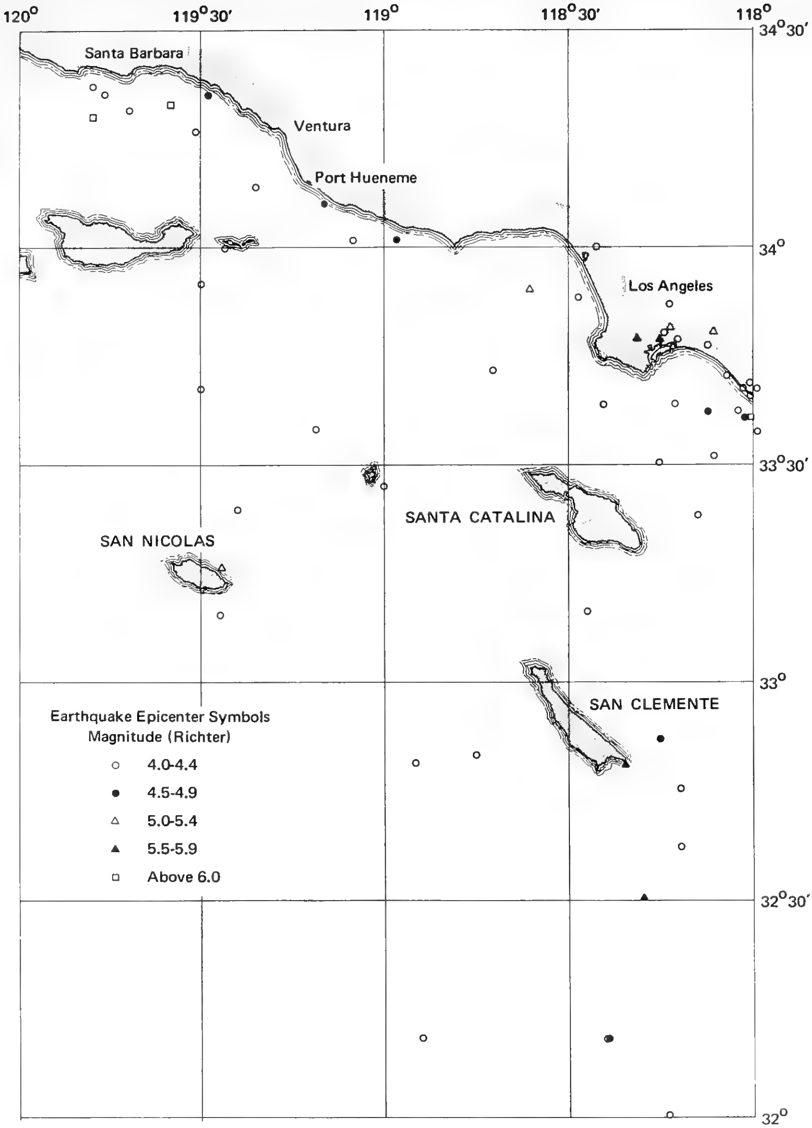

Figure 11. Epicenter locations off Southern California of earthquakes of magnitude 4.0 and greater on the Richter Scale occurring between 1934 and 1961. (Data from California State Department of Water Resources, 1964.)

Personal contacts should be made to acquire existing information on sites and determine ongoing or planned activities. These contacts may dictate whether a site will be available for use. As an example, in the conduct of the initial phases of the preliminary site survey for ocean construction experiments,[19] it was learned through personal contacts that the sites immediately south of the Channel Islands (off Port Hueneme) could not be used for bottom stations because the operations of the Pacific Missile Range would be inhibited by the presence of the bottom station and surface support activity. Thus, personal contacts should be made prior to conducting a reconnaissance survey.

In the event that the existing information is insufficient for placement of the particular structure and information from personal contacts is favorable, a reconnaissance survey is then conducted to locate specific candidate sites. The data collected from this survey are then evaluated and a particular site is selected for detail investigations in the next phase commensurate with the requirements for the particular bottom installation.

Detail Survey

In this survey, the site selected in the preliminary survey phase is subjected to detailed investigations. Those parameters for which there are sufficient existing data need not be reassessed; the quantities that lack sufficient information, however, must be evaluated in this survey. In general, only those parameters significant to the particular bottom station need be measured. Once the requirements of the structure are known, the field survey can be initiated, using the appropriate combination of survey gear presented in the next section.

Presently, there are two methods that could be used to assess the foundation engineering parameters. The first method is to secure core samples from the site using appropriate techniques and subjecting these samples to applicable tests. To obtain samples of minimum disturbance for these tests, the optimum corer dimensions described by Hvorslev[20] should be used. These are as follows:

$$\text{Kerf or Area Ratio, } C_a = \frac{D_w^2 - D_e^2}{D_e^2} \times 100 \geqslant 10\%$$

$$\text{Inside Clearance Ratio, } C_i = \frac{D_s - D_e}{D_e} \times 100 = 0.75 \text{ to } 1.5\% \quad \text{(for long samples)}$$

$$= 0 \text{ to } 0.5\% \quad \text{(for short samples)}$$

$$\text{Outside Clearance Ratio, } C_o = \frac{D_w - D_t}{D_t} \times 100 = 2 \text{ to } 3\%$$
(for cohesive soils)

where the dimensions are as shown in Figure 12. In addition, for samples of inside diameter of 2 to 3 inches, the length to diameter ratio **(L/D)** for stiff to very soft cohesive soils should be in the range

$$\frac{L}{D} = 10 \text{ to } 20$$

As suggested by Hvorslev, the above values are tentative.

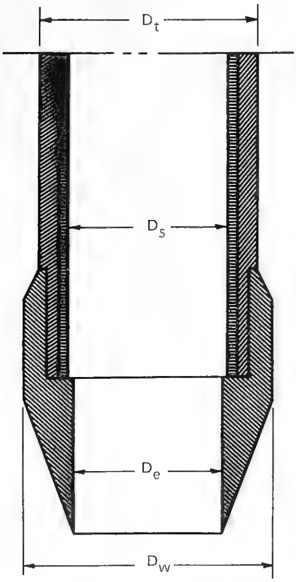

Figure 12. Dimensions of corer for use in computing area, inside, and outside ratios.

The length to diameter ratio limitation requires that incremental sampling techniques be used. This has also been concluded by Richards and Parker[21] in their study of core sampling for shear strength measurements. They concluded that for good-quality samples from sediment depths of 30 to 60 feet, this technique is the only feasible method.

The number, locations, and lengths of cores that should be obtained in the detail survey are questions that arise prior to each survey. Tentative guidelines (dependent on the requirements of the structure, the geographical location of the site, and characteristics of the site) could be set for these quantities, but the final decision should be based on one's own engineering judgement. The number and locations of cores to be taken are functions of the importance and the size of the structure. For example, NCEL'S Submersible Test Units could be placed with a fair degree of confidence on the basis of one core sample (if NCEL possessed the capability to place the structure in the exact location from which the core was taken). On the other hand, a 30 x 30-foot manned structure may require a minimum of three undisturbed cores: one at two diagonal corners and one in the center. The sample from each location should represent the sediment column to a depth approximately equal to the minimum overall lateral dimension of the foundation system.

The core samples obtained in accordance with the above techniques are then subjected to laboratory tests as prescribed by ASTM procedures for testing soils.[22] Some tests are modified to accommodate seafloor sediments. A few of these modified tests, examples of engineering properties data, and results of the site survey for the STU II series are presented by Hironaka.[23] The type of tests to be conducted depends on the requirements of the structure and on the consistency of the samples. The desired data are strength, consolidation, and other index properties that will be used in design and to evaluate the foundation-supporting capability of the sediment.

This first method for assessing the foundation engineering parameters also includes investigation of bedrock by core drilling for samples. Obtaining rock core samples from deep water is within sampling capabilities as has been demonstrated by the Project MOHOLE and JOIDES operations. Samples obtained in this manner are then subjected to laboratory tests as prescribed by ASTM procedures.[24,25] In addition to evaluating the strength characteristics and other properties of the samples, the location of bedrock below the sediment surface can be defined in the core drilling process. This investigation would be required in the event that piles or other foundation systems are to be placed on bedrock.

The second method for assessing the foundation engineering parameters that is being developed consists of in-situ measurement techniques. Although presently limited to sediment thicknesses of about 10 feet, some of these techniques may soon be capable of evaluating the sediment column to a depth of 100 feet. NCEL now has a vane shear device, a cone penetrometer device, a plate bearing device, and long-term settlement devices (LOBSTERs). (These devices will be discussed in detail in a later section.) Richards has also developed in-situ test devices,[55] including a vane shear probe, a gamma ray density probe, and a pore pressure probe. The Naval Oceanographic Office has also used a density probe. NCEL is currently conducting research to provide design information for a probe to measure sediment water content by nuclear methods.

The geological characteristics can be determined by the combination of core samples, seismic and magnetic surveys, accurate bathymetric charts, bottom photographs, and visual observation from submersibles. The requirements of the structure will govern the thoroughness required for the survey. In such a survey, it is desired to locate weak sublayers, indications of mass movements (creep, slides, turbidity currents), tension cracks on slopes, faults, and other features which may influence the stability of the structure.

The physical oceanographic parameters that will be required from a detail survey will generally include those properties which affect corrosion of materials and the stability of the structure. For corrosion, the physical and chemical properties indicated earlier will have to be evaluated. The laboratory procedures to measure these properties are well established. A few in-situ measuring instruments, however, are currently on the market that will accurately and rapidly measure some of the required properties. In particular, the salinity, temperature, and depth (STD) probe has proven to be superior to conventional methods because of the capability of obtaining continuous profiles of the water column. The initial cost of such probes is high, but this investment is quickly recovered as illustrated in Figure 13, which shows the results of the cost comparison study which was made for the classical water bottle technique used by NCEL as compared to the in-situ probe technique. Other techniques are indicated in the next section.

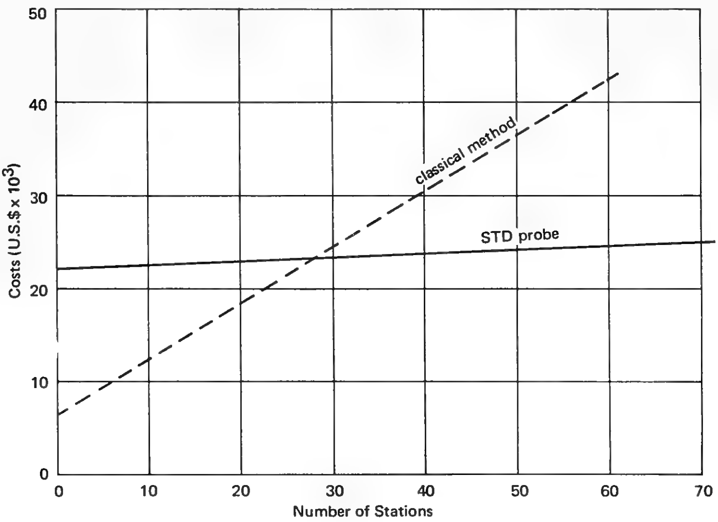

Figure 13. Comparison of sampling costs for classical water bottle method and in-situ STD probe for stations with 3,000-foot water depths.

With respect to the stability of the structure, water currents are the most important physical oceanographic measurement. It is necessary to monitor currents because of the possible effects of the forces associated with currents on scour (erosion) and fill of sediments and on the contributing effect of currents on overturning moments, which directly influence the stress distribution pattern on the foundation supporting medium. In general, scour and fill will not be much of a problem in the deep-ocean areas because of the relatively small current magnitudes that will be encountered there. For example, the average current of 0.1 knot (≈5 cm/sec) reported for one of NCEL's STU sites would have a negligible effect on scour, as is shown in Figure 14 (after Hjulström[26]). The effect of this current on the overturning moments of the structure, however, could be very significant, depending on structure characteristics. Thus, the magnitude and direction of the predominant currents will have to be evaluated using instruments listed in the next section.

The biological oceanographic parameters that should be assessed in the detail survey phase are those responsible for visibility, fouling and biodeterioration of engineering materials. Since the procedures to evaluate these quantities are not well established, it is difficult to generalize on the technique for site survey for all water depth locations. Presently, the techniques used to assess these effects include water sampling, trawling, and exposure of material specimens to the biological environment. It is believed that more rapid techniques could be developed that could be applied to site surveys. Research[9-15] in this area, however, is being conducted to determine those biological elements which are responsible for fouling and biodeterioration. The results of this research could lead to the techniques that could be used to evaluate the biological characteristics of each site in detail surveys.

Biological effects resulting from animal behavior are beyond the scope of this report. These effects, however, may be very significant to seafloor structures and their servicing vehicles. One example of unpredictable animal behavior is the well-publicized encounter between a 200-pound swordfish and the submersible *Alvin* at a depth of 1,809 feet.[27] Fortunately, in this encounter none of the submersible occupants were injured and the submersible was not damaged. Another incident involving a swordfish is described in Reference 28. In this instance a 300 pounder attacked a polypropylene rope at a depth of 1,000 feet and became trapped with its bill wedged between the strands of this rope. If this rope had been an umbilical power supply line to a manned bottom structure, as an example, the effects could have been disastrous. Other marine animals such as whales, sharks, and squid may have caused damages to lines and cables.[28]

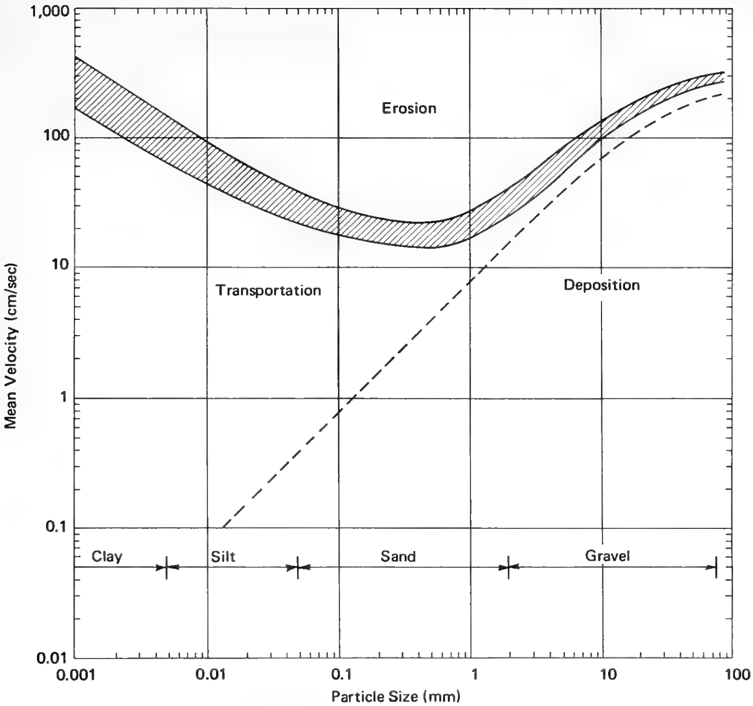

Figure 14. Erosion and deposition of various particle sizes as a function of mean water velocity. (From "Transportation of Detritus by Moving Water," by F. Hjulström, in Recent Marine Sediments. © Society of Economic Paleontologists and Mineralogists, 1955. Used by permission.)

The measurement of surface phenomena is routine and therefore needs no elaboration here. The U. S. Weather Bureau has standard procedures for measuring those meteorological parameters of interest in site surveys. The Weather Bureau also collects data for numerous locations from permanent weather stations and from weather satellites. Forecasting techniques are also available. Sea surface parameters measured with buoy systems are applicable to detail site surveys for structures.

MEASUREMENT OF PARAMETERS

To conduct site surveys for ocean floor structures, specialized equipment, vessels, and submersibles are required. A listing, therefore, has been prepared to facilitate selection of equipment for site surveying for specific structures. Since the field of oceanography is rapidly expanding, listings such as those prepared for this report soon become outdated. However, these listings are still useful for most structures currently being proposed for emplacement at various ocean floor sites.

Tables B-1 to B-9 of Appendix B list the various instruments that are available to assess the parameters required in site surveys. These tables are organized in the following categories:

positioning systems

core samplers

subbottom profilers

grab and dredge samplers

geological oceanographic systems

physical oceanographic systems

biological oceanographic samplers

underwater cameras and lights

These listings include the instruments on which information could be obtained from various manufacturers, distributors, and advertisements in periodicals.

Several instrument systems do not fall into such convenient groups. These instruments are used to assess the foundation supporting characteristics. Since this is the most important area of site selection and survey, comprising approximately 80% of the effort,[29] these instruments will be discussed first followed by the other items in the tables. The in-situ vane shear, cone penetrometer, plate bearing, long-term settlement devices, the Deep Ocean Test Instrument Placement and Observation System (DOTIPOS), and in-situ sediment density—water content probe will be discussed.

DOTIPOS System

The Deep Ocean Test Instrument Placement and Observation System (DOTIPOS) shown in Figure 15 has been designed for use in various seafloor project applications. It is approximately 18 feet high, 18 feet square, and weighs approximately 6,000 pounds in air and 2,500 pounds in seawater. Appurtenant parts to this device include a traction winch, diesel power unit, coaxial cable stowage drum, and an instrument van. The multiconductor coaxial armored cable, in addition to supporting the load, provides up to 15 kw of electrical power for use by various project in-situ test sensors and the TV monitoring system. The DOTIPOS is presently equipped for in-situ vane shear and cone penetrometer tests. Provisions have also been made for installing the long-term settlement devices with this system.

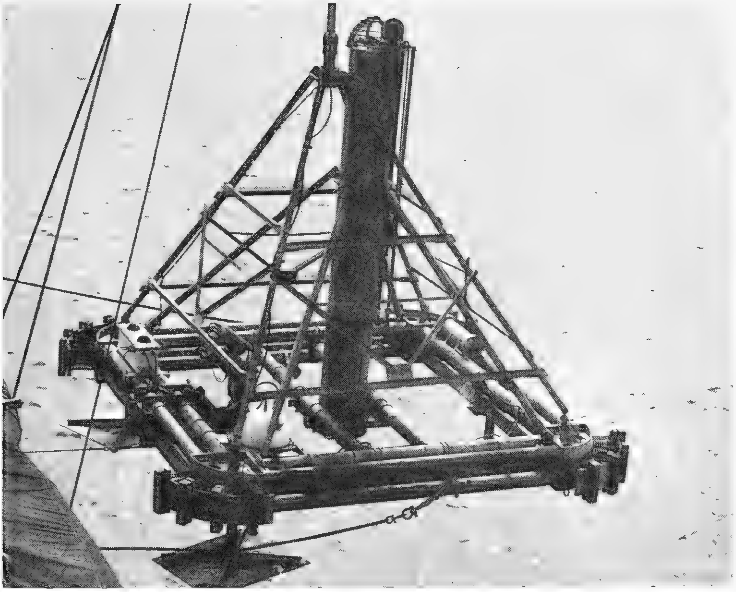

Figure 15. Deep Ocean Test Instrument Placement and Observation System (DOTIPOS) used in in-situ vane shear and cone penetrometer tests and in installing LOBSTERs.

In-Situ Vane Shear Device

The in-situ vane shear device[30] is capable of testing cohesive seafloor sediments in water depths to 6,000 feet and to sediment depths of 10 feet. This device is operated in conjunction with NCEL's DOTIPOS (Figure 15) as discussed earlier. Four-bladed vanes of various sizes ranging from 2 x 4 to 4 x 8 inches have been designed, the size to be used depending on the expected sediment strength range for a site. Sediments with shearing strengths up to approximately 10 psi can be tested with this device. Both initial and remolded sediment strengths can be assessed at selected sediment depth increments to 10 feet. A rotational speed of one revolution per hour is used for both tests. Remolding is performed at a rate of 10 revolutions per minute.

The test data are telemetered in analog form to the surface-support vessel through a combined coaxial load-handling and electrical cable. With the present system, these data are recorded on an oscillograph. A representation of the recorded field data is shown in Figure 16. The quantities recorded include penetration resistance, vertical position of the vane, torque, and rotational displacement of the vane. A series of traces such as that shown in the facsimile will comprise all the test data for one location to a 10-foot depth in the sediment.

The collected field data are reduced on the basis of the usual assumption[17] of the shear stress distribution around a vane. A typical peak-shear-stress-versus-sediment-depth plot is shown in Figure 17, which represents the strength profile at a particular location in the waters off the Southern California coast.

This vane shear device is considered primarily a tool for performing research on seafloor sediments for the purpose of determining the relationship between laboratory-measured values and in-situ-measured values of strength.

In-Situ Cone Penetrometer Device

The in-situ cone penetrometer device[31] is used also with the DOTIPOS to conduct static cone penetration tests in sediments. The depth capabilities of this device are the same as for the vane shear device. The conversion from the vane shear mode to the penetrometer mode is accomplished simply by replacing the vane with the cone penetrometer. The cone being used has a 90-degree apex angle, a diameter of 2.256 inches (4 square inches projected area), and a height of 1.625 inches.

In testing with this device, the cone is pushed into the sediment at a constant displacement rate of 10 inches per minute. During penetration, the force to drive the cone into the sediment and the depth of penetration are continuously recorded on deck through the same system as for the vane shear device. An example of the type of data obtained from reduction of the records is shown in Figure 18, which is a plot of penetration resistance versus depth in the sediment.

The static cone penetrometer test results can be related to the peak shearing strength of the sediments. This relationship has to be evaluated for marine sediments before the full meaning of the penetrometer test values can be understood and utilized.

The penetrometer test has advantages over the vane shear test in determining sediment strength properties. The penetrometer has the capability of performing tests more rapidly than the vane shear device. It also produces a continuous profile of strength with depth rather than at discrete depths as obtained by the vane shear. The vane shear, however, has the capability of testing remolded sediments, the strengths of which will be a controlling factor for many ocean construction projects and operations.

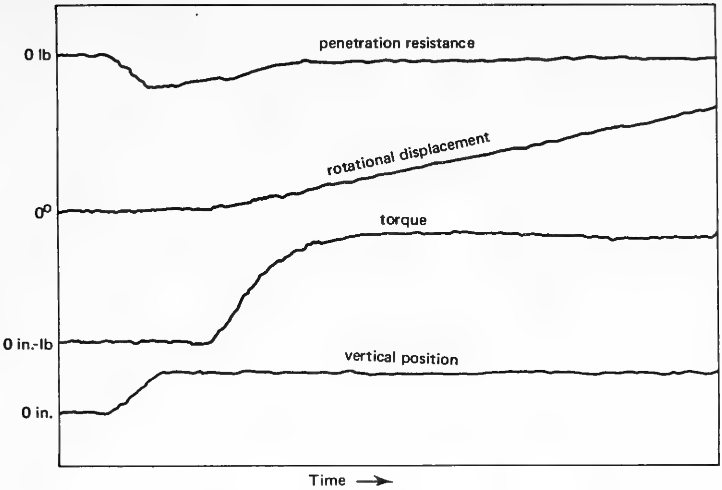

Figure 16. Representation of an oscillograph record from a vane shear test.

In-Situ Plate Bearing Device

The in-situ plate bearing device[32,33] shown in Figure 19 is used to assess the short-term bearing pressure—settlement response of the near-surface sediments. The device consists of a movable weight to which various sized plates are attached. The movable weight is supported by three hydraulic cylinders, which are metered to control the vertical displacement rate. The plates can be subjected to a maximum displacement of 11 inches. A tripod framework, used to guide the movable weight and support associated equipment, is in turn connected to three articulated bearing pads. The equipment has the capability to accommodate plate sizes up to 18 inches in diameter and can apply a total plate load of 6,000 pounds. The force acting on the plate during a test is monitored by a pressure-equalized electronic load transducer. Plate settlement is monitored by a linear potentiometer. The present depth limitation of the device is 12,000 feet—the limit of the pressure housing for the acoustic telemetry system.

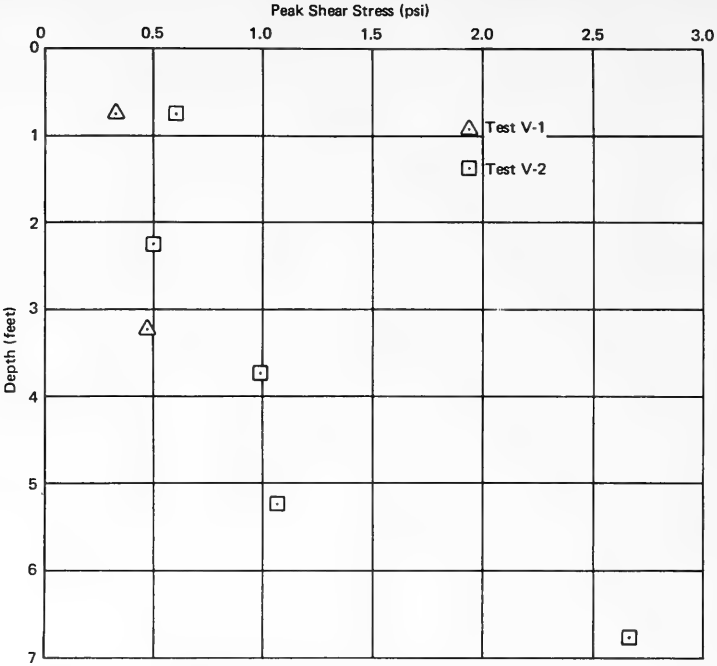

Figure 17. Peak shear stress versus depth determined from in-situ vane shear tests in a cohesive sediment off Pitas Point, California.

The acoustic telemetry system is used to transmit the test data to the support vessel; therefore, only a load-handling line is required from the vessel to this device. The transmitted data, in analog form, are monitored by a hydrophone receiver aboard the surface vessel, where signal conditioning and recording equipment are also located. Figure 20 is a representation of an oscillograph record which shows the quantities recorded for each test. Included in this oscillograph record are the measurements for load, displacement, and attitude of the device at corresponding times. An example of the data obtained from these records is shown in Figure 21, which presents load—settlement curves for various plate diameters for sediments in 6,000 feet of water off San Miguel Island.

The device is primarily a research tool being used to investigate the short-term bearing pressure—settlement response of a variety of marine sediments, initial studies of which have been reported by Kretschmer.[33] The relation between the laboratory-measured properties of the sediments and their response to footing loads as measured by the plate bearing device is being studied to enable the prediction of the short-term bearing pressure—settlement response for a proposed foundation on the basis of laboratory tests on core samples.

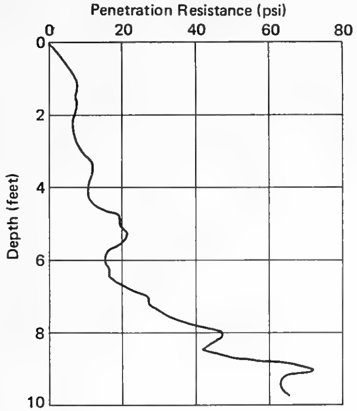

Figure 18. Static cone penetration resistance versus depth for cohesive sediments located off Pitas Point, California.

Long-Term Settlement Device

Structures founded on soft cohesive sediments typical of the deep-ocean areas will be subject to large long-term settlements resulting from consolidation of the underlying sediment layers. Such foundations can be designed for these large total and differential settlements or they can be designed to minimize these settlements by proper load distribution. Such designs require a knowledge of the in-situ sediment properties affecting long-term foundation settlement. These properties may be obtained from laboratory tests on core samples; however, the effects of core disturbance make it preferable to measure some of the more critical properties in situ.

The LOBSTER[34] (Long-Term Ocean Bottom Settlement Test for Engineering Research), a schematic of which is shown in Figure 22, is an in-situ test system designed to evaluate those sediment properties which control long-term foundation settlement. The overall diameter of the device is 6 feet. It is designed to be a large model footing capable of applying a low bearing pressure (approximately 100 psf over an area which has a diameter of 4 feet) to the seafloor. The resulting settlement is measured relative to an isolated reference system founded deep in the sediment beneath the footing. The settlement data including total settlement and differential settlement (foundation tilting) are monitored and recorded hourly on highly sensitive and accurate digital tape systems housed within instrument capsules attached to the footing as shown in the figure. The LOBSTER has the capability of measuring total settlements as great as 36 inches and foundation tilting as great as 15 degrees.

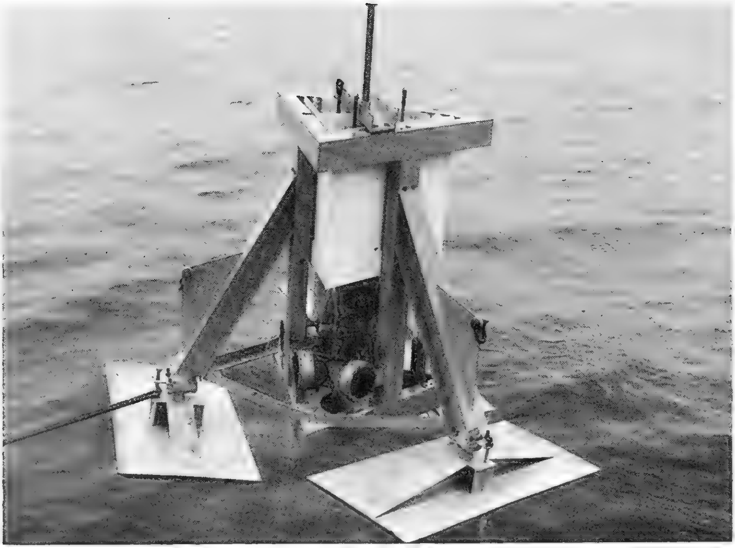

Figure 19. In-situ plate bearing device for assessing short-term bearing pressure settlement response of near-surface sediments.

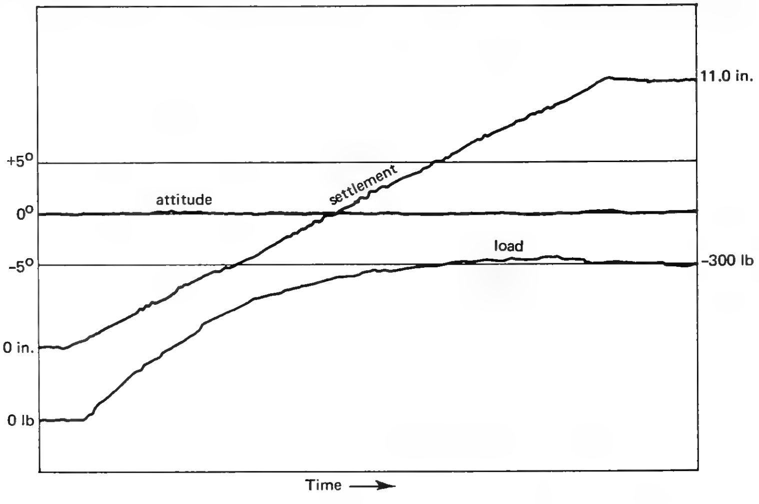

Figure 20. Representation of an oscillograph record from a plate bearing test.

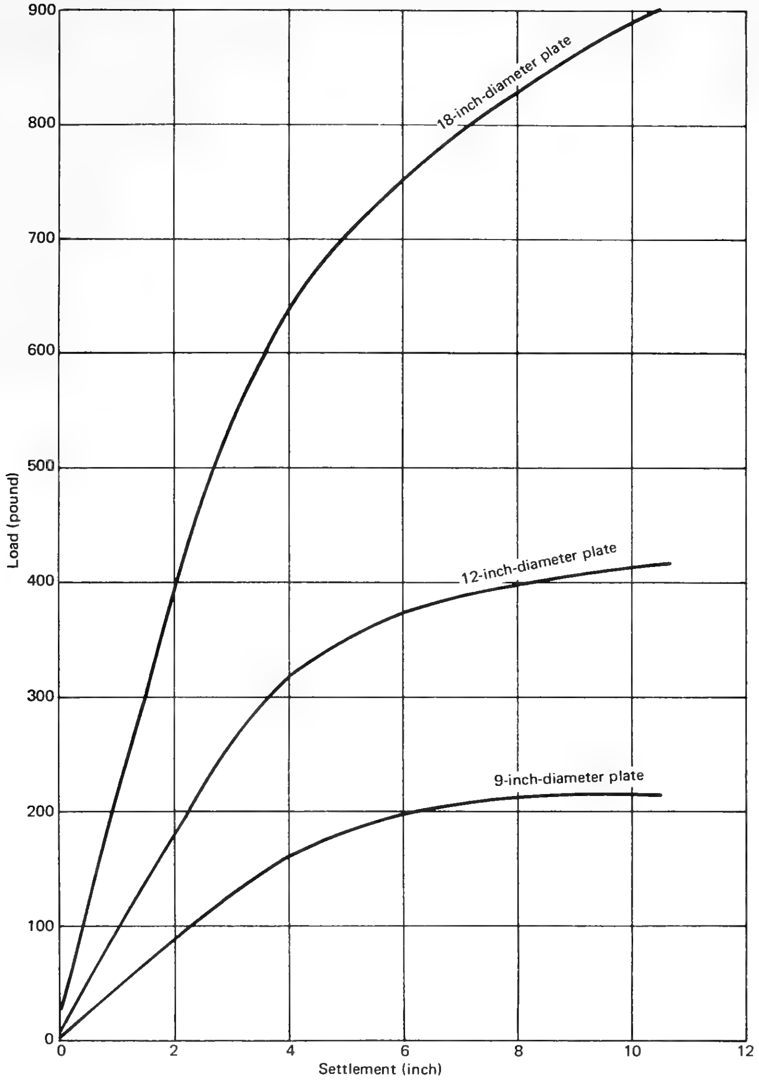

Figure 21. Load—settlement relationships from in-situ plate bearing tests for sediments in 6,000 feet of water off San Miguel Island.

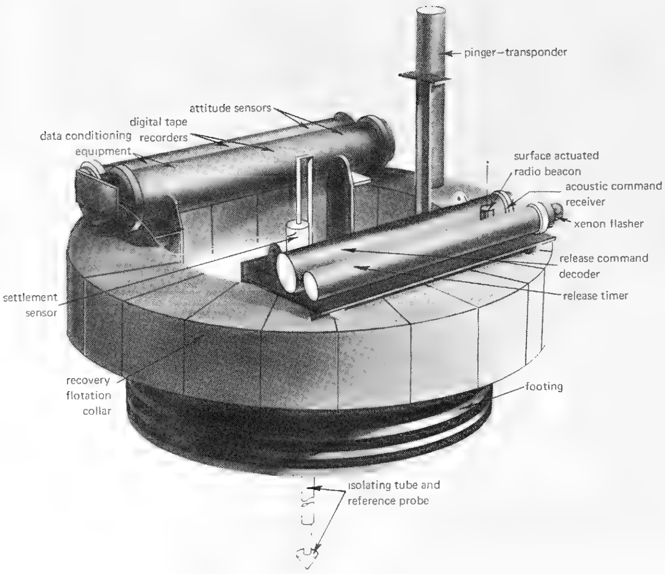

Figure 22. In-situ long-term settlement test device—LOBSTER.

The footing with attached instrumentation and the reference system will be installed on the seafloor in water depths to 6,000 feet with the DOTIPOS. Once the installation procedure is completed and the DOTIPOS removed, the LOBSTER continues its mission for a preselected duration of up to 1 year.

At the end of the preselected duration of the test or upon special acoustic command, the instrumentation capsules with attached relocation and recovery aids are released from the footing and brought to the surface by the floatation system. The digital tapes are then removed and the data reduced and analyzed. An example of the type of information to be obtained with this device is shown in Figure 23, which represents the results of a shallow-water system checkout in Mugu Lagoon. The instrumentation and recovery system, after overhaul and checkout, is fitted with another expendable concrete footing and reference system for installation in another site.

Data obtained from the deployment of a LOBSTER at the site of a proposed structure would be used in the design of the prototype foundation. Extrapolations may be made from the observed performance of the LOBSTER footing to predict the performance of the larger prototype foundation.

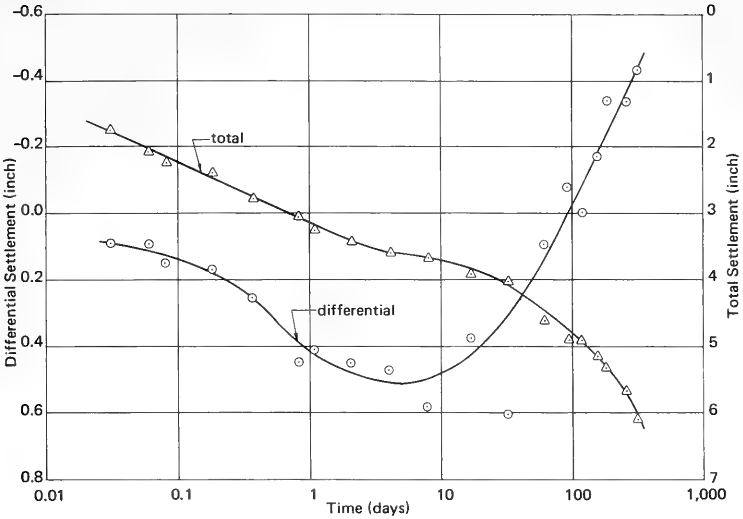

Figure 23. Example of results from a long-term settlement test (in Mugu lagoon sediments).

In-Situ Sediment Density—Water Content Probe

A device to measure sediment density and water content is being considered for development by NCEL. It is contemplated to design this device for a 10-foot sediment penetration initially. With the capability of rapid in-situ determinations, this tool will be useful in site survey and selection procedures. It is anticipated to use the collected results from this device combined with the other in-situ tests for the design and analysis of small structures and footings (<10 feet square).

Corers

Oceanographic corers have been the primary tool for retrieving sediment samples for engineering and geological analysis. Several types of these corers and other samplers with respective manufacturers are listed in Table B-1. Corers commonly used include the Kullenberg, Ewing, and other miscellaneous types such as the Phleger and free-fall corer (Boomerang and Moore Free Fall). With the objective of decreasing sample disturbance by attempting to fulfill criteria for corers suggested by Hvorslev,[20] several corers have been developed including the Hydroplastic by Richards and

Keller[35] and the Sigma by Inderbitzen.[36] These corers have the desirable feature of a larger diameter than the others, but the flexibility of the plastic core barrel prevents their taking long samples. The study of coring techniques for engineering purposes performed by Richards and Parker[21] will aid in the selection of corer type for use in a given application.

Corers using driving techniques other than gravity also have been developed. Gas-propelled corers include the Gas Operated Sea Floor Sampler[37] and the Free Fall Rocket Corer.[38] The DIVCOR developed by DIVCON, Inc. of Houston uses a bottom-sitting platform with a drilling technique to penetrate the sediment. This device has a 600-foot water depth limitation at the present time. Corers utilizing vibratory action as a driving means include the VIBRO-CORE[39] and the VIBRA-CORER.[40]

From studying the capabilities of present equipment, it is concluded that a new coring system is required. The new system should utilize a bottom sitting platform to enable taking incremental samples of the sediment column and should be capable of deeper penetration of the sediments than is now attainable with gravity-driven samplers. This sampler also should be capable of functioning in the deep ocean. Accordingly, NCEL is developing such a corer system based on an automated drill rig concept.

The development of the NCEL automated drill rig corer is currently in the final design stage. When completed, the corer will have the capability to take relatively undisturbed incremental samples 3 inches in diameter and 5 feet long from sediment depths to 50 feet in water depths to 6,000 feet. The corer will be capable of sampling primarily cohesive sediments. The coring system will be composed of the submersible automated drill rig which will rest on the seafloor during sampling operations, a coaxial load/power cable, winch, power supply, and a control console.

Positioning Systems

The techniques used for determining positions at sea include electronic, acoustic, laser, and visual systems. Each system has its particular applications and limitations. The most commonly used technique is the electronic. The laser and visual systems are limited to line-of-sight surveys; thus, applications are limited to near-shore areas. Instruments using these techniques will now be discussed.

Table B-2 is a listing of electronic positioning systems that may be suitable for use in a particular survey problem. This listing is based on the information presented by Ferrara[41] in his report on electronic positioning systems for surveyors. As indicated in this table, there are some limitations to each of the systems. Differences in atmospheric conditions at different times cause errors in observed positions. Intervening land and objects interfere with transmitted signals. Additionally, as indicated by Bigelow[42] and by SEISCOR,[43] instrument errors, signal propagation errors, and operator errors also affect the repeatability of readings. In general, most of the indicated electronic systems are not satisfactory for engineering surveys. However, the systems utilizing land-based triangulation survey techniques may be satisfactory for structures of minor importance. These systems are limited to line-of-sight areas.

The use of a satellite system appears to be very promising for navigation in open ocean areas. It can be used for navigating to some pre-selected general site, which can then be precisely surveyed utilizing a locally more accurate and relative means of positioning.

The use of bottom acoustic systems for positioning, such as those offered by Alpine Geophysical, Edo Western, and Bendix, may be sufficiently accurate for the requirements of many structures. These systems coupled with a dynamic ship-positioning system, such as is installed on the A. C. Electronics vessel, the *Swan*, may fulfill the survey positioning requirements of many seafloor projects. It is believed, however, that the best accuracies for positions would be obtained by using submersibles together with these acoustic systems which are placed at known absolute coordinates with respect to the reference system used by the U.S. Geodetic Survey.

The use of lasers for precise locations has been attempted by several organizations. As indicated by Thomas,[44] experiments are being conducted with lasers to replace the light sources in Geodimeters. For underwater applications, TRW Systems Group[45] has developed a laser surveying system for diver operations at water depths to 60 feet. The system consists of a unit analogous to a surveying transit, a stadia rod, and a tape. The design objective accuracies for distance and angles of the system are on the order of ±0.5 foot and ±10 minutes, respectively, for locating corners of a rectangle 30 x 90 feet. Lasers also have been used on various terrestrial construction projects. The major limitation of laser techniques is that they are applicable only to line-of-sight surveys. In underwater applications of lasers, the light energy is attenuated by the many particles in the water column such as plankton and organic debris.

The visual survey systems include the use of transits or theodolites in triangulation techniques. The base line for the triangulation survey is usually on land, but part of this line could span bodies of water. Since these techniques are routinely used in terrestrial surveys, they will not be discussed here.

Subbottom Profilers

This discussion of subbottom profilers is based principally on the survey made by Schlank[46] on currently available profiling equipment. A summary of the manufacturers of subbottom equipment and the various profiling systems, energy sources, detectors, and recorders is shown in Table B-3. Some of these systems shown are high-resolution, shallow-penetration profilers that are applicable to surveys for seafloor structures.

A subbottom profiling system consists of four components: energy source, detector system, amplifier and filter, and recorder. There are many types of energy sources, the common names of which include the following: transducers, sparkers, boomers, line sources, pneumatic sound sources, and thermodynamic sources. The actual sound is created by electromechanical, electric spark, pneumatic, gas explosion or other means. The detector system is usually an array of hydrophones that complement the type of sound source being used.

The objective of a subbottom system for use in surveying for ocean-floor structures is to be able to delineate structural characteristics of the seafloor which may influence the stability of the structure. These characteristics may include a very thin layer (<6 inches) of weak sediments, a similar layer which could be the path for a failure plane, tension cracks, discontinuities, and faults. To detect these features, it is necessary to utilize high resolution profilers.

The limitations of the profiling technique in general are significant, although efforts are being made to minimize and understand these effects. These limitations include the inability to accurately establish the velocity of sound through the various sediment layers in a given profile, to differentiate extraneous signals and noise, and to accurately interpret records that include side echoes and multiple reflections. Therefore further research in subbottom profiling systems is required to develop one suitable for site surveying for seafloor structures.

These subbottom profilers, various bottom profilers, and side-scan devices are summarized in Table B-4.

Bottom Mapping Systems

There are basically two ways to develop topographic charts of the seafloor. The first method is by the use of a bottom profiler such as a Precision Depth Recorder (PDR), Precision Graphic Recorder (PGR), or similar depth-sounding system together with a surface positioning system. This technique is based on the velocity of sound through the water column. Since the velocity of sound is a function of the salinity, temperature, and pressure of the water, a correction for these factors is required. The recording of the depth and respective positions during the survey on magnetic tape in computer-processable format, as is being done by NCEL, facilitates data reduction and application of corrections. Maps developed by the use of these sounding techniques from the water surface are deficient for surveys for seafloor structures. This deficiency was demonstrated by the survey conducted with the *Alvin*.[47] The echogram aboard the surface support vessel *Lulu* indicated a gentle rise over a particular area where as the *Alvin* actually determined a 200 meter (650 feet) near vertical cliff existed. Other similar situations can be demonstrated with the use of submersibles.

An improvement over the above technique involves the use of submersibles near the bottom with depth profilers and a local positioning system. At least one submersible has the capability to collect data in this fashion to later develop contour charts of the area. However, both the submerged and the surface technique are based on the propagation of sound emitted from a source; in some cases in a cone-shaped spectrum as large as 60 degrees. In many instances because of the wide cone of emission, the first echo (usually considered to be the bottom) may not be the depth to the bottom directly under the recorded surface position. Thus, a better system for mapping the seafloor is required.

The need for a better system for mapping the seafloor has stimulated the U.S. Naval Oceanographic Office (NAVOCEANO) to develop the photogrammetric technique for ocean applications. Initial phases of this development using a diver-operated vehicle were reported by Pollio.[48] The results obtained using this technique are satisfactory for application to structures on the seafloor. It was possible to draw contours to 1 decimeter (about 4 inches) with the collected data. Application of this technique to deep water using manned submersibles presents additional problems. These problems, as outlined in Pollio's paper, include improving camera systems, positioning systems, and submersible performance. In addition to NAVOCEANO, another organization pursuing the development of photogrammetric methods is NURDC, San Diego.

The photogrammetric technique, at the moment, appears to be the most promising to develop contour charts for application to structures on the seafloor. However, imaging techniques and laser techniques being developed may also prove fruitful.

Systems for Measuring Physical and Chemical Parameters

Instruments for assessing the physical and chemical oceanographic parameters of significance to ocean structures are listed in Table B-5. Included in this table under each manufacturer are the various instruments for determining water depth, salinity, temperature, dissolved oxygen, pH, sound velocity, and currents. A number of instruments have the capability to assess two or more parameters at the same time. For example, the Litton STD probe measures conductivity (salinity), depth, and temperature. There are other probes in the listing that measure the same parameters. The term *cable-connected* indicates whether the instrument requires electrical and telemetering cables from a surface or submersible vessel.

The use of a specific instrument system for site surveys will be dictated by the requirement and scope of the particular seafloor structure.

Grab and Dredge Samplers

The equipment for sampling surficial sediment layers and rocks is discussed here and listed in Table B-6.

Grab Samplers. These are of two types: clam shell and snapper. Most are bottom trigger operated. These are lowered in a cocked, open position, but on contact with the ocean bottom, a lever trips a catch and a powerful spring causes the jaws to snap shut enclosing a sediment sample. These types include the Berge-Ekman dredge, Dietz-LaFond sampler, Emery foot trip (modified Pettersen), and the mud snapper.

Orange Peel Bucket Dredges. These operate on the same principle as the grab samplers but are mechanically controlled upon retrieval. As tension is placed on the retrieval wire, a pulley arrangement closes the jaws entrapping a sample. A canvas cover is usually used over the top of the mechanism to prevent the sample from being washed out.

Tubular Sampler. These resemble corers except for the length of the sample. They free-fall into the bottom and the sample is retained in a small plastic tube.

Scoopfish (Emery-Champion). This type is towed and falls free to the bottom where it digs into the bottom and trips a mechanism which closes a cap and at the same time reverses the sampler which is retrieved vertically with the digging end up.

Pipe Dredges. These are as the name implies, a large pipe with one end sharpened and the other end closed by a mesh. They are allowed to lie on the ocean bottom and are dragged horizontally to fill the sampling cavity.

Rock Dredges. These are rectangular boxes made of metal frames with metal mesh and digging teeth. They are dragged along the bottom to break off and recover rocks. Sediment is not retained because the mesh netting is large. The front end is always kept open.

Biological Dredges. These are the same as the rock dredges except the teeth are smaller and the mesh is finer to retain biological samples such as shrimp, worms, etc.

Blockade Sampler. These resemble the tubular sampler except the sample is taken horizontally and features a messenger-activated closing device which moves over the mouth of the sampling tube to prevent the captured sample from being washed away during recovery.

Rectangular Box Sediment Sampler. This sampler consists of an open-bottom, rectangular-shaped box mounted at the end of a sturdy sliding vertical bar. A triggering mechanism permits the sampler to plunge into the bottom. A lever mechanism permits closure of the bottom end upon initiation of withdrawal. This sampler provides an undisturbed sample for tests and analyses of stratification of the near-surface layers. This device causes less disturbance than the other samplers mentioned above.

Biological and Water Samplers

Table B-7 includes the various available instruments for collecting biological and water samples. The specific instrument to be used for a particular survey will be dictated by the requirements and scope of the seafloor structure.

Further research is required in this area of biological and water sampling to determine parameters which are responsible for the initial causes of corrosion and fouling. Once these causes are identified, a particular instrument listed may be applicable to sample collection.

Underwater Cameras and Lights

Tables B-8 and B-9 are listings of underwater cameras and lights, respectively. Some of these instruments are designed into a package that will also permit taking grab samples of the seafloor.

The camera—light system for use in a particular survey is dictated by the scope and requirements of the particular structure. For example, the use of these instruments in stereo mapping applications will require special lens designs to eliminate distortions. The use of color and range gating techniques would also require special considerations in design. The design of a particular camera system would therefore require the services of personnel experienced in that particular field of application.

Oceanographic Research Vessels

Table C-1 lists the various surface oceanographic research vessels being used by U.S. Government agencies and universities. The information on most vessels in the table was obtained from publications on oceanographic vessels of the world which were prepared by the IGY World Data Center and the National Oceanographic Data Center.[49] Since these publications were prepared several years ago, information on some of the vessels may be slightly outdated. Information on the remaining vessels was obtained from various miscellaneous sources. The purpose of this listing is to identify all of the vessels that may be available for use in a particular survey project. These vessels are operated by the designated organizations, whose work may have priority; however, use of these vessels may be arranged by others, in some cases on a "not to interfere" basis. As an example, NCEL used the Bureau of Mines vessel *Virginia City* on this basis.

There are many oceanographic vessels owned by various private enterprises that may also be available for use in a particular survey project. The preparation of an exhaustive list of these vessels has not been attempted. A brief survey was conducted by NCEL to determine the type of vessels, costs, and other features of the vessels that are available for lease along the Southern California coast. Although these vessels are available for lease, in most cases a long lead time is required to secure their use. Costs for these vessels ranged from approximately $500 per day for a 65-foot-long vessel to $2,500 per day for a 185-foot-long vessel. In general, costs were variable and depended on ship size, available equipment, and other factors.

Submersibles

Table C-2 is a listing of various oceanographic submersibles in operation, or being designed or fabricated in the United States. The information in this table was abstracted from Reference 50 and other sources. Many of the submersibles operated by private industries are available for lease, although the cost to lease these submersibles is high. Depending on the particular submersible, the cost for leasing a submersible could range from $3,000 to $10,000 per day. The particular submersible that can be used will be dictated by the cost, the availability of the submersible, and the requirements of the particular survey project.

DATA PROCESSING AND ANALYSIS

There are many specialized instruments and techniques to process and analyze data collected in site surveys. Systems which are generally applicable to site surveys, will be described; specialized systems associated with a particular manufacturer's product will not be discussed.

In foundation engineering, computers have been used to process and analyze data on ocean sediments. Reference 51 is an accumulation of data processing and analysis techniques for tests on sediment core samples. In this reference are Fortran computer programs for reducing data from tests on engineering index properties, particle size, carbonate–organic carbon content, direct shear, triaxial shear, consolidation, and permeability. A program for settlement analysis is also included. This latter program incorporates values from the various test results to compute total settlement values due to consolidation for various characteristics of a given structure. Reference 52 contains programs which were originally written for application to terrestrial soils, but may be used, with possibly minor modification, for seafloor sediments. These programs use magnetic tapes for data input and output. The reduction of data from in-situ plate bearing tests has also utilized computer methods.

Computer methods have been applied to the determination of the geological characteristics of a site in site surveys. Seismic surveys, in particular, have received concentrated efforts directed to the application of computer methods. Data from these surveys are stored and later processed by computers with associated equipment which develops records for further studies and evaluation. Specialized equipment is also available which will process the data aboard the vessel and present the data in real time.

The tedious task of developing contour charts for a given site has been simplified and preparation time reduced by computer methods. Two examples of programs developed for this purpose are those developed by IBM (International Business Machines) and CALCOMP (California Computer Products, Inc.). The first system is called the IBM 1130 Numerical Surface Techniques and Contour Map Plotting. The CALCOMP system is called General Purpose Contouring Program (GPCP). The GPCP is claimed to be about 30 times faster than manual contouring techniques. An example of a map prepared by one of these programs (GPCP) is shown in Figure 24.

Physical and chemical oceanographic data have been processed by various computer techniques. Data obtained with in-situ probes for salinity, temperature, and depth which are recorded in computer-compatible formats are swiftly and conveniently reduced by computer procedures. The computation of temperature and thermometric depth from reversing thermometer data is facilitated by a computer program, such as that shown in Appendix D. Plots of current direction and magnitudes (histograms)[53] are prepared as a routine computer operation. There are many more computer programs for processing oceanographic data that are being used by activities in this field.

There has been some investigation of statistically processing biological data. These data, however, are not readily amenable to collection in computer-compatible form in site surveys.

The processing of surface data is almost routine. Data gathered by oceanographic buoys can either be stored or telemetered to a shore- or ship-based station and then easily processed by computer procedures.

Figure 24. Sample contour chart prepared by Cal Comp GPCP in Basic Mode.

From the above discussion on data processing and analysis, it is apparent that in most cases the data gathered from site surveys should be processed and analyzed by computer techniques. These techniques are more rapid, accurate, convenient, and economical than manual techniques. Unfortunately, since the requirements of each site survey differ, a step-by-step procedure cannot be established for data processing and analysis that would be applicable to all situations. The many computer programs written for particular problems by the various researchers in the oceanographic field, however, could be used in numerous cases, if they were available. Such programs can best be retrieved through the NODC (National Oceanographic Data Center). The programs available from NODC are usually referenced in their publications on summaries of computer programs, for example C-5.[54]

PRESENTATION OF RESULTS

There are a number of forms in which data from site surveys can be reported, such as, photographs, charts, graphs, tables, and logs. The choice of which form to use depends on the quantity and parameter being reported. In general, the selection should be governed by the question: "Which form is most explicit in conveying the information?" A mosaic of photographs is sometimes more useful than separate single shots. Charts, graphs, and tables are constructed easily by computer methods from field data. Since each problem may be unique, it is difficult to prescribe rules for presenting data for all site survey parameters. The method of presenting data is thus dependent mainly on one's own judgement.

CONCLUSIONS

The requirements for a given structure will govern the extent and type of parameters to be assessed in the site survey. In general, however, those parameters significant to the stability of the structure will have to be assessed for all structures. A definite set of rules cannot be established that would be applicable to site surveys for all structures. The data reduction and analysis of parameters measured in these site surveys, however, are in general best accomplished by computer techniques.

RECOMMENDED AREAS OF RESEARCH

Three areas requiring immediate concentrated research are positioning, bathymetry, and core sampling. It is recommended that capabilities in these areas be improved to fulfill the needs for site surveying for engineering structures.

Appendix A

POSSIBLE SOURCES OF SITE SURVEY INFORMATION

Table A-1. Possible Sources for Bathymetric Charts

Continental Shelf Data Systems, 424 Denver Hilton Office Building, Denver, Colorado

Geological Society of America, Box 1719, Boulder, Colorado 80302

World Data Center/A, Oceanography, Washington, D. C. 20390

National Geographic Society, 17th and M Street, N. W., Washington, D. C. 20036

U. S. Coast & Geodetic Survey, ESSA, Rockville, Maryland

Naval Oceanographic Distribution Center, Clearfield, Utah 84016 and 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120

Oregon State University, Department of Oceanography, Corvallis, Oregon

Scripps Institution of Oceanography, University of California, La Jolla, California

Texas A & M University, College Station, Texas 77843

University of Hawaii, Department of Geophysics, 2444 Dole Street, Honolulu, Hawaii 96822

University of Miami, Coral Gables, Florida 33124

University of Rhode Island, Kingston, Rhode Island 02881

University of Washington, Seattle, Washington 98105

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

Table A-2. Possible Sources for Underwater Photographs

Organizations and Individuals

Naval Oceanographic Office, Washington, D. C. 20390

National Oceanographic Data Center, Navy Yard Annex, Bldg. 160, Washington, D. C. 20390

Academy of Underwater Photographers, 2190 Alson Road, Santa Barbara, California

Jacques Yves Cousteau, Oceanographic Museum of Monaco, 16 Boulevard de Swisse, Monte Carlo, Monaco

Harold E. Edgerton, Edgerton, Germeshausen and Grier, Inc., Systems Division, 95 Brookline Avenue, Boston, Massachusetts 02215

Hydro Products, Division of Dillingham Corporation, 11803 Sorrento Valley Rd., San Diego, California 92121

Life Magazine Nature Books, Time & Life Building, Rockefeller Center, New York, N. Y. 10020

National Geographic Magazine, 17th and M Streets, N. W., Washington, D. C. 20036

Dimitri Rebikoff, Rebikoff Underwater Products, Inc., 245 S. W. 32nd St., Fort Lauderdale, Florida 33315

Carl Shipek, NURDC, San Diego, California 92132

Atlantic Richfield Oil Company, 260 South Broad Street, Philadelphia, Pennsylvania 19101

Gulf Oil Company, Gulf Building, Pittsburgh, Pennsylvania 15230

Humble Oil and Refining Company, Box 2180, Houston, Texas 77001

Phillips Petroleum Company, Bartlesville, Oklahoma 74004

Socony Mobil Oil Co., Inc., 150 East 42nd Street, New York, N. Y. 10017

Sun Oil Company, 1608 Walnut Street, Philadelphia, Pennsylvania 19103

Texaco Oil Company, 135 East 42nd Street, New York, N. Y. 10017

Union Oil Company of California, Union Oil Center, P. O. Box 7600, Los Angeles, California 90054

Magazines

Oceanology International, Industrial Research Publications Company, Beverly Shores, Indiana 46301

Ocean Industry, Gulf Publishing, P. O. Box 2608, Houston, Texas 77001

Offshore, Petroleum Publishing Company, 211 South Cheyenne, Box 1260, Tulsa, Oklahoma 74101

UnderSea Technology, Compass Publications Inc., Suite 1000, 1117 N. 19th Street, Arlington, Virginia 22209

Bibliography

Eastman Kodak Company. Pamphlet no. P-124: Bibliography on underwater photography and photogrammetry. Rochester, New York, 1968.

Table A-3. Possible Sources for Information on Sediment Geological and Engineering Properties

Journals

Bulletin of Geological Society of America, Box 1719, Boulder, Colorado 80302

Bulletins of Research Organizations

Journal of Geology, University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois 60637

Journal of Marine Research, Sears Foundation of Marine Research, Box 2025, Yale Station, New Haven, Connecticut 06520

Journal of Paleontology, Box 979, Tulsa, Oklahoma 74101

Journal of Sedimentary Petrology, Box 979, Tulsa, Oklahoma 74101

National Research Council, Annual Report, 2101 Constitution Avenue, N. W., Washington, D. C. 20025

Proceedings of Conferences, Congresses and Councils on Oceanography and Instrumentation

Transactions of the American Geophysical Union, 2100 Pennsylvania Ave., N. W., Washington, D. C. 20037

Government Organizations and Universities

Naval Civil Engineering Laboratory, Port Hueneme, California 93041

Naval Oceanographic Office, Washington, D. C. 20390

California Division of Mines and Geology, 1416 9th Street, Sacramento, California 95814

University of Southern California, University Park, Los Angeles, California 90007

U. S. Bureau of Mines, Marine Minerals Technology Center, 3150 Paradise Drive, Tiburon, California 94920

U. S. Geological Survey, 18th and F Streets, N. W., Washington, D. C. 20242

Magazines

Deep-Sea Research and Oceanographic Abstracts, Pergamon Press, Inc., Maxwell House, Fairview Park, Elmsford, New York 10523

Table A-4. Possible Sources for Oceanographic Data

Universities and Colleges

Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

Scripps Institution of Oceanography, University of California, P. O. Box 109, La Jolla, California 92037

Oregon State University, Corvallis, Oregon 97331

Texas A & M University, College Station, Texas 77843

University of Hawaii, 2444 Dole Street, Honolulu, Hawaii 96822

University of Miami, Coral Gables, Florida 33124

University of Rhode Island, Kingston, Rhode Island 02881

University of Washington, Seattle, Washington 98105

U. S. Naval Laboratories

Naval Civil Engineering Laboratory, Port Hueneme, California 93041

Naval Oceanographic Office, Washington, D. C. 20390

Naval Postgraduate School, Monterey, California 93940

Naval Undersea Research and Development Center, Pasadena and San Diego, California 92132

Oceanographer of the Navy, The Madison Bldg., 732 N. Washington Street, Alexandria, Virginia 22314

Office of Naval Research, Washington, D. C. 20360

U. S. Government Agencies

Environmental Science Services Administration, Washington Science Center, 1180 Old Georgetown Road, Rockville, Maryland 20235

Environmental Science Services Administration, Atlantic Oceanographic Laboratories, 901 S. Miami Avenue, Miami, Florida 33130

Environmental Science Services Administration, Pacific Oceanographic Laboratories, 1801 Fairview Avenue, East Seattle, Washington 98102

World Data Center A, Oceanography, Washington, D. C. 20390

National Oceanographic Data Center, Navy Yard Annex, Bldg. 160, Washington, D. C. 20390

U. S. Army Coastal Engineering Research Center, 5201 Little Falls Road, N. W., Washington, D. C. 20016

U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi 39180

U. S. Bureau of Mines, Department of Interior, Tiburon, California 94920

Other Sources

Interagency Committee on Oceanography. ICO Pamphlet no. 9: Bibliography of oceanographic publications, Washington, D. C., April 1963

American Meteorological Society. Bibliography on Marine Corrosion, compiled by P. A. Keehn, Washington, D. C. 1967. (Special bibliographies on oceanography. Contribution No. 4)

Bulletin of National Research Council, 2101 Constitution Avenue, N. W., Washington, D. C. 20025

Journal of Marine Research, Sears Foundation, Yale University, New Haven, Connecticut 06520

Limnology and Oceanography, Allen Press, Lawrence, Kansas 66044

American Meteorological Society. Collected bibliographies on physical oceanography (1953-1964), Washington, D. C., 1965. (Special bibliographies on oceanography. Contribution No. 1)

Table A-5. Possible Sources for Marine Geological Data

U. S. Government Activities

National Oceanographic Data Center, Navy Yard Annex, Bldg. 160, Washington, D. C. 20390

Defense Documentation Center, Building 5, Cameron Station, Alexandria, Virginia 22314

Chief, Input Section, Clearinghouse for Federal Scientific and Technical Information, 5285 Port Royal Rd., Springfield, Virginia 22151

Books

K. O. Emery. The sea off southern California, New York, Wiley, 1960

F. P. Shepard. Submarine geology, 2nd ed., New York, Harper and Rowe, 1963

California Division of Mines and Geology. Special Report 44: Bibliography of marine geology and oceanography, California Coast, Sacramento, California, 1955

Articles

Lamont-Doherty Geological Observatory, Columbia University, Palisades, New York 10964

National Science Foundation, 1800 G Street, N. W., Washington, D. C. 20550

U. S. Coast and Geodetic Survey, Washington Science Center (1), 1180 Old Georgetown Road, Rockville, Maryland 20325

World Data Center A, Oceanography, Washington, D. C. 20390

Journals

American Journal of Science, Yale University, Kline Geology Laboratory, New Haven, Connecticut 06520

Bulletin of American Association of Petroleum Geologists, Box 979, Tulsa, Oklahoma 74101

Bulletin of Geological Society of America, Box 1719, Boulder, Colorado 80302

Journal of Geophysical Research, American Geophysical Union, Suite 435, 2100 Pennsylvania Avenue, N. W., Washington, D. C. 20037

Journal of Geology, University of Chicago Press, 5750 Ellis Avenue, Chicago, Illinois 60657

Journal of Paleontology, Box 979, Tulsa, Oklahoma 74101

Journal of Sedimentary Petrology, Box 979, Tulsa, Oklahoma 74101

Magazines

Oceanology International, Industrial Research Publications Company, Beverly Shores, Indiana 46301

Ocean Industry, Gulf Publishing, P. O. Box 2608, Houston, Texas 77001

Offshore, Petroleum Publishing Company, 211 South Cheyenne, Box 1260, Tulsa, Oklahoma 74101

UnderSea Technology, Compass Publications, Inc., Suite 1000, 1117 N. 19th Street, Arlington, Virginia 22209

Petroleum Industry

Atlantic Richfield Oil Company, 260 South Broad Street, Philadelphia, Pennsylvania 19101

Gulf Oil Company, Gulf Building, Pittsburgh, Pennsylvania 15230

Humble Oil and Refining Company, Box 2180, Houston, Texas 77001

Phillips Petroleum Company, Bartlesville, Oklahoma 74004

Shell Oil Company, New York, N. Y.

Socony Mobil Oil Company, Inc., 150 East 42nd Street, New York, N. Y. 10017

Standard Oil Company, 910 S. Michigan Avenue, Chicago, Illinois 60680

Sun Oil Company, 1608 Walnut Street, Philadelphia, Pennsylvania 19103

Texaco Oil Company, 135 East 42nd Street, New York, N. Y. 10017

Union Oil Company of California, Union Oil Center, P. O. Box 7600, Los Angeles, California 90054

Table A-6. Possible Sources for Biological Data

Bibliographies

National Research Council, Prevention of Deterioration Center, Bibliography on marine fungi and algae, compiled by Richard W. H. Lee, Washington, D. C., 1962

Naval Applied Science Laboratory. Technical Memorandum no. 1 on Project 9400-72: Bibliography on microbiological corrosion (deep sea), by E. Fischer. Brooklyn, New Hampshire, June 1965

Interagency Committee on Oceanography. ICO Pamphlet No. 9: Bibliography of oceanographic publications, Washington, D. C., April 1963.

World Data Center A, Oceanography, Washington, D. C. 20390

National Oceanographic Data Center, Navy Yard Annex, Bldg. 160, Washington, D. C. 20390

Oceanic Index, Oceanic Research Institute, 6811 La Jolla Blvd., P. O. Box 2369, La Jolla, California 92307

Smithsonian Institution, Office of Oceanography and Limnology, 1000 Jefferson Drive, S. W., Washington, D. C. 20560

Periodicals

Limnology and Oceanography, Allen Press, Lawrence, Kansas 66044

Oceanology International, Industrial Research Publications Company, Beverly Shores, Indiana 46301

Ocean Industry, Gulf Publishing Company, P. O. Box 2608, Houston, Texas 77001

Ocean Science News, Nautilus Press, Inc., 1056 National Press Bldg., Washington, D. C. 20004

Science Magazine, American Association for the Advancement of Science, 1515 Massachusetts Avenue, N. W., Washington, D. C. 20005

Scientific American, 415 Madison Avenue, New York, N. Y. 10017

Sea Frontiers, International Oceanographic Foundation, 10 Rickenbacker Causeway, Virginia Key, Miami, Florida 33149

Undersea Technology, Compass Publications Inc., Suite 1000, 1117 N. 19th Street, Arlington, Virginia 22209

Table A-7. Possible Sources for Data on Weather and Surface Effects

Weather reports are available from both Government sources and private sources. The best source of current total weather information is the U. S. Weather Bureau station in your area. Other sources are:

World Data Center A, Oceanography, Washington, D. C. 20390

Krick Industrial Weather Forecasters, Denver, Colorado 80201

U. S. Coast and Geodetic Survey, Washington Science Center (1)
1180 Old Georgetown Road, Rockville, Maryland 20325

The U. S. Navy maintains weather stations at most shore based stations along the coasts and in foreign areas. Consult local phone service.

U. S. Weather Bureau, Department of Commerce, "Climatological Data." Various state weather composite reports by years, Silver Spring, Maryland.

Compiled at: National Weather Records Center, Federal Building, Asheville, North Carolina 28801

Climatological Data is available on subscription through the Superintendent of Documents, Government Printing Office, Washington, D. C. 20402

Table A-8. Possible Sources for Data on Earthquakes and Earthquake Effects

American Meteorological Society. Bibliography on marine seismics, by O. Leenhardt, Washington, D. C., 1967. (Special bibliographies on oceanography. Contribution No. 3)

University of Hawaii, Hawaii Institute of Geophysics, Report HIG-67-25: Bibliography to the preliminary catalog of tsunamis occurring in the Pacific Ocean, by K. Iida, D. C. Cox, and G. Pararas-Carayannis, Honolulu, Hawaii, December 1967

Navy Mine Defense Laboratory. Report 181: Bibliography on sieches, by F. C. W. Olson, Panama City, Florida, August 1962. (AD 283510)

University of Hawaii, Hawaii Institute of Geophysics, Honolulu, Hawaii 96822

Kresge Seismological Laboratory, California Institute of Technology, 220 North San Rafael Avenue, Pasadena, California. 91105. A Prime Source of Earthquake Information.

University of California, Seismological Department, Berkeley, California 94720

University of Tokyo, Hongo, Bunkyo-Ku, Tokyo, Japan

Bulletin of the Seismological Society of America, P. O. Box 826, Berkeley, California 94701

Journal of Geophysical Research, American Geophysical Union, Suite 435, 2100 Pennsylvania Avenue, N. W., Washington, D. C. 20037

U. S. Earthquake Mechanism Laboratory, Environmental Science Services Administration, 390 Main Street, San Francisco, California 94105

Appendix B

SITE SURVEY INSTRUMENTS

Table B-1. Core Samplers

Manufacturer	Model	Type	Weight (lb)	Length (ft)	Diameter (in.)	Liner
Alpine	202-209	Ewing	150-200	12	1-3/8, 2-1/2	plastic
	210-211	gravity	50	2	1-3/8	plastic
	vibracore	air operated	—	30	3-3/8	waterproof paper
American Undersea	67	deep core	500	10	3	polyethylene tube
CM^2	413	piston	705	28	4-1/3	plastic
	420	free fall	286	6-1/2	2-1/2	plastic
Hydroplastic Plastic	840	Phleger	30	2	1-3/8	plastic
	880, 881	Moore	157	4	2-9/16	plastic
Hytech (Division of Bisset-Berman)	sigma	gravity or piston	variable to 300 lb	5	3-3/4	none
		Kullenburg	—	—	—	plastic
		Boomerang	—	—	—	plastic
Kahl Scientific Co.	217WA305	Ewing	300	12	—	plastic
	217WA200	Phleger	90	2	—	plastic
Norwegian Geotechnical Institute	NGI	piston gas operated	1,125	6	2-1/8	plastic
Ocean Science and Engineering	Horton	—	—	10-100	—	none
S.P.A.F. France	SM200	—	—	300	3	—

Table B-2. Electronic Positioning Systems

System Type	Application	Range	Resolution	Limitations
AUTOTAPE	precision hydrographic surveys	line of sight—25 miles	0.1 meter	intervening land or objects will interfere or cause multipath signals
DECCA (Decca Navigator, Survey Decca, Two Range Decca)	medium range navigation or surveying	300 miles for Decca Navigator, much less for other two	0.01 lane	need special charts with imprinted DECCA lanes, needs four radio channels or frequencies
DISTOMAT	precise distance measurement	12 miles	1 cm	line-of-sight use only, affected by meteorological conditions
ELECTROTAPE	precise distance measurement	-	1 cm	same as DISTOMAT
ELECTROTRANSIT	precise angle measurements	30 miles	±10 arc-seconds	–
E.O.S.	precision base-line measurement	9 miles (day), 15 miles (night)	–	line-of-sight use
GEODIMETER	precision base-line measurement	line of sight	about 1 cm	used mostly at night, line of sight must be clear of foliage or other light-obstructing objects, such as fog or rain
HI FIX	medium-range hydrographic surveys	150 miles for 100-watt transmitter	0.01 lane	affected by sky-wave interference
LAMBDA	long-range surveys	300-500 miles depending on regional noise level and transmitter power	–	same as above
LORAC	medium-range hydrographic surveys	250 miles	0.01 lane	sky-wave interference causes lane jumps
LORAN B	medium range precise navigation	250 miles	0.01 μsec	requires very strong signal-to-noise ratio
MAP	short-range surveying	line of sight or about 30 miles from shore station	–	not as accurate as phase comparison systems
MORAN	short-range surveying	line of sight	1/1,000 mile	same as above
RAYDIST	medium range hydrographic surveys	150 miles for 100-watt transmitter	0.01 lane	requires a number of frequencies, usually 4
SHIRAN	precision short range surveying system	line of sight	0.2 meter	meteorological variations affect accuracies
SHORAN	short-range surveying	line of sight, usually about 40 miles	1/1,000 mile	not as accurate as phase comparison systems, cannot be used in many areas because of interference with signals to satellites
TELLUROMETER	precise distance measurements	line of sight	1 mm	
TRANSIT	precise long range navigation	within receiving range of satellite	1/100 minute of latitude or longitude	must be within range of satellite

Table B-3. Summary of Subbottom Profiling Equipment

Manufacturer	Subbottom System	Energy Source	Detector	Recorder
Alden Electronic and Impulse Recording Equipment Co.		–		OSR-19, OSR-19T, OSR-11, OSR-11T
Alpine Geophysical Associates, Inc.	Seismic Reflection Profiler System, Continuous Stratification Profiler System	Series 501 Sparkers, Gas Exploder	Eel Array	PESR Mod 460, PESR Mod 465, CSPR Mod 464, Dual Channel Mod 462
Bolt Associates, Inc.	–	PAR Mod 600A, PAR Mod 1900, PAR Mod 1500B, PAR Mod 800A (air gun)	–	–
Edgerton, Germeshausen, and Grier, International, Inc	1,000 watt-second, 8,000 watt-second, 24,000 watt-second, Seismic Profiling Systems	Boomer Mod 236, Spark Array Mod 267A, Pinger Probe Mod 228A, Pinger Probe Mod 229A	Mod 262G, Mod 263B, Mod 264A (arrays)	Alden
Edo Western Corp.	Mod 415 Acoustic Bottom Penetration System, Mod 400 Acoustic Bottom Penetration System	Mod 404 Transducer, Mod 240 HC Transducer	Mod 404 Transducer, Mod 240 HC Transducer	PBR Mod 333 (modif), PBR Mod 333
Geo Space Corp.		24 Inch Land/Marine Dinoseis, Marine Dinoseis	MP-1, MP-3, MP-4, MP-7, MP-9, MP-8 (single geophones and hydrophones)	–
Geotech	SUBot (Subbottom Profiling System)	"Hydrode" Arcer Mod 25441	SUBot Hydrostreamer	Raytheon and Magnetic Tape
	SSP (Seismic Section Profiler)	"Lectro-Pulse" Sparker Mod 24218	Hydrostreamer Mod 24257	Raytheon and Magnetic Tape
	WASSP (Wire Arc Seismic Section Profiler)	Wire-Arc Mod 24218	Hydrostreamer Mod 24257	Raytheon and Magnetic Tape
	GASSP (Gas Source Seismic Profiler)	Gas Gun	Hydrostreamer Mod 24257 (CDP streamer cable)	Raytheon and Magnetic Tape
T. H. Gifft, Co.	–	–	–	CDR 1C-19, CDR-1C-19T, CDR-1C-11, CDR-1C-11T
Huntec, Ltd.	Hydrosonde Mark 2A	MK2A Sparker (and Bolt PAR)	MP37 Single Detector	Alden
Mystic Oceanographic Co.	Precision Acoustic Pulse System, Low Power Sparker Profiling System	Sparker (100,000 joule) Sparker (3,000-25,000 joule)	Array Array	Alden Alden
Ocean Research Equipment, Inc	Model 1050 Subbottom Profiling System	O.R.E. Towed Transducer Vehicle	–	O.R.E./Alden GDRT 19-Inch Precision Sonar Transceiver/Recorder
Ocean Science and Engineering Co (services only)	Lizard Acoustic Profiler, Pulser Acoustic Profiler	Towed Fish Transducer (magnetostrictive) Towed Fish Transducer (eddy current repulsive)	– –	Gifft Gifft, Alpine
Raytheon Co	–	Mod BE-1146-1, Mod BE-1146-2, Hydro acoustic		PSR-1910B, PSR 193B

Table B-4. Geological Oceanographic Systems

Manufacturer	Model	Type	Bottom Profiler	Subbottom Profiler	Side-Scan Sonar	Echo Sounder	Transducer Type	Towed Fish	Frequency
Alpine	460-465	PESR				•		• (eel array)	
	440-445	CSPR		•			gas or sparker	•	
	450-454			•			gas or sparker	•	
	523						AT200/UQN-1	•	
	466		recorder only	recorder only	recorder only		any	•	
Braincon	V-Fin	V-Fin	•	•				•	
Decca	AN 6014					•			
Edo-Western Corp.	326	PDR	•				Edo 326-1		23 kHz
	415	PDR		•				•	3.5-7.0 kHz
	578	survey				•	Std Mod 480 Opt Mod 290		38 kHz, 18° beam 80 kHz, 8° beam
	185	UQN				•	Edo 353		
	333	PSR	• (plus recorder)	• (plus recorder)					
	313		•				Edo 202		16, 25, 35 kHz
	240		•	•			Edo 240	•	3.5 kHz, 30° beam
	340	Sea View 1A			•				200-500 kHz
	349	PBR					Edo 323	•	1-37 kHz
EG&G	254	seismic	•	•			boomer or sparker array	•	200 kHz
	Mark 1				•		pinger probe		
General Oceanographics	custom	G.O.		•				•	9-10 kHz
Gifft	1C-19, 19T	GDR	recorder only	recorder only					
Honeywell	S-1311-A1				•			•	175 kHz
Hydra	survey		•						
Kelvin-Hughes	MS 38	PES				•	bar type or crystal		1 kHz
Ocean Research Equipment	1050	SBPS		•				•	3.5-12 kHz
Ocean Sonics	OSR 19T	OSR	•	•			sparker, boomer thumper, popper	•	8 kHz
	OSR 11/19	PGR	recorder only	recorder only	recorder only				
Raytheon	DE714/715					•	7166 or 7191B Keelmant		25 kHz
	193A, B	PFR	recorder	recorder	recorder				
	1910B	PSR		recorder					
Teledyne (Geotech)	SUBot			•			arc discharge	•	
	SSP			•			arc discharge	•	
	WASSP			•			arc discharge	•	
	GASSP			•			gas discharge	•	
Westinghouse	linear scan				•			•	215/225 kHz
	angular scan				•			•	215/225 kHz

Table B-5. Physical and Chemical Oceanographic Systems

Manufacturer	Model	Cable Connected	Parameters Measured						
			Depth	Salinity	Temperature	Dissolved Oxygen	pH	Sound Velocity	Currents
Beckman	990						•		
	778					•			
Benthos	311		•		•				
Bissett-Berman (Hytech)	9006	•	•	•	•				
	9030G		•	•	•				
Braincon	381								•
CM^2	513			•					
	TSE2	•	•		•				•
	515		•	•	•				
	TS 2		•		•				•
Edo Western	429	•							• (doppler type)
Geodyne	102								•
	A850				• (A119-4)				•
	A605		•	•	•	•	•	•	•
	A775		•	•	•				•
Hydro Products	460	•			•				•
(Div. of Dillingham Corp.)	501B								•
	450S								•
	502								•
Hytech (Div. of	6007			•	•				
Bissett-Berman)	SA-2								•
	SA-1								•
	A005			•	•				
Interstate Electronics	CV 200								•
Kahl Scientific Co.	118WA300			•	•				
	Ekman								•
Kelvin-Hughes	direct reading	•							•
	M330	•							•
	M335	•							•
	M518	•							•
Litton (Amecon Div.)	1001		•	•	•			•	
	2001		•	•	•			•	
Marine Advisers	Q9/Q12								•
(Div. of Bendix)	Q15/Q16								•
NUS	SDS1	•	•					•	
Ramsey	MK-1	•	•		•			•	
Weston & Stack	300					•			

Table B-6. Grab and Dredge Samplers

Manufacturer	Model	Type	Weight (lb)	Capacity
Alpine	244	snapper grab	60	1 pint
CM^2	401-403	snapper grab	<140 kg	30-300 CM^3
	406-412	dredge	<140 kg	<0.5 M^3
EG&G	283	Campbell grab	750	0.6 M^2
Hayward	dwarf	orange peel	330	1 ft^3
	clamshell	clamshell	?	4 ft^3
Hydro Products	860	Shipek	134	5-1/2 ft^3
Kahl Scientific Co.	214WA110	mud snapper	71	6 oz.
	214WA130	Dietz LaFond	60	?
	214WA180	Ekmen barge	12	216 $in.^3$
	214WA210	orange peel	45	300 $in.^3$
	214WA150	Emery dredge	18	2 liters
	214WA160	Emery dredge	33	4 liters
	214WA123	Emery pipe	551	500 $in.^3$

Table B-7. Biological and Water Samplers

Manufacturer	Model	Type	Depth (m)	Sample	Container	Length (in.)	Opening (in.)
Alpine	800-802	net	0-2000	plankton			
Bissett-Berman		multiple rosette	any	water sterile	plastic bellows		
		bellows		water sterile	plastic		
		Nansen					
		Fjaklie					
		Van Durn					
Braincon	540	multiple	any	water	metal bottle		
CM^2	301-310	net and gage	0-500	plankton	vinyl cup mesh lined	52-93.6	2.8-20
Geodyne	A555	Niskin	any	water	plastic bellows		
Kahl Scientific Co.	002WA100		all	bacteriological			glass tube
	008WA160	net		plankton			
	012WA300	Clarke Bumpus	1,800	plankton	bucket	36	5
	012WA553	deck	surface	plankton	continuous	37	6
	012WA601	BE		plankton			
	015WA00	Isaacs Kidd	shallow	plankton	bucket	46	1
	013WA150	Gulf V metal	100	plankton	bucket	50	16
	012WA400	Clarke Bumpus	1,800	plankton	bucket	48	12
	012WA200	Miller	150	plankton	bucket	36	4

Table B-8. Underwater Cameras

Manufacturer	Model	Type	Focus	Film Size (mm)	Shutter Operator	Depth or Pressure Capability	Exposures	Stereo	TV	Shutter Speed (sec)
Alpine	311-314	Thorndyke		35	bottom contact	<10,000 psi	36			
EG&G	205	Photo Grab	3M	35	bottom contact	<3,000 meters	20-25	●		1/15 and 1/200
	200/204	Photo Grab	4M	35	bottom contact	<12,000 meters	500	●		
Hydro Products	TC100-140					<5,000 ft			●	
	TC200F					1,000 ft			●	
	TC303					2,000 ft			●	
	PC700	Shipek		70		20,000 ft	400			
	PC770	Shipek		70		500 ft	400			
	PC780	Shipek		70		5,000 ft	400			
	PC790	Shipek		70		2,000 ft	400			
	PC750	Shipek	remote	70	bottom contact	5,000 ft	450			1 and 1/125
Kahl Scientific Co.	225WA100	Ewing		35	bottom contact	100 meters	18			

Table B-9. Underwater Lights

Manufacturers	Model	Type	Maximum Depth	Output Energy	Weight (lb)	Power (volts)	Life
EG&G	206	strobe	3,000 m	50 w/sec	5	510 (internal)	400-500 flashes
	210	xenon	12,000 m	100 w/sec	53	6	500 flashes
	214	xenon	12,000 m	200 w/sec	30	24-28 (external)	1,000 flashes
	208	xenon	8,000 m	250 w/sec	54	20-30 (external)	2,300 flashes
	244/245A	quartz-iodide	15,000 ft	<7,000 watts	9	24-30 DC/120 AC	650 hours
	210	strobe	500 ft	50 w/sec	6	510 DC	500 flashes
	243	incandescent	22,000 ft	750 watts	2-1/2	120 AC	500 hours
Hydro Products	MV-3	mercury	8,000 ft	1,000 watts	5	110 AC	4,000 hours
	MV-4	mercury	8,000 ft	250 watts	10	110 AC	5,000 hours
	MV-250D	mercury	20,000 ft	250 watts	1	20 DC	500 hours
	LQ-2	quartz-iodide	5,000 ft	75 watts	1-1/2	20 AC/DC	500 hours
	LQ-5	quartz-iodide	5,000 ft	250 watts	1-1/2	120 AC/DC	500 hours
	LQ-10	quartz-iodide	5,000 ft	500 watts	1-1/2	120 AC/DC	500 hours
	LQ-1000	quartz-iodide	8,000 ft	1,000 watts	10	115 AC/DC	2,000 hours
	PF-100	strobe	500 ft	100 w/sec	12	510 DC	800 hours
	PF-101	strobe	2,000 ft	100 w/sec	15	510 DC	800 hours
	PF-102	strobe	800 ft	200 w/sec	11	24 DC	150 hours
	L-2	mercury	8,000 ft	52,000 lumens	5	110 AC	4,000 hours
	L-4	mercury	8,000 ft	2,800 candlepower	10	110 AC	5,000 hours
	LT-6	thallium-iodide	8,000 ft	25 watts	11	115 AC	500 hours

Appendix C

OCEANOGRAPHIC RESEARCH VESSELS

Table C-1. Oceanographic Survey Vessels (U. S. Government and Universities)

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Absecon		311	41	13-1/2	134	4	U. S. Coast Guard	
Acona	Alaska	80	22	10	total 14		University of Alaska	Juneau
Addenda Ranier	U. S. West Coast	231			79	yes	ESSA	Seattle
Agassiz	Pacific	180	32	10	18	13	Scripps Institution of Oceanography	San Diego
Alaminos	Gulf of Mexico	180	32	8-1/3	18	14	Texas A & M	Galveston
Albatros IV	New England	187	33	16-1/2	22	16	U. S. Bureau of Commercial Fisheries	Woods Hole
Allegheny	Caribbean	143	34	13	40	6	Hudson Laboratories	Bayonne, N. J.
Alpha Helix		133	31	10-1/2	12	10	Scripps Institution of Oceanography	La Jolla, Calif.
Androscoggin		255	43	16-1/2			U. S. Coast Guard	
Archerfish		311	27	15	67	4	U. S. Bureau of Commercial Fisheries	Florida
Argo	South America	213	39-1/2	15	40	28	Scripps Institution of Oceanography	San Diego
Atka		269	63	29	234	0-20	U. S. Navy	
Atlantis II	Gulf Stream	210	44	16	28	25	Woods Hole Oceanographic Institution	Woods Hole
Bartlett	U. S. West Coast	209	39	14	43	11	U. S. Naval Oceanographic Office	San Francisco
Bent	Japan	285	48	15	78	yes	U. S. Naval Oceanographic Office	New York

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Black Douglas		150	32	12	11	11	U. S. Bureau of Commercial Fisheries	
Bowditch		454	62	31	59	47	U. S. Naval Oceanographic Office	
Bowers, Geo. M.	Gulf of Mexico	74	20	8	4	6	U. S. Bureau of Commercial Fisheries	Pascagoula, Miss.
Brown Bear		116	27	13	11	19	University of Washington	Seattle
Burton Island		269	63	29	234	0-20	U. S. Navy	
Carite		65-1/2	16-1/2	7	1-4	4	University of Puerto Rico	Mayaguez
Casco		311	41	13-1/2	150	18	U. S. Coast Guard	
Catamaran Vessel		141	52-1/2	9	17	17	University of Miami	
Chain	Gulf Stream	213	41	15	59	yes	Woods Hole Oceanographic Institution	Woods Hole
Cisco		60-1/2	18	8	4	5	U. S. Bureau of Commercial Fisheries	Ann Arbor, Mich.
Cobb, John N.	U. S. West Coast	93	25	12-2/3	10	4	U. S. Bureau of Commercial Fisheries	Seattle
Commando		67	18	8-1/2	4	5	University of Washington	Seattle
Compass Island	North Atlantic	564	76	26	261	33	U. S. Naval Applied Science Laboratory	Brooklyn
Conrad	World Wide	211	37-1/2	15	40	2	Lamont-Doherty Geological Observatory	New York

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Crawford	Gulf Stream	125	23	8-1/2	22	yes	Woods Hole Oceanographic Institution	Woods Hole
Cripple Creek	U. S. West Coast	65	17-1/2	6-1/2	7	1	U. S. Bureau of Mines	Tiburon, Calif.
Cromwell, Townsend	Equatorial Pacific	158-1/2	33	9-1/2	22	2	U. S. Bureau of Commerical Fisheries	Honolulu
Davidson	U. S. West Coast	175	38	13	36		ESSA	Seattle
Davis, C. H.	East Pacific	209	40	15	24	15	U. S. Naval Oceanographic Office	San Francisco
R/V Delaware	New England	147-1/2	29	12	21	2	U. S. Bureau of Commercial Fisheries	Gloucester
R/V Delaware II	New England	155-1/2	30	14	24	2	U. S. Bureau of Commercial Fisheries	Gloucester
De Steiger	U. S. West Coast	209	39	14	43	11	U. S. Naval Oceanographic Office	San Francisco
Discoverer	Atlantic	303	52	18	86	17	ESSA	Miami
Dolphin		107	25	9 forward 12.5 aft	9	5	U. S. Department of Interior	Sandy Hook, N. J.
Eastward	West Atlantic	117-1/2	28-1/2	10-4/5	15	15	Duke University	Beaufort, N. C.
Eastwind		269	63	29	234	0-20	U. S. Coast Guard	
Edisto		269	62	29	234	0-20	U. S. Navy	
Empire State IV		489	69-1/2	25-1/2	105	406 cadets 2 scientists	University of New York Maritime College	New York
Evergreen	Grand Banks, Labrador Sea, Davis Strait	180	37	13	45	7	U. S. Coast Guard	

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Eltanin	South Pacific Antarctic	266	51-1/2	19-3/4	47	32	Military Sea Transportation Service	Melbourne, Fla.
R/V Erling	Bermuda	100	29-2/3	6	5	48	Lamont-Doherty Geological Observatory	Field Station, Bermuda
Explorer		219-1/2	38	15	79	23	University of Southern California and Geological Survey	
Fairweather	U. S. West Coast	221	42	13	total 82		University of Southern California and Geological Survey	Seattle
Flip		355	25	13-2/3	3	3	Scripps Institution of Oceanography	San Diego
R/V Freeman, Miller	U. S. West Coast and Alaska	215	42	17-1/2	35	4	U. S. Bureau of Commercial Fisheries	Seattle
Gasnold	West Atlantic	99	21	8	17	yes	Woods Hole Oceanographic Institution	Woods Hole
R/V Gerda	North Sea	75	21	10-1/4	3	8	University of Miami	
Geronimo		143	34	13-1/2	15	10	U. S. Bureau of Commercial Fisheries	
Gibbs	North Atlantic	310	42	14	48	24	Hudson Laboratories	Bayonne, N. J.
Gilbert, Chas. H.	Hawaiian Islands	123	21	10-1/2	12	5	U. S. Bureau of Commercial Fisheries	Honolulu
Gilliss	West Indies	209	37	14	43	11	U. S. Naval Oceanographic Office	New York
Glacier		309	74	28-1/2	341	0-20	U. S. Navy	

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operators	Homeport
Grouper		307	27	17	73	15	U. S. Navy	New London, Conn.
Gus III	Gulf of Mexico	88	23-2/3	10	4	5	U. S. Bureau of Commercial Fisheries	Galveston
Hidalgo	Gulf of Mexico	136	24	10	8	14	Texas A & M	
Hoh	Washington Coast	65	16	6	1	7	U. S. Navy University of Washington	Seattle
Horizon	East Tropical Pacific	143	33	13-1/2	35	yes	Scripps Institution of Oceanography	San Diego
Hugo M. Smith	California	128	29	14	14	8	Scripps Institution of Oceanography	San Diego
H. W. Streeter		45	14	6	1	5	U. S. Public Health	
Hydrographer		165-1/2	31-1/2	14	38	10	University of Southern California and Geological Survey	
Inland Seas		114	27	11-1/2	8	8	University of Michigan	Ann Arbor, Mich.
Jordon, David Starr	California	171	37	11-1/2	22	13	U. S. Bureau of Commercial Fisheries	San Diego
Kaho		65	18	85	4	2	U. S. Bureau of Commercial Fisheries	Ann Arbor, Mich.
Kane	Gulf of Mexico	280	48	15	41	38	U. S. Naval Oceanographic Office	San Francisco
R/V Kelez, Geo. B.	Eastern Pacific	176-1/2	32	8-1/2	12	4	U. S. Bureau of Commercial Fisheries	Seattle

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Kyma	New York Coast	65	17				University of New York	N. Y. Maritime Academy
Littlehales		132	31	9	21		U. S. Navy	
Lulu	West Atlantic	141	52-1/2	9	34	yes	Woods Hole Oceanographic Institution	Woods Hole
Lynch	Caribbean	209	39	14	43	11	U. S. Naval Oceanographic Office	New York
Manning	U. S. East Coast	65	18	8	total 4		Hudson Laboratories	Bayonne, N. J.
Marmer	Louisiana	100-1/2	22	10	17		ESSA	Norfolk
Marysville		185	34	9-3/4	63	5	U. S. Navy	San Diego
McArthur	Hawaii	175	35	13	36		ESSA	Honolulu
Mizar	Bermuda	266	51	18	51			Bayonne, N. J.
Mt. Mitchell	South Atlantic	231	42	13	76	3	ESSA	
Murre II	Alaska	86	24	7-1/2	4	5	U. S. Bureau of Commercial Fisheries	Auke Bay, Alaska
Musky II	Great Lakes	45	14	6	2	3	U. S. Bureau of Commercial Fisheries	Sandusky, Ohio
Mysis		50	15	6	2	3	University of Michigan	Ann Arbor, Mich.
Navoceano I	U. S. East Coast	75	17	5	3	13	U. S. Naval Oceanographic Office	Suitland, Md.
Natchik	Alaska	38-1/4	12	3-1/2	1	3	University of Alaska	Point Barrow, Alaska
Nomad	Varies	20	10	6-1/2	(unmanned)		Bureau of Naval Weapons	
Northwind		269	63	29	234	0-20	U. S. Coast Guard	

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Oceanographer	Northeast Pacific	303	52	18	95	19	University of Southern California and Geological Survey	Seattle
Oconostota	Northern California	102	25	10	10	4	Scripps Institution of Oceanography	San Diego
Onar	Washington Coast	65-1/2	17-1/2	7	1	9	University of Washington	Seattle
Orca	California	98	23	7-1/2	12	10	Scripps Institution of Oceanography	La Jolla, Calif.
Oregon	Florida East Coast	100	26	14	10	8	U. S. Bureau of Commercial Fisheries	St. Simonds Island, Ga.
Oregon II	Gulf of Mexico	170	34	12-1/2	27	5	U. S. Bureau of Commercial Fisheries	Pascagoula, Miss.
Paolina-T	California	80	22	9-3/4	9	5	Scripps Institution of Oceanography	La Jolla, Calif.
Pathfinder	Virginia	55	17	6	2	5	College of William and Mary	Glouchester Pt., Va.
Pathfinder	Alaska	229-1/2	39	15-1/2	79	19	University of Southern California and Geological Survey	Seattle
Perspicacity	California	65-1/2	18	7	4	8	U. S. Department of Interior	Tiburon, Calif.
Phalarope II	Maine	40-1/2	12-1/2	4-1/2	1	0-6	U. S. Bureau of Commercial Fisheries	Boothbay Harbor, Maine

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Pierce	Massachusetts Coast	163	33	9-1/2	36		University of Southern California and Geological Survey	Jacksonville, Fla.
R/V Pillsbury	Bahamas	177	32-1/2	10-1/2	20	15	University of Miami	
Pioneer		311	41	14	total 118		University of Southern California and Geological Survey	
Prevail		220	32	10-1/3	105	4	U. S. Navy	
Rehoboth		310	41	14	172	8-10	U. S. Navy	
Requiste		220	32	10-1/3	105	4	U. S. Navy	
Researcher	Atlantic and Gulf of Mexico	278			67	18	ESSA	Miami
Rorqual	Massachusetts	65	16	6	2	4	U. S. Bureau of Commercial Fisheries	Gloucester, Mass.
Sands	Caribbean	209	39	14	43	11	U. S. Naval Oceanographic Office	New York
San Pablo		310	41	14	172	8-10	U. S. Navy	
Scripps	East Pacific	95	24	6	6	7	Scripps Institution of Oceanography	San Diego
Sea Gull	Northern California	39	11	6	total 4		Humbolt State College	Eureka, Calif.
Serrano		205	39	16-1/2	108	2	U. S. Navy	
Sheldrake		220	32	10-1/2	105	4	U. S. Navy	
Sir Horace Lamb	Caribbean	136	25	9	15	8	Columbia University	Field Station, Bermuda

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
Siscowet	Great Lakes	53	14-1/2	7	2	3	U. S. Bureau of Commercial Fisheries	Ashland, Wisc.
Spencer F. Baird		143	33	13-1/2	18	17	Scripps Institution of Oceanography	La Jolla, Calif.
Staten Island		269	63	29	234	0-20	U. S. Navy	
Stranger		134	24	13-2/3	14	10	Scripps Institution of Oceanography	San Diego
Surveyor	North Central Pacific	292-1/4	46	16	89	4	University of Southern California and Geological Survey	Seattle
T-441	California	65-1/2	17-2/3	6-1/4	total 9		Scripps Institution of Oceanography	La Jolla, Calif.
T-426		65	17-3/4	7-1/2	5	4	Columbia University	Field Station, Bermuda
Taney		327	41	14-1/4			U. S. Coast Guard	
Towhee		220	32	11	94	6	U. S. Naval Oceanographic Office	
Teritu	Hawaiian Islands	90	21	8-1/2	9	6	University of Hawaii	Honolulu
Thompson	West Coast of Mexico	209	41	14	41	11	University of Washington	Seattle
Trident	Northwest Atlantic	180	32	20	18	13	University of Rhode Island	Narragansett, R. I.
Undaunted	Gulf of Guinea	143	33	14	15	14	U. S. Bureau of Commercial Fisheries	Miami

continued

Table C-1. Continued

Name	Area of Operations	Length (ft)	Beam (ft)	Draft (ft)	Crew	Scientific Personnel	Operator	Homeport
U. S. Coast Guard (All Boats)	World Wide						U. S. Coast Guard	
Valero IV & V	Southern Calif.	110	27-1/2	13-1/2	11	7	University of Southern California	San Pedro
R/V Vema	North Atlantic	202	33	17	19	17	Lamont-Doherty Geological Observatory	New York
Virginia City	U. S. West Coast	205	39-1/4	15	32	16-20	U. S. Bureau of Mines	Tiburon, Calif.
Washington	Gulf of California	210-2/3	30-1/2	14-1/2	41	yes	Scripps Institution of Oceanography	San Diego
Westwind		269	63	29	234	0-20	U. S. Coast Guard	
Whiting	New York and Puerto Rico	163	33	9-1/2	36		ESSA	Norfolk
Yaquina	Oregon	180	32	10-1/2	18	20	Oregon State University	Newport, Ore.
YFU 44		119	34	4	total 10		U. S. Naval Weapons Center	

Table C-2. Submersibles

Name	Owner	Operating Depth (ft)	Length (ft)	Weight (tons)	Number of Personnel		Payload (lb)	Remarks
					Crew	Observers		
Aluminaut	Reynolds International	15,000	51	73	2	4	6,000	Equipped with six EG&G tungsten filament, iodine atmosphere lights on bow; the craft has two fully independent arms with 9-foot 1-inch reach from shoulder pivet; each is capable of lifting 200 pounds
Alvin	U. S. Navy (ONR)	6,000	22	16.5	2	1	1,670	*Alvin* is prototype research submersible; it is considered a successful general purpose oceanographic vessel and has set guidelines for other small subs
Alvin II	U. S. Naval Ship Systems Command	6,500	26	21	1	2	1,200	Dual manipulator, underwater telephone and radio
Amersub-300	Mako	300	13	11	2[a]		500	Vessel has range of 12 to 16 miles; crewmen have 360° visibility through 1-inch-thick Plexiglas conning tower view-ports; air recirculation system uses CO_2 absorption unit, a desiccant and makeup oxygen giving 8-hour fresh air supply

continued

Table C-2. Continued

Name	Owner	Operating Depth (ft)	Length (ft)	Weight (tons)	Number of Personnel		Payload (lb)	Remarks
					Crew	Observers		
Amersub-600	Mako	600	13	1.75	2[a]		750	Single conning tower with wrap-around plexiglass window; 8-inch port in forward bottom
Asherah	University of Pennsylvania	600	17	4.2	1	1	175	Used primarily for ocean archaeological work; used late last summer to obtain detailed data on Roman shipwreck discovered by Scripps near Bodrum, Turkey
Autec I	U. S. Naval Ships Systems Command	6,500	26	21	1	2	1,200	Dual manipulator, underwater telephone and radio
Beaver Mark IV	North American Rockwell	2,000	2.5	13.5	5[a]		2,000	Designed for use as work vehicle, scientific vehicle, diver lock-in, lock-out vehicle, habitat lock-on vehicle, or as passenger vehicle
Benthos V	Lear-Siegler	600	11.3	2.1	2[a]		400	Used primarily for bottom search and survey work; has six viewports
Deep Quest	Lockheed Aircraft Corp.	8,000	39.5	52	2	2	7,000	The unit has a closed system emergency breathing aparatus using lithium hydroxide as CO_2 absorbent; San Diego laboratory has marine rail system for moving sub into maintenance shop

continued

Table C-2. Continued

Name	Owner	Operating Depth (ft)	Length (ft)	Weight (tons)	Number of Personnel		Payload (lb)	Remarks
					Crew	Observers		
Deep Star 4000	Westinghouse Electric Corp. Underseas Division Ocean Research and Engineering Laboratory Annapolis, Md.	4,000	18	9.5	3		450	Ascends and descends in helicoidal pattern; recently outfitted with new propulsion system prior to moving from California to East Coast of U. S. for work with Naval Sound Laboratory
Deep Star 2000	Westinghouse Electric Corp. Underseas Division Ocean Research and Engineering Laboratory Annapolis, Md.	2,000						Being designed
Deep Star 20,000	Westinghouse Electric Corp.	20,000	28	20	3[a]		1,000	Under construction
Dolphin (AGS-555)	U. S. Navy	4,000	152	700	22[a]			Submarine for oceanographic research at great depths
DOWB	General Motors Defense Research Laboratories	6,500	16	7.1	2[a]		1,020	Put into service in 1967; has 120 cells outboard; built in Santa Barbara
DSRV-1 Six Vessels	U. S. Navy	3,500 (minimum)	50	33	3[b]		24 rescuees from disabled sub (appx. 4,200 lb)	Sub can be carried piggy back by a nuclear (mother) sub or by Navy auxiliary ship rescue vessel; *DSRV-2* is expected to be almost a carbon copy of *DSRV-1* now under construction; definite decision on *DSRV-2* design expected early in 1968.

continued

Table C-2. Continued

Name	Owner	Operating Depth (ft)	Length (ft)	Weight (tons)	Number of Personnel		Payload (lb)	Remarks
					Crew	Observers		
DSSV-1	U. S. Navy	20,000						To be built by Lockheed Missiles & Space Co., and to be operational in early 1970's; will operate for 40 hours at 3 kt
Grouper (AGSS-214)	U. S. Navy	Unknown	307		73[a]			Built in 1942; has 10,000-mile range, 60-day endurance; Navy sub of COMSUBLANT under operational control of COMSUBRON TWO; has several specialized labs located in former torpedo tubes to hold specialized electronic equipment for acoustical work
Pisces	International Hydrodynamics Co., Ltd.	5,000	16	6.5	2	3	1,500 (incl. crew)	Sub's manipulator is designed to handle MK-48 torpedoes; recently set record by recovering >2,000-lb torpedo from 1,000-ft depth in 28 minutes; four similar subs now under construction
PC 3X	Defense Research Laboratory, Austin, Texas	300	18.5	2.4	2[a]		750	Experimental submarine model; sold by Perry to Geraldine Laboratories, later bought by present owner
PC 3A	Kentron, Hawaii Ltd.	300	18.5	2.4	2[a]		750	Duplicate of *PC 3X* sub

continued

Table C-2. Continued

Name	Owner	Operating Depth (ft)	Length (ft)	Weight (tons)	Number of Personnel		Payload (lb)	Remarks
					Crew	Observers		
(PC 3A)	U. S. Air Force Pacific	300	18.5	2.4	2[a]		750	Used to retrieve spent missile cones for evaluation
PC 3B	Perry Submarines (leased to Ocean Systems)	600	22	2.75	2[a]		750	Used extensively by Ocean Systems in search and survey work in the Gulf of Mexico, the Atlantic and during the search for the H-bomb off the coast of Spain
NA1'A (PC5C)	Pacific Submersibles Inc. of Honolulu, Hawaii	1,200	22	5.13	3[a]		1,000	Used for exploration and mining of coral off Hawaii (see Ocean Industry, Sept. 1967, page 13)
Perry-Link Deep Diver	Ocean Systems, Inc.	1,350	23	8.25	2	2	2,000	First submersible with diver lock-out, lock-in capability; sub lock-out chamber is pressurized to allow diver's egress while holding water out; on return trip, chamber serves as decompression chamber; Ocean Systems working on details to release divers at 1,000 feet
PX-15	Grumman Aircraft	4,000	48.5	130	12[a]		5,000	Built by fabricators of *PX-8*; due to arrive at Florida homeport in April; newest submersible in world; to investigate gulf stream drift, a 42-day mission

continued

Table C-2. Continued

Name	Owner	Operating Depth (ft)	Length (ft)	Weight (tons)	Number of Personnel		Payload (lb)	Remarks
					Crew	Observers		
Star-I	General Dynamics	200	10.1	1.3	1[a]		200	Prototype test vehicle
Star-II	General Dynamics	1,200	17.75	4.7	1	1	500	Variable-speed hovering motor mounted in the fairwater permits vertical maneuvering; horizontal movement controlled by variable-speed stern thrusters and a hydraulically-operated rudder
Star-III	General Dynamics	2,000	24.5	9.5	1	1	1,500	Recently used to inspect AT&T cables and plant buoys in Atlantic; also used to place a parabolic reflector to focus sound between deep scattering layer and array transducer for U. S. Navy Underwater Sound Laboratory
Submaray	Hydrotech	300	13	1.6	1	1	150	Sub has ultrasonic voice communication system with maximum range of more than 1 mile; this is used to track sub and permits recording both ends of all transmissions; *Submaray* used in the filming of McHale's Navy and other television programs.

continued

Table C-2. Continued

Name	Owner	Operating Depth (ft)	Length (ft)	Weight (tons)	Number of Personnel		Payload (lb)	Remarks
					Crew	Observers		
Trieste II	U. S. Navy	3,600 with Krupp Sphere 20,000 with Terni Sphere	76	73 less ballast & aviation gas	3[a]		20,000 with Terni Sphere	Available with two different spheres; has five television cameras

[a] The number of crew members and number of observers were not differentiated.

[b] Two operators and one medic-crewman.

Appendix D

COMPUTER PROGRAM FOR TEMPERATURE AND DEPTH CALCULATIONS

```
C       SHIP,S1,S2 - SHIP NAME
C       CRUISE - CRUISE NUMBER
C       IMONTH / IDAY / IYEAR - DATE
C       STANO - STATION NUMBER
C       LATD - LATITUDE DEGREES
C       ALATM - LATITUDE MINUTES
C       LOND - LONGITUDE DEGREES
C       ALONM - LONGITUDE MINUTES
C       FWMR - FATHOM WHEEL MAXIMUM READING, FATHOMS
C       WIREAN - WIRE ANGLE, DEGREES
C       NOFBOT - NUMBER OF BOTTLES IN CAST
C       WIRED - WIRE DEPTH, METERS
C       FWREAD - FATHOM WHEEL READING FOR RESPECTIVE BOTTLES
C       TMAIN - UNCORRECTED MAIN THERMOMETER READING, DEGREES C
C       TAUX - AUXILIARY THERMOMETER READING, DEGREES C
C       CAUXT - CORRECTION FOR AUXILIARY THERMOMETER
C       VO - VOLUME OF MERCURY BELOW ZERO DEGREE MARK, DEG. CELSIUS
C       TIC - INDEX CORRECTION
C       K=6100 = 1/COEFFICIENT OF THERMAL EXPANSION (CONSTANT)
C       Q - PRESSURE COEFFICIENT FOR UNPROTECTED THERMOMETER
C       Z - THERMOMETRIC DEPTH, METERS
C       RHO - DENSITY (EQUATION DERIVED FROM DATA FOR THE EASTERN NORTH
C             PACIFIC PUBLISHED BY THE HYDROGRAPHIC OFFICE)
      1 READ 100,SHIP,S1,S2,CRUISE,IMONTH,IDAY,IYEAR,STANO,LATD,ALATM,
       1LOND,ALONM
    100 FORMAT(3A4,F8.1,5X,I2,I3,I3,F8.1,5X,I4,F6.2,5X,I4,F6.2)
        READ 115,FWMR,WIREAN,NOFBOT
    115 FORMAT(10X,2F8.2,I4)
        PUNCH 101,STANO
    101 FORMAT(20X,19H**** STATION NUMBER,F6.1,5H ****,/)
        PUNCH 116,LATD,ALATM,LOND,ALONM
    116 FORMAT(15X,8HLATITUDE,I4,F6.2,2H N,10X,9HLONGITUDE,I4,F6.2,2H W)
        PUNCH 102,SHIP,S1,S2,CRUISE,IMONTH,IDAY,IYEAR
    102 FORMAT(1X,6HSHIP -,3A4,10X,10HCRUISE B -,F8.1,10X,6HDATE -,
       1I3,I3,I3)
        PUNCH 103
        PUNCH 104
        PUNCH 105
    103 FORMAT(1X,10HWIRE DEPTH,8X,4HTRUE,7X,12HTHERMOMETRIC,6X,5HDEPTH,
       17X,8HACCEPTED)
    104 FORMAT(2X,8H(METERS),5X,11HTEMPERATURE,7X,5HDEPTH,8X,
       110HDIFFERENCE,5X,5HDEPTH)
    105 FORMAT(19X,3H(C),10X,8H(METERS),7X,8H(METERS),5X,8H(METERS))
        WIRED=100.
        WIREAN=3.1416*WIREAN/180.
        Z=100.*COSF(WIREAN)
        DIFF=WIRED-Z
        PUNCH 109,WIRED,Z,DIFF
    109 FORMAT(F9.2,22X,F8.2,6X,F8.2)
        DO 10 I=1,NOFBOT
C       COMPUTE CORRECTED PROTECTED THERMOMETER READING
        READ 106,FWREAD,TMAIN,TIC,TAUX,CAUXT,VO
    106 FORMAT(6X,5F8.2,F8.1)
        TAUX=TAUX+CAUXT
        WIRED=1.8288*(FWMR-FWREAD)+0.005
        C=(TMAIN+VO)*(TMAIN-TAUX)/(6100.-100.)
        TW1 = TMAIN+C+TIC
        READ 108,TMAIN,TIC,TAUX,CAUXT,VO,Q
        IF(Q)3,2,3
      3 TW=TW1
        GO TO 4
      2 TAUX=TAUX+CAUXT
        C=(TMAIN+VO)*(TMAIN-TAUX)/(6100.-100.)
        TW2 = TMAIN+C+TIC
        TW=(TW1+TW2)/2.
```

```
C     COMPUTE CORRECTED UNPROTECTED THERMOMETER READING
      READ 108,TMAIN,TIC,TAUX,CAUXT,VO,Q
  108 FORMAT(14X,4F8.2,F8.1,F10.8)
    4 TAUX=TAUX+CAUXT
      C=(TMAIN+VO)*(TW-TAUX)/6100.
      TU=TMAIN+C+TIC
      RHO1=(562696.5*WIRED-129.0491*WIRED**2.)/10000000.
      RHO2=(0.0166113*WIRED**3.)/10000000.+245.032
      RHO=1.0+(RHO1+RHO2)/10000.
      Z=(TU-TW)/(RHO*Q)+0.005
      TW=TW+0.0005
      DIFF=WIRED-Z
      PUNCH 110,WIRED,TW,Z,DIFF
  110 FORMAT(F9.2,7X,F8.3,7X,F8.2,6X,F8.2)
   10 CONTINUE
      GO TO 1
   30 CALL EXIT
      END
```

**** STATION NUMBER 1.0 ****

LATITUDE 34 17.35 N   LONGITUDE 119 42.63 W

SHIP -BARTLETT   CRUISE B - 001.1   DATE - 1 27 70

WIRE DEPTH (METERS)	TRUE TEMPERATURE (C)	THERMOMETRIC DEPTH (METERS)	DEPTH DIFFERENCE (METERS)	ACCEPTED DEPTH (METERS)
100.00		96.59	3.40	
.07	13.810	4.16	-4.08	
15.01	13.518	18.42	-3.40	
30.01	12.366	30.77	-.76	
45.03	11.472	46.70	-1.67	
60.02	10.867	65.99	-5.96	
75.02	10.481	77.14	-2.12	
91.02	10.128	94.83	-3.81	
106.03	9.692	102.90	3.13	
121.03	9.553	113.68	7.34	
136.03	9.390	130.14	5.89	
151.04	9.269	145.21	5.83	
167.04	9.067	153.19	13.84	
182.04	8.758	161.18	20.85	

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The increase in interest by the Navy and other organizations in placement of structures on the seafloor necessitates establishing site parameters relevant to such construction, and equipment for measuring these parameters. Included in this report are the site parameters significant to designing, constructing, operating, and maintaining a seafloor structure; an outline of the site survey procedure; the equipment available for conducting these site surveys; and data handling and reduction techniques. Also included are recommendations for research required prior to placement of structures and equipment.

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Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Civil Engineering Laboratory Port Hueneme, California 93041	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

SITE SURVEYING FOR OCEAN FLOOR CONSTRUCTION

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final; October 1967 to April 1969

5. AUTHOR(S) (First name, middle initial, last name)

M. C. Hironaka and W. E. Hoffman

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1970	97	55

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. 56-010	TR-691
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Facilities Engineering Command Washington, D. C.

13. ABSTRACT

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DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Ocean floor investigation						
Foundation engineering						
Shear strength						
Consolidation characteristics						
Sediment thickness						
Bottom topography						
Subbottom structure						
Sediment type						
Seismicity						
Sediment transport						
Currents and tides						
Temperatures						
Ocean water chemistry						
Marine biology						
Marine surface phenomena						
Measuring instruments						
Mapping						
Sampling						