TECHNICAL REPORT H-73-9

PORT CONSTRUCTION IN THE THEATER OF OPERATIONS

by

A. A. Clark, R. J. Lacavich, D. N. Brown
W. K. Dornbusch, R. W. Whalin, F. B. Cox

June 1973

Sponsored by **Office, Chief of Engineers, U. S. Army**

Conducted by **U. S. Army Engineer Waterways Experiment Station**
Hydraulics Laboratory
Vicksburg, Mississippi

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION. CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG. MISSISSIPPI 39180

N REPLY REFER TO: WESAR

27 June 1973

Errata Sheet

No. 1

PORT CONSTRUCTION IN THE THEATER OF OPERATIONS

Technical Report H-73-9

June 1973

1. Acknowledgement is made to the following companies for permission to use the following figures:

Figure	Page	Company
10	46	Edo Western Corporation
15	52	Edo Western Corporation
18	54	EG&G International, Inc.
32	72	Ocean Research Equipment, Inc.
42	95	Southwest Research Institute Ocean Science and Engineering Laboratory

2. In figure 18, page 54, for "CAPACITATOR" read "CAPACITOR."

TECHNICAL REPORT H-73-9

PORT CONSTRUCTION IN THE THEATER OF OPERATIONS

by

A. A. Clark, R. J. Lacavich, D. N. Brown
W. K. Dornbusch, R. W. Whalin, F. B. Cox

June 1973

Sponsored by Office, Chief of Engineers, U. S. Army
Project No. 4A664717D895, Task 22, Work Unit 012

Conducted by U. S. Army Engineer Waterways Experiment Station
Hydraulics Laboratory
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

FOREWORD

This study was performed by personnel of the U. S. Army Engineer Waterways Experiment Station (WES) during the period June 1971-August 1972. The project (4A664717D895, Task 22, Work Unit 012) was funded by the Directorate of Military Engineering, Office of the Chief of Engineers, U. S. Army.

The analysis of the equipment with respect to the WES vehicle cone index system was performed under the direction of Messrs. S. J. Knight and E. S. Rush, Mobility and Environmental Systems Laboratory, WES. Analysis of flexible pavement, landing mat, unsurfaced media, and high-strength soils was performed by Mr. D. N. Brown, Soils and Pavements Laboratory, WES. The sections on "Collection of Terrain Intelligence Data for Port Construction," through "Hydrographic Surveying" (pages 19-102) were prepared by Mr. W. K. Dornbusch, also of the Soils and Pavements Laboratory. The section on "Consideration of Waves in Selecting Sites" was prepared by Dr. R. W. Whalin of the Hydraulics Laboratory, WES. The calculation and preliminary design work for the prefabricated reinforced concrete pier module was performed by Mr. F. B. Cox of the Concrete Laboratory, WES.

The study and coordination of the project were performed by CPT A. A. Clark and SP4 R. J. Lacavich of the Hydraulics Laboratory, WES, under the general supervision of Mr. M. B. Boyd, Chief of the Mathematical Hydraulics Division, and Mr. H. B. Simmons, Chief of the Hydraulics Laboratory. Portions of this report not mentioned above were written by CPT Clark and SP4 Lacavich.

Director of WES during the conduct of the study and preparation of this report was COL Ernest D. Peixotto, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONTENTS

Page

LIST OF FIGURES AND TABLES

LIST OF FIGURES AND TABLES

LIST OF FIGURES AND TABLES

LIST OF FIGURES AND TABLES

Figure | | Page

LIST OF FIGURES AND TABLES

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
square feet	0.092903	square meters
miles (U. S. statute)	1.609344	kilometers
miles (U. S. nautical)	1.852	kilometers
square inches	6.4516	square centimeters
acres	4,046.856	square meters
cubic inches	16.3871	cubic centimeters
cubic yards	0.764555	cubic meters
pounds (mass)	0.45359237	kilograms
kips (mass)	453.59237	kilograms
kips (force)	4.448222	kilonewtons
short tons (2000 lb)	0.907185	metric tons
long tons (2240 lb)	1,016.05	kilograms
pounds (force) per square inch	0.6894757	newtons per square centimeter
pounds (mass) per square foot	4.88243	kilograms per square meter
pounds (force) per square foot	47.88026	newtons per square meter
pounds (mass) per cubic inch	27,679.91	kilograms per cubic meter
kips per foot	14.59390	kilonewtons per meter

Multiply	By	To Obtain
kips (force) per square inch	6,894.757	kilonewtons per square meter
foot-pounds	0.138255	meter-kilograms
ft-kips	138.255	meter-kilograms
feet per second	0.3048	meters per second
miles per hour	1.609344	kilometers per hour
knots (international)	0.5144	meters per second

SUMMARY

Recent developments in marine shipping will have a profound effect on military port construction. The use of large container vessels and super tankers already requires that commercial marine terminals be extensively modified in order to operate efficiently. The Army must develop the capability to construct facilities that are compatible with these new developments.

This report furnishes basic reference information for use in selecting sites for military ports and port facilities, fulfilling the requirements of container facilities, and solving engineering problems that new developments in shipping will place on the military engineer. It involves only present state-of-the-art techniques and equipment that permit the off-loading of all types of commercial and military cargo vessels at the earliest practical time after a site has been tactically secured.

The report describes the effects of new shipping developments and the modifications that they will require in base development plans. A number of suggestions are introduced that will help in the planning of a port.

A comprehensive section is included on the collection of terrain intelligence data that will aid in proper planning of a port site. The intelligence data cover topographical, hydrographical, and cultural aspects of the proposed port location and sources and techniques to acquire the data that are necessary for sound engineering decisions.

Design considerations for structures are discussed with emphasis placed on container facilities. One of the critical design factors is the type of equipment that will be using the facility. Individual pieces of equipment will have to be checked to ensure that they do not impose greater loads than those for which the structure was designed.

An evaluation was performed of the Army's existing DeLong barges to determine if they could be efficiently utilized as container facilities, and, if so, to determine the engineering problems that would develop.

The design considerations and problems involved in the selection of fenders are also discussed herein. Steps in designing a fender system are illustrated using a DeLong barge as an example. Fendering systems for a DeLong pier are discussed and illustrated.

In the section on surfacing and transient storage areas, flexible pavement curves, M8A1 landing mat requirements, and vehicle cone indexes for sample container handling equipment operating on unsurfaced soils are developed. The criteria for operation of aircraft on unsurfaced areas were used for medium- and high-strength soils, and the criteria for the design of military roads and airfields were employed in the analysis of M8A1 landing mat and flexible pavements. Surface area requirements for container facilities are discussed, and several layouts for different pieces of equipment are illustrated.

The capabilities and uses of different types of dredges and new developments in transportability to the theater of operations are discussed.

Cranes, pile driving equipment, and construction barges are discussed regarding their use in constructing port facilities in the shortest possible time.

Results of the study indicate that recent developments in marine shipping will significantly change the requirements for port facilities within the theater of operations.

PORT CONSTRUCTION IN THE THEATER OF OPERATIONS

PART I: INTRODUCTION

Purpose and Scope

1. The purpose of this project was to prepare a technical report that would furnish basic information, guidelines, and reference material for use in selecting sites in a theater of operations (TO) for military ports and port facilities, the types of facilities required, and appropriate construction techniques. Primary emphasis was to be directed toward outlining procedures and techniques that would permit the off-loading of all types of commercial and military cargo vessels at the earliest practical time after a site had been tactically secured.

2. The scope of the research was to be limited to the immediate time frame, and only present state-of-the-art techniques, equipment, and materials were to be considered. The capabilities of existing Army construction units were not to have a governing influence. Ports in Vietnam were constructed almost entirely by civilian contractors whose capabilities far exceeded those of military engineer units primarily because of their experience and the equipment that was available to them.

3. The definition of "port," as interpreted for this project, is a sheltered harbor area immediately adjacent to the land/water interface in which marine terminal transportation units and the petroleum wharf platoon normally operate. Facilities normally associated with depot operations were not considered.

Reports on Past Port Construction

4. A study was made of previous military port construction operations. These operations are summarized in the following paragraphs.

European Theater, 1942-1945

5. The final report of the Chief Engineer, European Theater of

Operations (ETO), reviewed the American port rehabilitation operations in France. Preliminary planning began with the collection of all available information for each of the ports to be studied. This information permitted the Section Engineers to develop detailed plans that proved to be quite accurate in most cases.

6. The Chief Engineer concluded that experience in the ETO showed that it is impossible to place too much emphasis on the value of modern, large-capacity construction equipment. He praised the 40-ton* crawler crane as the most valuable individual piece of equipment but noted that there was a shortage of 60-ton trailers on which to transport them. Adequate dredging equipment was not available in sufficient quantities. Of the four hopper dredges available, only the shallow-draft "Hoffman" could be gainfully employed. A dipper or bucket dredge with a capacity of approximately 8 cu yd would have been of great assistance in removing underwater debris alongside the quays had one been available. Port repair ships were primarily used for their machine shops. When such ships are used, they should be amply supplied with various sizes of stock and plate.

Southwest Pacific, 1941-1945

7. A number of comments on port construction techniques were included by the Chief Engineer, General Headquarters, Army Forces, Pacific, in his report of engineer operations in the Southwest Pacific. The pier facilities developed in the South Pacific Theater were later adopted into the present Army's facility component system.[1]

8. Although no specific deficiencies were noted in the area of port construction, descriptions of individual operations indicated that seldom were pile-supported wharves constructed in less than 60 days after an operation began; usually construction of such wharves took much longer. Floating piers constructed of Navy pontoons were usually assembled in a matter of days from causeway sections and 5 by 12 barges. These units apparently performed adequately when located in protected

---

* A table of factors for converting British units of measurement to metric units is presented on page xv.

areas. The lack of adequate port facilities in both Australia and New Guinea aggravated the shortage of available shipping, the high deadline rate of landing craft, and the shortage of repair parts for engineer equipment. Port construction companies did not participate until the capture of Manila. Prior to this, the task of building marine terminal facilities was assigned to whatever construction unit happened to be in the area. These units apparently had little or no experience in pile driving or overwater construction. Some problems were experienced with attempting to drive timber piles into hard coral, damage caused by marine borers, piles of insufficient length, and with the use of cranes that were too small for heavy construction tasks. Most of the problems could be attributed to inadequate staff planning. Priority for planning was directed toward airfields and future amphibious and combat support operations.

Vietnam

9. A report by the Joint Logistics Review Board (JLRB)[2] documents the logistic support to U. S. combat forces in Vietnam during the period 1965-1970. This report provided the primary guidance to current research and development programs within the Department of the Army concerning base developments and transportation within the theater of operations.

10. Many recommendations were made in all areas of combat service support. The ones that have the greatest bearing on port construction in the theater of operations were:

- a. The use of containers should be developed and exploited as rapidly as possible.
- b. Rather than concentrating on specific details, such as individual line item identification and siting, contingency base development planning should emphasize the following:
    - (1) Determination of gross requirements derived from typical site layouts.
    - (2) Troop and contractor on-site construction effort requirements.
    - (3) Funding requirements for various force levels, locations, types of operations, and climatic conditions.

(4) Key construction items with long lead times with particular attention to dredges, pile drivers, prefabricated piers, and rock crushers.

c. The Military Sea Transport Service (MSTS), now Military Sealift Command (MSC), nucleus fleet should include a mixture of barge-carrying ships, medium-sized container ships, "handy-sized" tankers, and multipurpose ships.

d. Personnel who possess specialized logistical skills of the type needed during a contingency operation should be identified (to the maximum extent practicable in the active forces--otherwise in the reserve forces).

e. The planning and implementation of construction programs related to contingency operations should incorporate the use of preengineered, prefabricated, relocatable facilities as a means of improving construction responsiveness and reducing the construction effort.

Effects of New Shipping Developments

11. Recently a number of developments in ocean freight transportation occurred that will have a significant effect on future military logistics operations. A number of studies have been made that evaluate the effectiveness of commercial operations that have been or could be incorporated into military logistic systems.

12. One of the topics that is not receiving all the attention that it should is the effect that these new developments will have on military port construction. New container facilities at ports all over the world are being built because it is impractical to modify existing facilities to handle containerized cargo or to accept the high-speed discharge of roll-on/roll-off ships. This fact alone should be significant enough to focus attention on the inadequacy of existing contingency plans and standardized facility designs for use as container facilities.

13. It is actually somewhat ironic that the military introduced the wide-scale use of roll-on/roll-off techniques, the use of large freight containers, and the use of lighter aboard ships (LASH), Civilian developments emanating from these concepts have outdistanced existing military capability for rapid employment of container ships.

Containerization

14. Containerization of cargo, as we know it today, has a number of advantages for military logistics operations. It allows ships to be off-loaded seven to ten times faster than ships carrying break-bulk cargo, thus reducing the required number of berthing facilities. Containerization also allows the cargo to clear the port in a minimum time with a high degree of economy and eliminates the need for large quantities of covered storage. It also reduces pilferage and the need for large security forces.

15. On the other hand, there are a number of disadvantages to containerization. Because a large container ship will replace five break-bulk vessels, the loss of one ship will have five times the impact on the total system. One container berth is equal to seven to ten break-bulk berths, and its loss can have a staggering effect if reserve facilities are not available. Each berth must be supplemented by large transient storage areas to achieve potential discharge rates, and many existing ports have only limited space available. Large capital investments and tremendous demands for good management are necessary for the containerization system to operate efficiently.

Large high-speed container ships

16. Container ships have increased steadily in size since the first ships were created by modifying existing break-bulk vessels. As the traffic in containerized cargo has increased and terminals capable of handling large volumes of containers have been constructed, the larger container ships have become more economically attractive. Vessels are now in operation and under construction that will carry more than two thousand 20-ft container equivalents. A number of the ships are more than 900 ft long and 100 ft wide, and draw more than 35 ft of water when fully loaded. Displacements run in excess of 40,000 long tons.

17. From a construction standpoint, the possible introduction of ships of this size into a military operation is of great importance. Berth facilities must be 1000 ft long or longer, and channel depths must be maintained in excess of 40 ft. Container cranes must be capable of

lifting containers up to 110 ft from the face of the fender. Fendering piers and wharves in exposed locations will involve a major design and construction effort. Transient storage areas will have to be large and carefully designed to permit the unimpeded flow of container handling equipment.

Roll-on/roll-off ships

18. The major advantage of roll-on/roll-off ships over lift-on/lift-off ships is their fast turnaround time in port. This advantage may offset the large loss of shipping cubage on relatively short hauls when the time spent in port is a significant portion of the total cycle. Roll-on/roll-off ships also permit a reduction in the number of terminal facilities because more ships can use an individual facility, and the cargo can be cleared from the port very rapidly. In addition to these vessels, there is an increasing number of ships such as those operated by the Atlantic Container Line which combine container lift-on/lift-off systems with roll-on/roll-off systems. These vessels offer the advantages of either system, depending on the needs of a particular customer. Construction considerations for roll-on/roll-off ships vary considerably depending on the size of the ships using the facility, the locations of their doors and ramps, and the tidal range of the port. Navy LST's have their ramps through or over the bow, while most commercial vessels have either stern ramps, side doors, or both. There appears to be no specific facility design that is compatible with all types of ships.

Container handling equipment

19. At the present, standard commercial containers may weigh up to 30 long tons (67,200 lb). Equipment capable of lifting and moving loads of this magnitude is commercially available. Little work has been done, however, on the effect that container handling equipment has on flexible and rigid pavements, and virtually no work has been done on the effect of container handling equipment on expedient surfaces and unsurfaced soils. The problem of designing pavements and marine structures to carry these loads is addressed in this report.

Shipboard and pier-mounted cranes

20. Most existing dock cranes were not capable of lifting large

freight containers when they were first introduced. Therefore, the early container ships were made self-sustaining by equipping them with their own deck-mounted gantry cranes. As the container trade routes developed and new container shipping facilities were constructed, the new facilities were equipped with pier-mounted gantry cranes designed for container operations.

21. With these pier-mounted cranes, it was possible to service a number of ships rather than just the one on which the deck crane was mounted. Pier-mounted cranes are also advantageous in that they do not burden the ship with nonrevenue producing cargo. Also, pier-mounted cranes can be ganged at one berth so as many as four cranes can service a ship when the other berths along the wharf are not occupied.

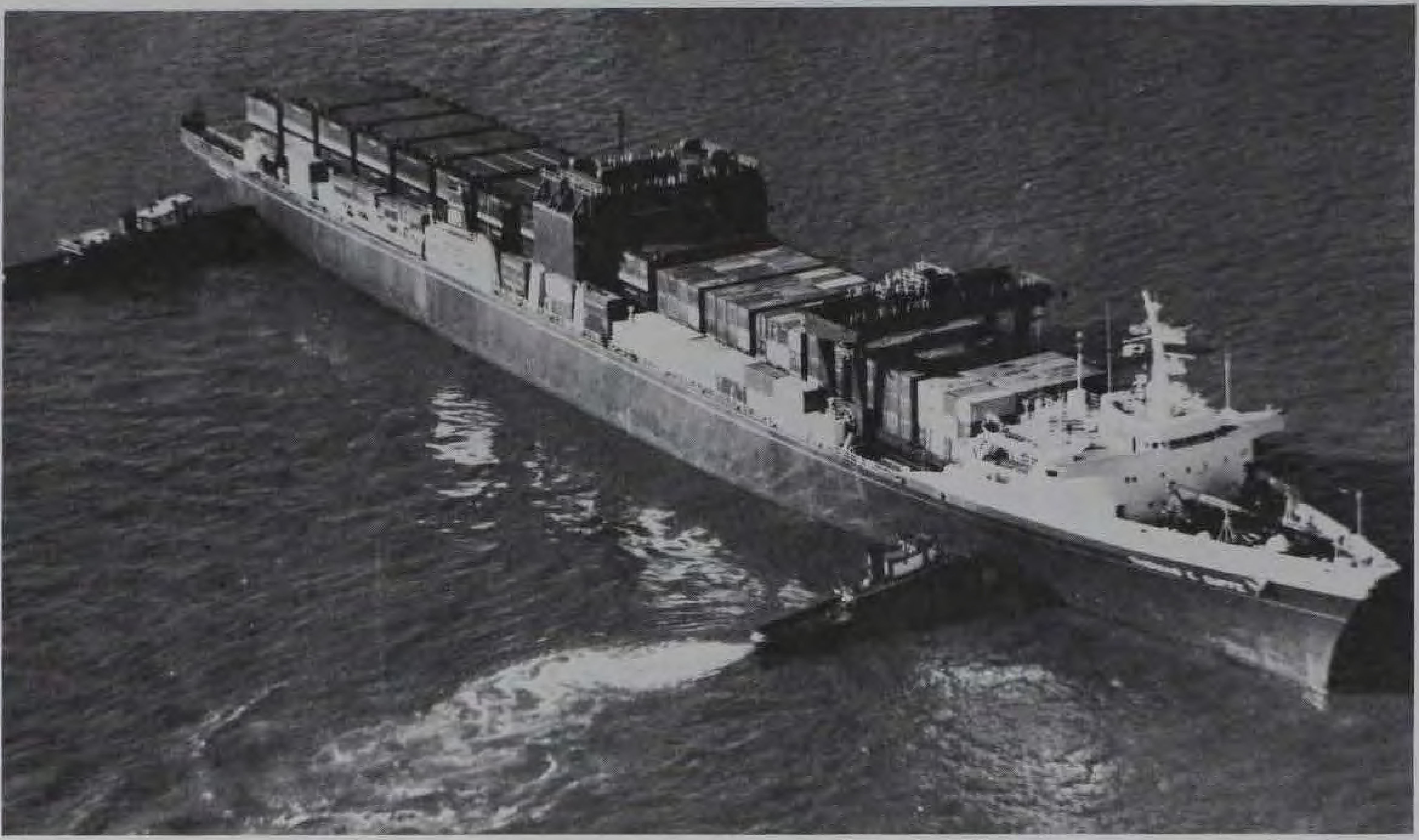
22. From a construction standpoint, these new cranes presented some interesting design problems. For one, the larger cranes weigh 500 tons or more, with design wheel loads of 100,000 lb on 4- to 5-ft centers. Piers had to be built that were capable of supporting these cranes as well as uniform live deck loads of 1000 lb/sq ft. The Army's DeLong barge was designed for break-bulk cargo of 600 lb/sq ft. Another problem involved with pier-mounted gantry cranes is that they take from two to five months to erect and prepare for operation. This is hardly compatible with the time constraints of most military logistics operations.

Heavy-lift helicopters

23. A number of studies and tests have been made to determine the helicopter's ability to discharge container ships at sea. For the most part, these studies have shown that the costs are excessive and that some means must be available for removing hatch covers and preventing containers stored below deck from jamming in their cell guides during pickup. The heavy-lift helicopter also requires major construction effort ashore in the form of dust palliation and surfacing mediums.

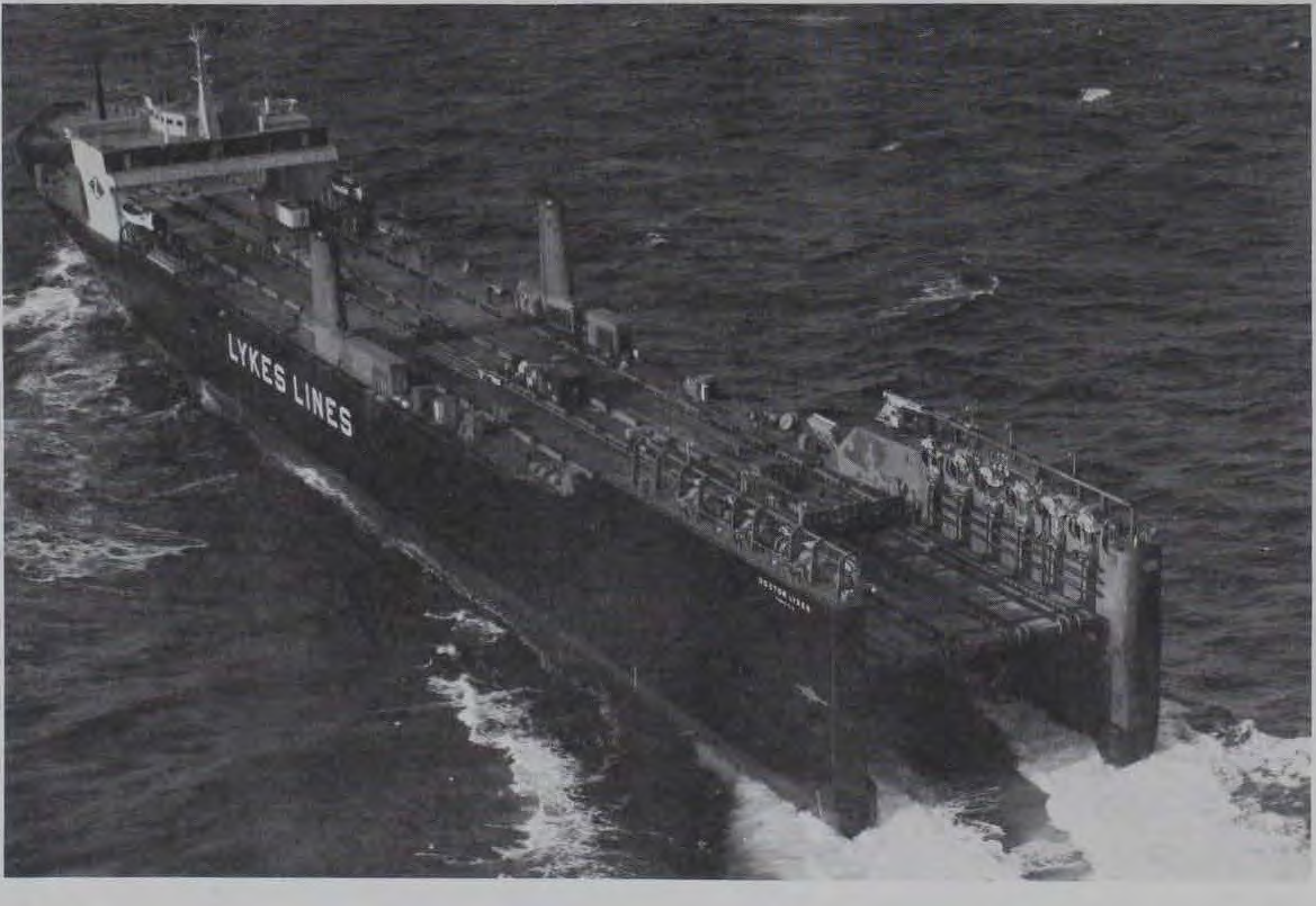
Barge ships

24. One of the latest developments in marine shipping has been the use of barges as containers. There are presently two different systems in use; the LASH (fig. 1) and the Seabee (fig. 2). The LASH ships



(Courtesy of Lash Systems, Inc., New Orleans, La.)

Fig. 1. LASH barge ship



(Courtesy of General Dynamics, Quincy, Mass.)

Fig. 2. Seabee barge ship

carry a mixed cargo of 415-short-ton-capacity barges and standard containers. A 500-ton-capacity gantry crane lifts and lowers the barges into vertical cells and transports them to and from the stern. The Seabee barge ship carries thirty-eight 850-ton-capacity barges that are lifted from the water by a 2000-ton-capacity marine elevator. The barges are stored on three noncellular decks and are moved by a transporter mounted on rollers (fig. 3).

(Courtesy of General Dynamics, Quincy, Mass.)

Fig. 3. Lower deck of Seabee barge ship

25. Both of these ships will have a significant influence on construction because they are self-sustaining and they can transport extremely large prefabricated engineer modules. The Seabee is able to transport barges up to 100 ft long and 70 ft wide on its top deck. If shortened, the DeLong "B" barge can be shipped to overseas locations three and one-half times faster than by the present method of towing. The ship can also transport construction barges, dredges, tugs, landing

craft, petroleum tanks, floating cranes, standard containers, helicopters, and wheeled and tracked vehicles (fig. 4). Because of its noncellular horizontal hold, the Seabee can also be easily transformed into a tanker, troop carrier, or hospital ship by inserting tanks or compartmented modules.

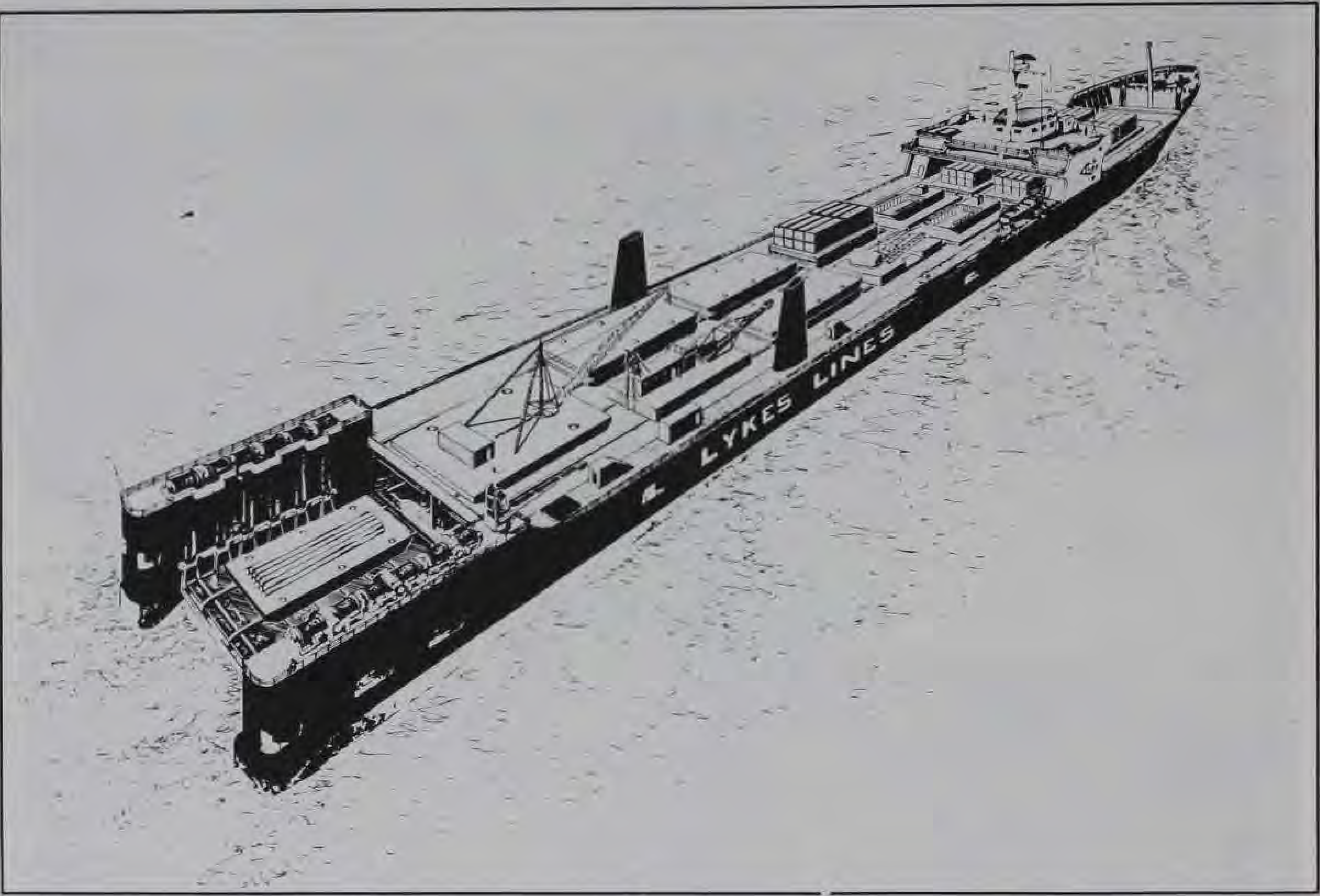


Fig. 4. Artist's concept of Seabee loaded with engineering equipment

26. The standard LASH and Seabee barges are ideal for military operations because their shallow drafts and narrow beams allow them to be towed into restricted waters and unloaded by cranes currently in the inventory. This greatly reduces the dependency on dredging, wreckage clearance, and the construction of piers, wharves, tank farms, power generating facilities, machine shops, and repair parts facilities in the early stages of port development.

27. Because there will be only three of the Seabee ships in operation by mid 1973, competition for their use will be great. During the study, an inquiry was made in an effort to determine just what the

probable uses of these ships would be during the deployment of troops to an overseas area. Because the Department of Defense's containerization program has just begun, no firm doctrine has yet been established concerning the role that barge ships will have in a major logistics operation.

Large tankers

28. In 1955, 92.8 percent of the world tanker fleet tonnage was hauled in ships of 30,000 dwt capacity or less, and ships over 50,000 dwt capacity were just being introduced. By 1970, only 21.9 percent of the total tonnage was hauled in ships of 30,000 dwt capacity or less, and 52.5 percent was hauled in tankers of over 50,000 dwt capacity. These facts are important because tankers over 50,000 dwt capacity normally draw 50 ft of water or more when fully loaded.[3]

29. The use of large tankers will require construction of facilities with adequate water depths, high-capacity discharge systems, large tank farms, and effective provisions for controlling spillage. These facilities must be capable of being constructed under much more severe time restraints than is normally required for the construction of civilian facilities.

PART II: PLANNING A MILITARY PORT

Initial Planning

30. The initial planning of a military port is normally the function of the base development planning board. This board is responsible to the theater commander for projecting the facilities needed to provide adequate combat service support to tactical units. Because ports can be expected to handle 95 percent of the total resupply tonnage required for major operations, they logically should receive a significant portion of the planning effort.

31. The preparation of the theater base development plan is governed by the guidelines set forth in references 4 and 5. The base development plan is actually an element of the logistics annex to the theater operations plan. The construction planning described in the document is very general in nature due to the level at which the planning is conducted, the flexibility required for long-range plans, and the need to allow subordinate commands freedom of action.

32. One of the primary objectives of base development or any other contingency plan is to identify major problem areas so that appropriate action can be taken to ensure that any detrimental effects on operations can be maintained within tolerable limits. For instance, long-lead-time items must be identified to permit their prestockage or at least to "flag" them for early procurement should the operations plan be partially or wholly implemented. One limitation of the current system is that the items identified are only those currently listed in the Army Facilities Component System (AFCS), with the exception of self-elevating barges.

33. Many items employed in the construction of marine terminal facilities are either not listed in the AFCS as independent facilities or, when included, require specific knowledge of the site. For example, mooring buoys, anchors, and chains are included only as components of the submarine pipeline facility. These unidirectional mooring arrangements are not suitable for single-point mooring of ships and barges.

The free-swinging, riser-type, and telephone-type moorings would normally be employed and are included in the Navy Advanced Base Component System. Because they are not included in the AFCS, however, it is doubtful that they would normally be included in most Army contingency plans. The amount and type of fendering to be installed at piers primarily depends on the size of the ships being berthed and the degree of exposure of the site. All fendering presently included is designed for extremely light loading conditions that would be adequate only in sheltered harbors. The situation may arise in which materials requisitioned for the construction of facilities included in the AFCS are found to be completely incompatible with those that are actually needed. For instance, it may be found that even long timber piles are too short for foundation soils that are extremely weak. If materials must be used from other planned projects to complete a facility, the number of facilities to be constructed could be reduced. The port discharge rates may turn out to be only a fraction of those planned due to the reduced number of facilities. The AFCS is currently being revised to include the design of marine facilities that can be adapted to a wide range of site condition and load requirements.

Personnel

34. If large marine construction projects are to be conducted without major problems developing, personnel experienced in marine construction are an absolute necessity. A port engineer office staffed by experienced personnel should be established at each major site and should have staff responsibility for all design, construction, and maintenance activities. It would function in the same general manner as a civilian port engineer office within a port authority.

35. Fig. 5 is a flow chart constructed to show the sequence of tasks that a port engineer office might perform during the various phases of planning, construction, and maintenance of port facilities.

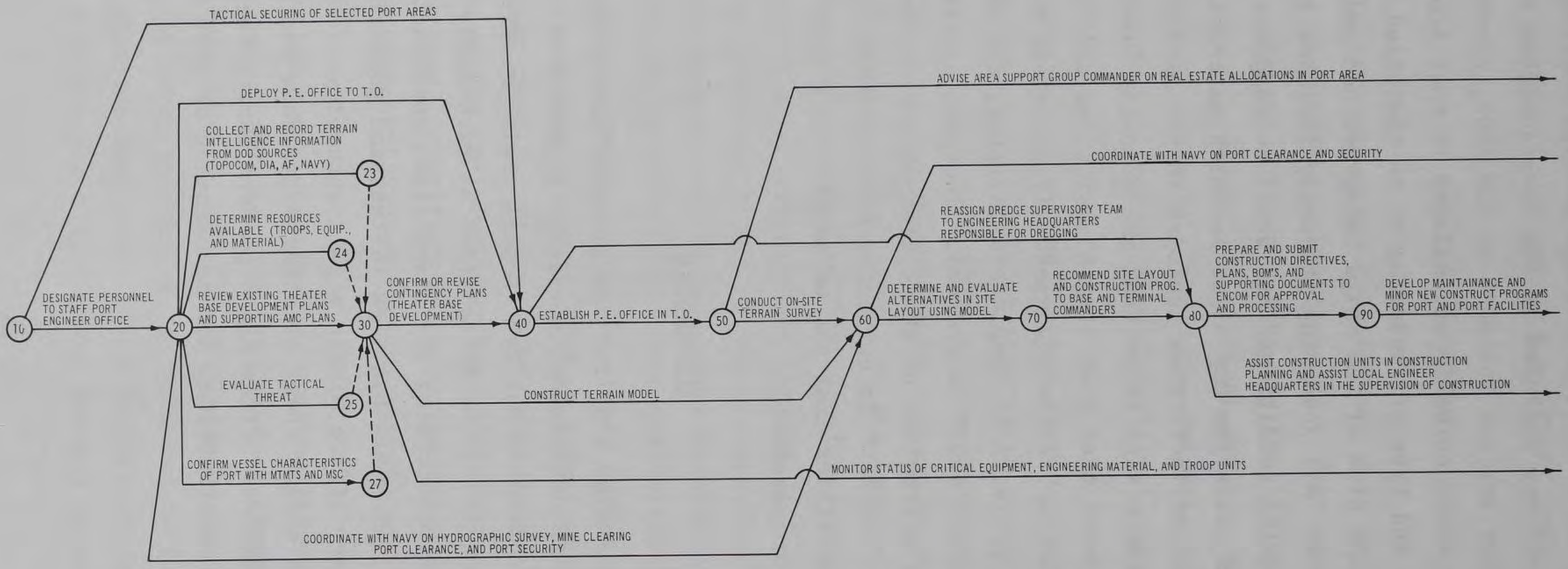


Fig. 5. Work diagram for port engineer office

Terrain Model

36. A tool that would greatly assist in the planning of a port facility would be a terrain model. Once a particular area has been designated for a port, a physical model can be constructed for use in deciding where the individual facilities should be placed. Since the approval authority for base development lies within a number of headquarters staffed by personnel from different branches and backgrounds, the model serves as a monitor of the status of planning and construction.

37. For instance, the different branches with vested interests and responsibilities in port planning are:

Branch	Interests and Responsibilities
Engineers	Terrain intelligence, real estate allocation, construction, and maintenance
Transportation	Port operations
Quartermaster	Petroleum, oil, and lubricant (POL) storage
Military police	Security and traffic control
Air defense artillery	Air defense
U. S. Navy	Port debris clearance, offshore coastal defense, and inshore riverine warfare

38. The port engineer office appears to be the most logical choice for preparation of the model. To determine the actual value a model would have in planning a military port, it was decided to construct a model of Cam Rahn Bay in the Republic of Vietnam.

39. The model (fig. 6) was constructed in about three 8-hr days and was approximately 63 in. square and weighed about 50 lb. With the experience gained from constructing this model, it was considered that the two trained draftsmen could construct subsequent models in approximately half the time it took to construct the first.

40. The model was constructed of 1/2-in. layers of urethane. A 1:25,000-scale topographic map was enlarged to a scale of 1:6,250. By using the contour lines of the map as a guide, successive layers of urethane were cut. These layers of urethane were glued together on a

Fig. 6. Terrain model of Cam Rahn Bay, Vietnam

base of 1/2-in. plywood. The model was then painted with blue representing the area covered by water and tan for land areas. The material used for construction of this model was light and easily handled. New and pertinent information can be added when acquired. The model also acts as a check to determine if all the data needed for construction purposes have been acquired.

41. As soon as the model has been laid out and approved, a photograph can be taken to serve as the port development plan. Several such plans can be analyzed in a staff study format to give the approval authority a choice of several workable solutions.

42. The physical model provides a tangible record of the progress of the planning process from the collection of terrain intelligence information to the final approval by the responsible authority. It forces a continual evaluation of the factors influencing decisions on site layout so that only the most pertinent factors need be collected and

displayed. The model also provides a much needed "open-ending" of the planning process so that the personnel involved in the collection operation have a specific objective upon which they can orient.

43. In the Cam Rahn Bay model, only two basic schemes (fig. 7) were tried because of a problem with ammunition facility safety distances listed in reference 6. If there is insufficient time for dredging, the ammunition facility must be located in the outer harbor, as shown in fig. 7a, or there must be a reliance in lighterage. LASH and Seabee systems will apparently make problems worse by flooding the port with a large number of loaded barges. If these barges are spread out according to safety regulations, the entire inner harbor is contaminated for other uses.

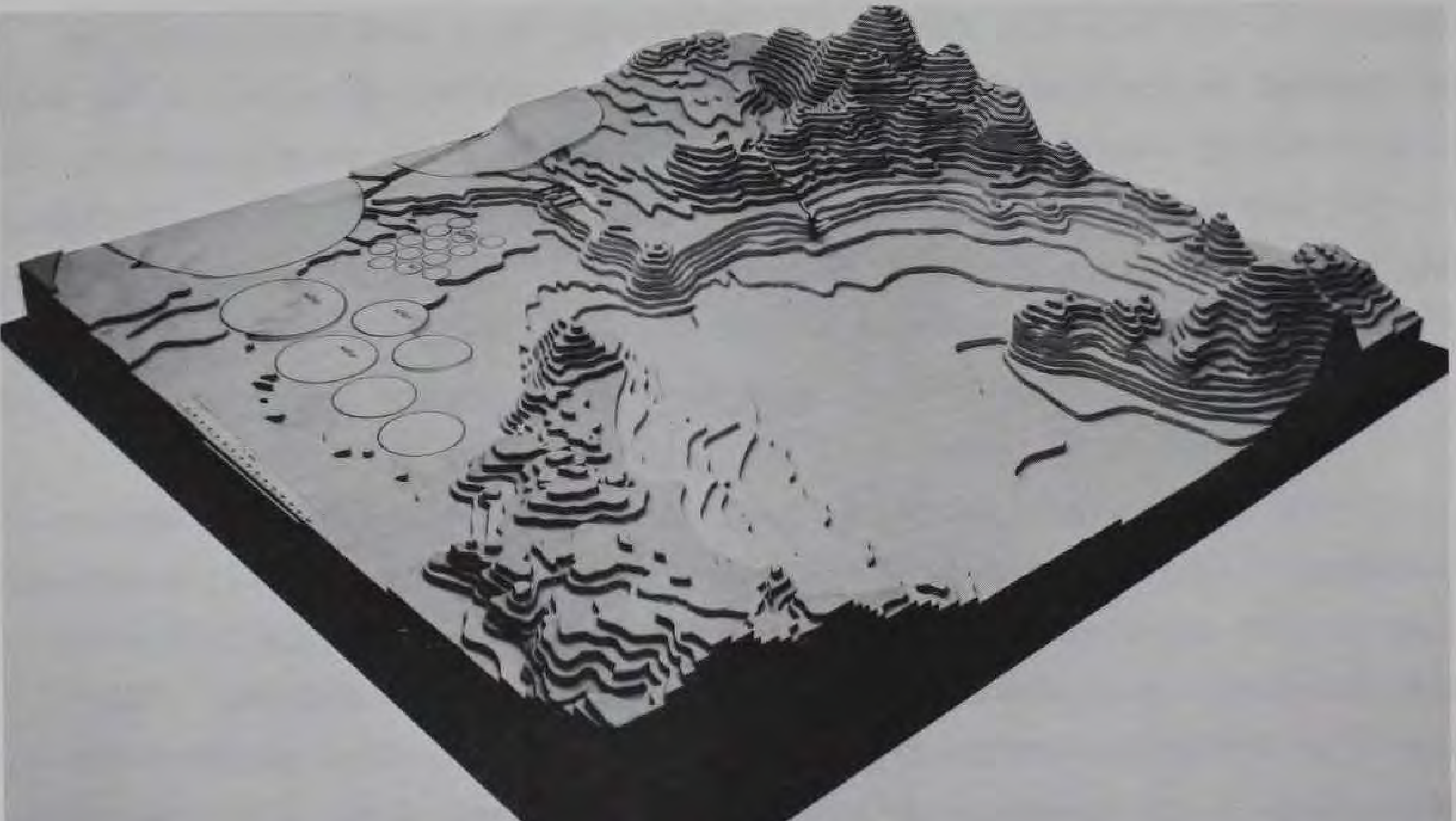
44. If dredging is possible, the ammunition facility may be moved into the inner harbor, but must be located well north of the airstrip. The tanker discharge facility should then be moved to a safer location in the outer harbor. Alternate pipelines should be run to the dry cargo or ammunition piers and charged with water for fire fighting. These same lines should be capable of handling POL in the event that something happens to the main POL facility. Of course, this same philosophy can be applied to the ammunition facility. If possible, at least one breakbulk facility should be separated from the rest to act as a backup to the primary ammunition pier or wharf. This was not possible at Cam Rahn Bay because of limited space (see fig. 7b).

Book Set

45. During this study, a great amount of published material was reviewed to glean information pertinent to the project. A list has been compiled of material that will give both planning and design personnel information on port planning and the design of port facilities. This book list comprises civilian texts, handbooks, U. S. Navy Design Manuals, U. S. Army Field Manuals and Technical Manuals, and U. S. Army Engineering Pamphlets.

46. The most comprehensive texts are, Design and Construction of

a. Scheme I



b. Scheme II

Fig. 7. Schemes I and II of Cam Rahn Bay model

Ports and Marine Structures,[7] and Waterfront Operational Facilities.[8] A complete listing of the book set is presented as Appendix A.

Collection of Terrain Intelligence Data for Port Construction

47. Port construction in the Theater of Operations (TO) must be responsive to both the current and immediate needs, strategic and tactical, of Army forces. It must consider the receipt, storage, and dissemination of enormous volumes of supplies that are required in support of the military operations. In addition, the construction must be responsive to the requirements of supporting elements of the Navy and Air Force. Since the port and component facilities represent construction effort of major proportions and since time is a vital factor, comprehensive and visionary planning is of an essence. The planning must consider the mission of the port, its requirements, general geographic location, tentative methods of construction, and personnel, and material requirements. To allow required decisions as to type and method of construction and to provide sufficient guidance as to the optimum layout, adequate area intelligence must be available. This intelligence must cover all of the topographical, hydrographical, and cultural aspects of the proposed port location to allow accurate evaluations regarding adequacy for navigation, volumes of shipping traffic, construction techniques, storage, expansion requirements, transportation and communication, security, and protection from natural phenomena, e.g., wind, waves, and flooding. Construction of TO ports capable of supporting massive military operations within limited time frames has long presented a major problem. Too often inadequate intelligence during the planning phases has resulted in ineffectual overall operation. Poorly conceived layouts, unrealistic choices of structural types, and improper construction techniques are avoidable when planning proceeds within the environmental limitations of the port location.

48. The purpose of this portion of the report is to present procedures and techniques for the collection of relevant environmental data that are needed for meaningful planning of a port facility. Both the

collection of background and on-site data are discussed. The types of data required and the sources from which they may be acquired are identified. Field data collection techniques that can be applied in the time period allotted for the site investigation, i.e., two weeks, are also described and evaluated. Surveying systems that are optimum from the standpoint of operationability, accuracy, and expediency are described and recommended. The economic aspects of the recommended systems were not a factor in the evaluation and ultimate selection. The techniques described herein are sufficiently flexible to permit local conditions such as time and environmental complexity to dictate operational changes.

49. This report is specifically purposed to describe site investigation techniques within priority areas where the construction of pile-supported structures, namely DeLong and Ammi piers, is considered the most feasible. Although the survey vessel is adequately staffed and equipped to conduct hydrographic surveys over an entire harbor area, its activities have been restricted to the priority areas. Surveys of an entire harbor for navigational purposes are characteristically a function of the Navy. The hydrographic surveying systems package was generated for this study, and it is doubtful that the unique range of capabilities, in total, could be as effectively applied to other surveying requirements. Many facets of the hydrographic survey are direct adaptations of standard procedures detailed in the included references. The development of the site investigation techniques has been purposely oriented toward a time limitation of two weeks. The techniques have been kept as flexible as possible and thus may be expanded or abbreviated to meet changing time requirements. The list of sources for oceanographic data is partial but representative. It must be realized that hydrographic surveying is a rapidly expanding field of technology and that innovations in both techniques and instrumentation may offer substantial improvements upon the techniques described herein.

Types of Background Data

50. Background data include all physical and cultural and

climatic intelligence that may be available in the general area of proposed port construction. The data include a wide variety of types, and the availability of each type may vary widely from one geographic locale to another. Background intelligence data required to evaluate the suitability of an area for port construction are principally: (a) physical and cultural aspects of the shoreline and contiguous interior, (b) weather regimes, intensities and extremes, and (c) bathymetric and subbottom characteristics. Types of data from which this intelligence may be derived can be conveniently categorized as: (a) maps, (b) photography and imagery, (c) documents and records, and (d) historical data describing existing port facilities. These data may be obtained from sources both in the Continental United States (CONUS) and in the TO. The types of data and the principal sources are discussed in the following paragraphs.

Maps

51. Topographic maps. Scales of these maps vary widely. Coverages of 1:50,000 and 1:250,000 are available for sizable portions of the world, although more extensively for highly developed areas. Slope, relief, and configurations of shoreline landscapes are obtainable directly from the maps, with the degree of accuracy being a function of the scale and contour interval. Drainage patterns, land use, natural vegetation, and cultivation are also portrayed on these maps as are population centers and transportation networks. Bathymetric contours and navigation hazards, e.g., mud, shoals, rock, coral, etc., are delineated.

52. Soil maps. These maps are prepared for a variety of purposes, e.g., agricultural potential, land use, and construction. Soil surveys have been conducted for entire countries in some instances but more frequently cover only limited areas. The distribution of soils is portrayed on soil maps, and descriptions are normally in textural terms. Depths to parent rock may be included. Scales vary widely; e.g., 1:25,000 maps are available for portions of West Germany, while 1:1,000,000 maps represent the best coverage for certain poorly developed countries. World soil maps, excluding the United States, have been prepared by the United States Soil Conservation Service (USCS) with descriptions in

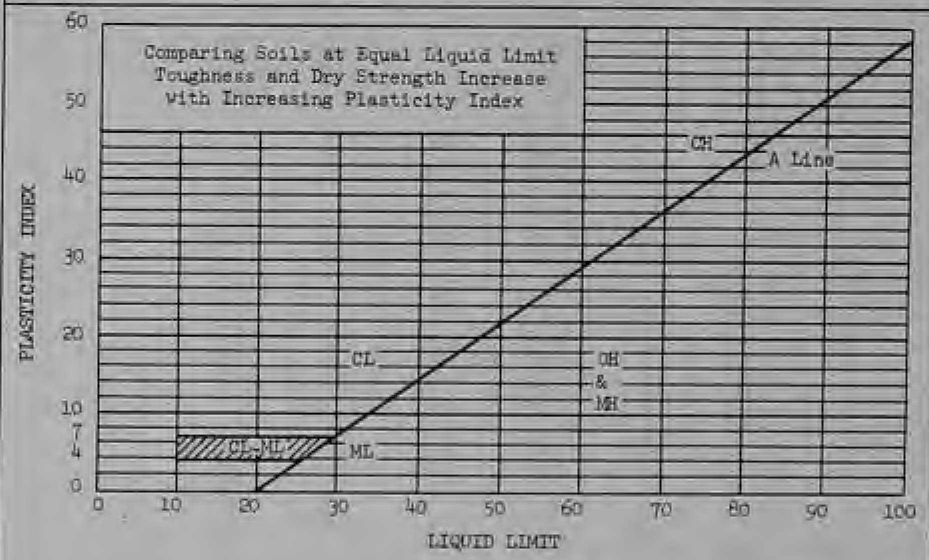
United States Department of Agriculture terms. The distribution of soils portrayed on these maps is usually determined by landform and physiographic association and is of questionable accuracy. Detailed soils maps prepared in support of agricultural and engineering studies provide comparative detail, but their occurrence is sporadic and unpredictable. In many cases, descriptive agricultural terms used in soil surveys are translatable into the engineering terms (USCS) required for this study (fig. 8).

53. Geologic maps. Geologic maps depict a number of geologic or geologic-related conditions such as the surface and substrate distribution of formations, structure, and the distribution of landforms. Such maps often provide information regarding the configurations and dimensions of shoreline landforms, engineering characteristics of overburden materials, the nature of surficial soils, and classification and distribution of surface or near-surface rock and associated soils. In addition, the maps usually symbolize drainage patterns, land use, and vegetative patterns. Geologic maps, when prepared in sufficient detail, can provide a general basis for the selection of construction sites as well as sources of suitable construction materials.

54. Pictomaps. Pictomaps are usually large-scale maps, viz. 1:25,000, which have been prepared from controlled aerial photomosaics. Colors and symbols are used to denote vegetation and hydrologic and cultural patterns, which are superimposed upon the photographic image. Surface and bathymetric contours are included on the maps most frequently at 1-, 5-, and 10-m intervals. The pictomap probably represents the most suitable base for generation of a three-dimensional terrain model of a port area (see paragraph 36).

55. Hydrographic charts. These charts depict hydrologic conditions along and immediately inland of the shorelines of the world. Depth soundings in feet are presented for both offshore and inland waters. Navigable waterways are indicated, and navigation hazards and man-made structures such as platforms, stakes and markers, and lighthouses are located. Tidal information is provided for selected stations

UNIFIED SOIL CLASSIFICATION
(Including Identification and Description)

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)			Information Required for Describing Soils	Laboratory Classification Criteria			
1	2		3	4	5			6	7			
Coarse-grained Soils More than half of material is larger than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.			For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics.	Use grain-size curve in identifying the fractions as given under field identification.	Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5% = GW, GP, SW, SP, More than 12% = GM, GC, SM, SC, 5% to 12% = Borderline cases requiring use of dual symbols.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.						Not meeting all gradation requirements for GW	
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses.			Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).						Atterberg limits above "A" line with PI greater than 7	
	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.						$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
			SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.						Not meeting all gradation requirements for SW	
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).			Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).			Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).						Atterberg limits above "A" line with PI greater than 7	
Fine-grained Soils More than half of material is smaller than No. 200 sieve size.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size							
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)					
	Silts and Clays	Liquid limit is less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.		 PLASTICITY CHART For laboratory classification of fine-grained soils		
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium					
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight	Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses.				
	Silts and Clays	Liquid limit is greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium					
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High					
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium	Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).				
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.							

(1) Boundary classifications: Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. standard.

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS

These procedures are to be performed on the minus No. 40 sieve size particles, approximately 1/64 in. For field classification purposes, screening is not intended, simply remove by hand the coarse particles that interfere with the tests.

Dilatancy (reaction to shaking)

After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics)

After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its strength by breaking and crumbling between the fingers. This strength is a measure of the character and quantity of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.

High dry strength is characteristic for clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (consistency near plastic limit)

After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size, is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.

After the thread crumbles, the pieces should be lumped together and a slight kneading action continued until the lump crumbles.

The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.

Highly organic clays have a very weak and spongy feel at the plastic limit.

Adopted by Corps of Engineers and Bureau of Reclamation, January 1952.

021260A

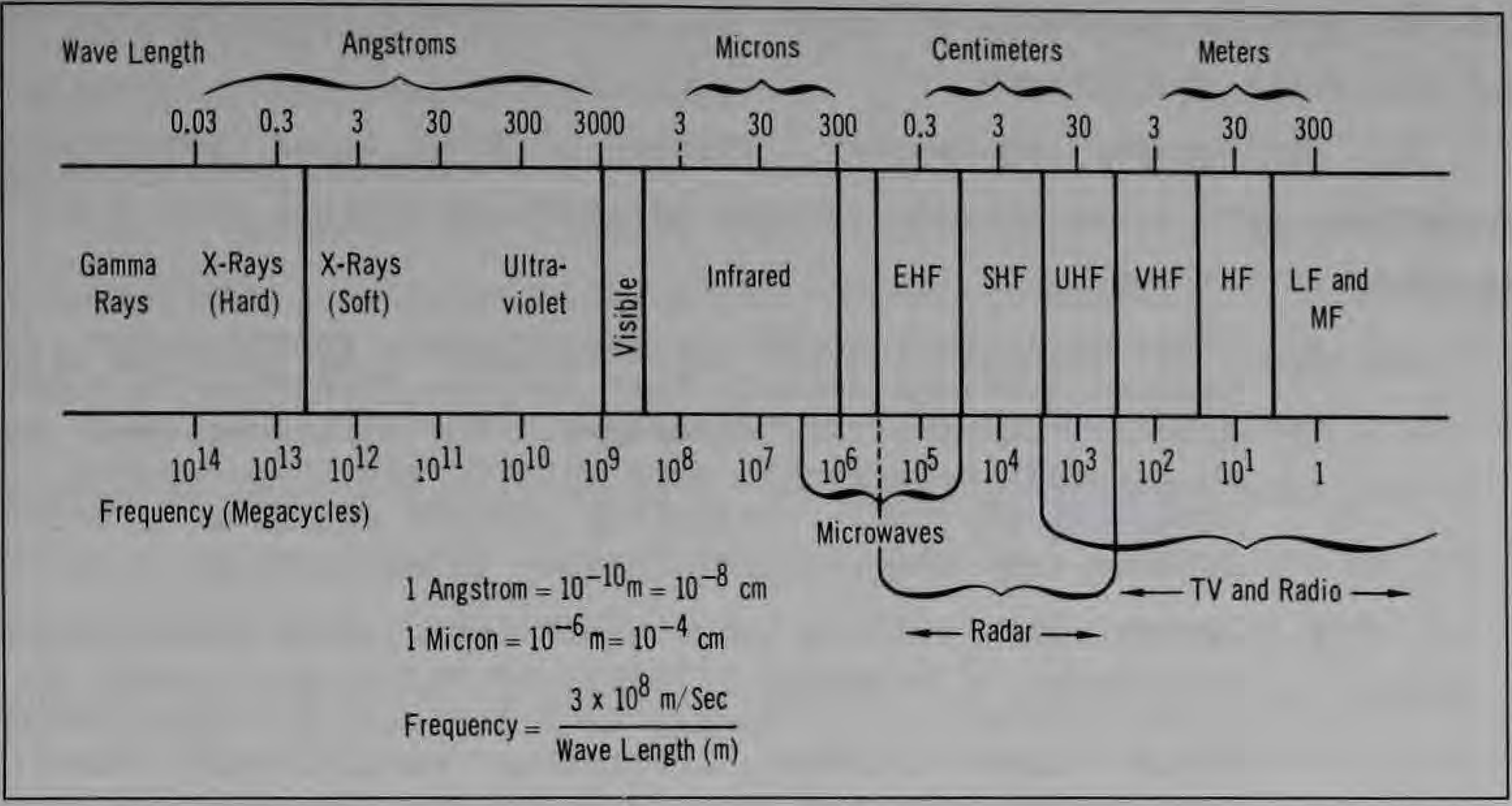
Fig. 8. The Unified Soils Classification System (USCS)

on the chart. Topographically higher areas on land are indicated by lighter colored patterns.

56. Climatic maps. These maps may be compiled for individual countries; however, they are most often compiled for the entire world and thus are usually small scale. They portray the distribution of areas characterized by ranges of mean annual temperatures and precipitation and climatic types determined by combinations of temperature ranges, amount and frequency of precipitation, and natural vegetation. Other climatic maps give distribution of major ocean currents, mean sea surface temperatures, hurricane tracks, air masses, etc.

Photography and remote imagery

57. Photography and imagery of various types potentially represent an important source of terrain and hydrographic information. Photography may be of two types: ground and aerial. Ground photography in remote areas is limited and often unavailable. When available, it is sporadic in coverage and most often ineffectual in its application to site descriptions. One of the most consistently useful types is photography used to document reconnaissance performed for military interests. Such reconnaissance usually evaluates existing facilities such as ports, bridges, airstrips, etc., and assesses terrain in terms of its potential for construction sites, cover and concealment, cross-country movement, sources of construction materials, etc. Aerial photography as discussed here includes both conventional photography, black and white and color, in and near the visible portions of the electromagnetic spectrum and imagery from the near and far portions of the spectrum. Imagery systems currently being utilized for terrain evaluation purposes include radar, infrared, microwave, ultraviolet, gamma-ray, etc. (fig. 9). All imagery data are recorded on magnetic tape to facilitate electronic manipulation, but most data can readily be reduced to a conventional photographic format, although the resulting tones do not lend themselves to classical photographic interpretation techniques. For instance, thermal infrared imagery taken at night reveals light tones for warmer marsh environments and dark tones for cooler sand beaches,



a. Spectrum by frequency and wavelength

Frequency Band	Wavelength	Frequency	Remarks
Ultraviolet	Below 0.40 Microns (4000 Angstroms)	Over 7.5×10^{14} cps	
Visible	0.40–0.70 Micron	$7.5–4.3 \times 10^{14}$ cps	Operating range of photo camera.
Violet	0.40–0.46 Micron	$7.5–6.5 \times 10^{14}$ cps	
Blue	0.46–0.51 Micron	$6.5–5.9 \times 10^{14}$ cps	
Green	0.51–0.58 Micron	$5.9–5.2 \times 10^{14}$ cps	
Yellow	0.58–0.60 Micron	$5.2–5.0 \times 10^{14}$ cps	
Orange	0.60–0.63 Micron	$5.0–4.8 \times 10^{14}$ cps	
Red	0.63–0.70 Micron	$4.8–4.3 \times 10^{14}$ cps	
Infrared	0.70–1000 Microns	$430–0.3 \times 10^{12}$ cps	Operating range of infrared surveillance using infrared detectors.
Near IR	0.70–1.5 Microns	$430–200 \times 10^{12}$ cps	
Middle IR (Intermediate)	1.50–5.6 Microns	$200–5.0 \times 10^{12}$ cps	
Far IR	5.60–1000 Microns	$5.0–0.3 \times 10^{12}$ cps	
Hertzian (Radio) Waves			
EHF	1 mm–1 cm	300,000–30,000 mcs	High precision radar.
SHF	1–10 cm	30,000–3,000 mcs	High resolution radar.
UHF	10 cm–1 m	3,000–300 mcs	Line-of-sight military and commercial
VHF	1–10 m	300–30 mcs	communications (TACAN) EW, GCI, FC,
HF	10–100 m	30–3 mcs	DF stations, military communications,
MF	100–1,000 m	3–300 kc/s	long distance commercial broadcast.
LF	1,000–10,000 m	300–30 kc/s	Polar communications, area coverage,
VLF	Greater than 10,000 m	Below 30 kc/s	navigation aids.

b. Wavelength and frequency limits of bands in spectrum

Fig. 9. The electromagnetic spectrum (from reference 9)

which are exactly opposite the tones that would result from conventional black and white photography.

58. Photography and imagery coverages of areas being investigated as potential port sites provide several definite advantages over other data types as follows:

a. Large-scale photography or photographic reproduction of imagery provides details that are not presented on topographic and other map coverages. For instance, even large-scale topographic maps with 5- and 10-m contour intervals may fail to identify surface features or conditions that are relevant to site investigation.

b. Remote imageries can be obtained immediately after the occurrence of dramatic climatic or hydrologic events to permit assessment of damage or modification. Such events would include flooding, hurricanes, tidal surges, etc. Such information may often dictate the location for, type of, and technique for construction.

c. Photography and imagery coverage permits current assessments to be made of man-made features such as transportation networks, industrial complexes, urban development, and existing port facilities.

d. Photography and imagery coverage permits periodic monitoring of shoreline evolution and modification to determine the influence of the physical and climatic elements on port location and construction.

e. In the absence of map coverages, the photography and imagery coverage would serve to provide topographical, geological, pedological, hydrographical, vegetational, and even cultural information required for site selection and investigation. Identification of the required environmental characteristics would necessitate interpretation by personnel skilled in these various disciplines.

59. Aerial photography and imagery at various scales are available for areas throughout the world. These coverages are of various types, e.g., mapping, reconnaissance, tactical, surveying, etc., and may vary significantly in scale, format, sensor configurations, and reproducduction. The Defense Intelligence Agency in Washington, D. C., is the official depository within the Department of Defense for all foreign film coverages. World coverages are plotted on 1:250,000 maps, each covering 1 deg latitude and 1 deg longitude. An overlay is provided for each separate coverage available with the 1-deg-square area. Computer

tab runs are provided upon request, which is made by providing the coordinates of the area of interest.

Documents and records

60. Documents and records are valuable sources of various types of topographic, hydrographic, and historical information. These references are available from the CONUS sources discussed in paragraphs 64-84 and from sources in the TO. Some of the most common of these types of references include trade journals; geologic, geographic, soil, and oceanographic bulletins; environmental handbooks; tourist guides and traveler accounts in periodicals and professional journals; published tide tables and pilot handbooks; economic and transportation atlases; climatic records; and various indigenous governmental reports. Unpublished environmental, meteorological, and scientific data are available at government offices and research centers both in CONUS and in the TO. Reference materials are also available from engineering firms, private societies, and individuals with personal interests.

61. Intelligence studies that deal with gross geographical areas are prepared by various agencies of the Department of Defense such as the Defense Intelligence Agency (DIA), Central Intelligence Agency (CIA), and Office of Naval Intelligence (no longer existent) and by foreign intelligence agencies such as the Naval Intelligence Division of the British Admiralty and indigenous intelligence organizations. If the potential port location is in sympathetic territories, information by these organizations is available. Some of the more useful of these are discussed briefly as follows.

a. British Admiralty Naval Intelligence Division - geographical handbooks. The purpose of these handbooks is to provide the military with a concise, comprehensive account of the physical, climatic, and cultural aspects of selected geographical regions. Topics included relevant to site description are geology and physical geography, descriptions of coasts, climate, vegetation, economic geography, and ports and towns. Indexes on published volumes are available.

b. Engineer Intelligence Files (EIF's). These reports cover a wide range of subjects of interest to those involved in port site description and construction. Each report deals with a specific topic and may have a unique format. Unfortunately, there are no known indexes that list and describe available reports. These reports are on file at the Documents Library, DIA.

c. National Intelligence Surveys (NIS's). Published under the auspices of the CIA, these surveys provide basic intelligence information for the countries of the world. They also provide general terrain descriptions augmented by maps, charts, and tables. Subject areas included are soils, surface rock, landforms, vegetation, drainage, and suitability for various types of military construction.

d. Lines of Communication (LOC). These studies are usually accompanied by maps that delineate the transportation network in specified areas. Highways, railroads, inland waterways, pipelines, airfields, ports, etc., are described and discussed in terms meaningful to military support operations.

e. Terrain studies. These reports are generally prepared for strategic planning purposes and describe gross terrain characteristics and major aspects of land, water, and air movement.

f. Special reports on military geography. These are prepared principally for strategic planning and evaluate the major aspects of the environments in terms of cross-country movement, amphibious operations, and airborne operations.

g. Engineer reconnaissance reports. The purpose of these reports is to provide current information pertaining to the status of LOC's. Reconnaisance is also conducted for the purpose of locating construction sites, sources of construction materials, and water resource surveys.

Historical port intelligence data

62. Historical data concerning existing port facilities represent potentially the best source of information available in a TO. The types and orientations of piers, breakwaters, dock facilities, etc., are most often the result of comprehensive investigations or at worst trial-and-error type construction. The construction of these facilities is often well documented, with feasibility and investigative reports being available at the old port headquarters, local governmental administrative offices, private engineering firms, or government archives. Types of information to be expected include soil borings, soil bearing and shear

tests, soil classification and analysis, pile friction tests, tidal station data, weather data, groundwater investigations, severity of flooding, locations and characteristics of construction materials, and bathymetric surveys indicating the slope and configuration of the harbor bottom and the presence of obstacles such as rocks, reefs, and debris. Many potential TO port locations will be devoid of existing facilities, or, in other cases, the facilities may be in evidence but documentary data lacking.

Sources of Background Data

63. The collection of background data is a function of the base development planning staff and is performed during the planning phase of the base development plan. This information consists of (a) troop and equipment density, (b) standards of construction, (c) time phasing of troop/contractor construction forces, material, and development of facilities, (d) expected duration of the operation, and (e) area site intelligence. Data on the first four items are available within the theater command and are detailed as a part of the Operations Plan, while site intelligence data are available both from sources within the TO and from CONUS. The most prolific of these sources merit brief discussion in the following paragraphs. Discussions include the names of the sources and the types of data available.

CONUS sources

64. DIA, Washington, D. C. The DIA is the official DOD depository for foreign film coverage. All of their holdings are computerized and retrievable if map coordinates of the desired area are provided. Holdings are in photographic negative form and require reproduction. Suitable priorities normally ensure expedient processing. The DIA maintains an intelligence library consisting of books, serials, journals, documents, maps, and charts. Among the extensive holdings in the technical library are numerous intelligence reports that include: (a) NIS's, (b) EIF's, (c) terrain studies, (d) special reports on military geography, (e) LOC studies, and (f) engineer reconnaissance reports.

65. Library of Congress, Geography and Map Division, Cameron Station, Alexandria, Virginia. No comprehensive catalog of the Division's holdings exists; however, extensive collections of large- and medium-scale topographic, geologic, and soils maps of many foreign countries are available. Nautical and aeronautical charts are also collected. Selected groups of maps and atlases have been recorded in published bibliographies and are available on request.

66. Army Library, Office of the Chief of Engineers, Washington, D. C. Numerous references document Corps activities in the fields of civil and military engineering, hydrology, hydraulics, geology, topographic surveying, and soil mechanics throughout the world.

67. U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia. Holdings include books, periodicals, maps, catalogs, atlases, and bibliographies covering various parts of the world. Subject matter of these references includes climatology, engineering, geodesy, mapping, geography, geology, oceanography, and natural resources.

68. Defense Mapping Agency, Washington, D. C. This agency serves as the central depository of topographic maps and related data for the DOD. Subjects include geography, geodesy, engineering, geology, and hydrology. The Defense Mapping Agency holdings are grossly divisible into three major categories as follows:

- a. Stock items. Stock indexes cover all on-shelf topographic maps. The indexes are published annually with periodic supplements.
- b. Ozalid indexes. These indexes include all old or out-of-print topographic, photo, and picto maps. Maps included in these indexes can be reproduced.
- c. IBM card index. In addition to topographic maps, this index includes geologic, soils, vegetation, and land use maps filed by countries. A tab run, which consists of a complete printout of available items, can be obtained upon request.

69. Coastal Engineering Research Center, U. S. Army Corps of Engineers, Washington, D. C. This Center collects, analyzes, and disseminates information on coastal engineering research and technology and also prepares bibliographies and state-of-the-art reports. The subject

matter includes wave action in coastal waters, shore processes, tides and surges, inlet dynamics, estuary dynamics, coastal works evaluation, functional design of coastal works, structural design of coastal works, coastal construction techniques, environmental data collection (coastal), and coastal harbors and channels. The Center maintains an extensive collection of photographs of coastal features.

70. Naval Facilities Engineering Command, Naval Civil Engineering Laboratory, Port Hueneme, California. The technical library contains numberous reports, books, monographs, and journals. The subject matter includes nuclear defense engineering, structural mechanics, construction materials, soil mechanics, pavements, water waves, waterfront structures, amphibious equipment, anchors and anchoring systems, ocean engineering, water supply, and amphibious equipment.

71. Office of Professional and Technical Information, Naval Facilities Engineering Command, Arlington, Virginia. Areas of interest include planning and design of naval shore establishments, civil engineering, and construction of Navy yards, docks, airfields, and other naval facilities.

72. Defense Documentation Center (DDC), Alexandria, Virginia. The DDC is the central depository of the DOD for all technical and scientific documents resulting from the research efforts of the Army, Navy, Air Force, and Marine Corps and their contractors and grantees. Their collection covers all fields of science and technology including earth sciences, materials, structural engineering, military sciences, navigation and guidance, and ships and marine equipment. Bibliographic searches are available upon request by countries and by subject matter. Holdings are computerized for fast searching. A Technical Abstract Bulletin is prepared twice monthly containing bibliographic citations and abstracts of documents received. The Center operates a referral service that covers the activities within the DOD.

73. CIA, Washington, D. C. The holdings of this agency and the library that it maintains are both extensive and diverse. However, no publications are issued that list these holdings, and access to information in the CIA's collection must be channelized through the appropriate

official offices. Nevertheless, the CIA collects a wealth of data on military and terrain intelligence throughout the world. Holdings include documents, publications, maps, and photographic coverages on numerous subjects. Requests funneled through official channels should identify the precise location of interest, type of subject matter, and the nature of interest.

74. American Geographical Society, New York, N. Y. Holdings consist of books and periodicals covering all aspects of geography including physical geography. Also represented are holdings in such related fields as geology, climatology, etc. The Society's reference catalog is classified by region and subject, which from 1923 to 1961 has been published in book form. The Society also has a map department with holdings consisting of maps from U. S. Government agencies, foreign governments, and commercial map publishers. Types of maps include general reference maps; topographic series; aeronautical and hydrographic charts; oceanographic maps of winds, currents, temperature, and salinity; communications; geological maps; soil surveys; and other special-purpose maps. The map catalog is arranged by geographic area and cross-referenced by author and publisher and by approximately 800 subject categories. A Society publication issued ten times yearly lists additions to the research catalog.

75. Research Analysis Corporation, McLean, Virgina. This corporation has an extensive collection of references including publications dealing with military operations and engineering.

76. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts. Holdings cover all aspects of oceanography including instrumentation, marine meteorology, geology, and geophysics. The library distributes a monthly accession bulletin.

77. U. S. Naval Research Laboratory (NRL) Technical Library, Washington, D. C. This Library maintains a collection of technical material of interest to NRL and to the Office of Naval Research (ONR). Holdings relate to a broad scope of physical sciences including oceanology and acoustics. The Library prepares and distributes several publications periodically, among which is "Annual Holdings Lists of

Periodicals in the Naval Research Laboratory Library and the Office of Naval Research Library."

78. Naval Reconnaissance and Technical Support Center, Suitland, Maryland. Holdings include volumes, periodicals, classified documents, charts, and maps. Subject matter includes photographic interpretation, photography, photogrammetry, terrain model making, and military intelligence.

79. U. S. National Oceanic and Atmospheric Administration (NOAA), Scientific Information and Documentation Division (SIDD), Rockville, Maryland. SIDD serves as the central point for all scientific and technical information and documentation activities in NOAA. Responsibilities include supervision, coordination, information storage and retrieval, documentation, and library functions. SIDD facilitates the transfer of information both within NOAA and between NOAA and other governmental organizations, the scientific community, and other national and international interests. Subject coverage includes oceanography, meteorology, climatology, hydrology, hydrography, limnology, seismology, ocean survey, and sea condition forecasting. SIDD publishes monthly publication announcements and selective lists on request.

80. U. S. National Oceanographic Data Center, Naval Oceanographic Office, Washington, D. C. This Center serves as a national clearinghouse for bathythermographic and oceanographic station data. While these data relate principally to the North Atlantic, increasing amounts of data from the Pacific and Indian Oceans are being processed. The Center also collects technical reports, scientific literature, and journals and exchanges information with other oceanographic organizations. The Center will provide data in the form of listings, summaries, tabulations, and printouts as required. Requests should include type of data, specific geographic limits of the area involved, and other relevant information. A newsletter is published eight times a year containing information on the Center's programs and publications.

81. U. S. Geological Survey (USGS), Washington, D. C. This is an extensive research library dealing with geology and geology-related subjects such as paleontology, mineralogy, petrology, mineral resources,

water resources, surveying and cartography, chemistry and physics, oceanography, soil science, zoology, natural history, remote sensing, and environmental science. The collection includes official publications of all countries, societies, universities, etc. USGS provides reference sources of information on published and otherwise available topographic and planimetric maps, geological and soils maps, aerial photography, data on surveying and mapping, and aerial mosaics. USGS distributes numerous publications indicating the availability of geologic and geology-related materials, both of the United States and foreign. The USGS maintains a publications exchange program with approximately 500 foreign institutions.

82. World Data Center A, Oceanography, Washington, D. C. This Center is collocated with and administered by the National Oceanographic Data Center. The Center conducts an international exchange of oceanographic data and publications in addition to collecting, cataloging, and archiving data. It acquires data for national programs, international cooperative expeditions, and other oceanographic programs. The subject coverage includes physical and chemical data of the following major types: serial station, bathythermographic, current, bottom topographic, bottom composition, biological, meteorological, and sea surface. The international data base includes over 250,000 serial oceanographic station records and reports that have been machine processed and are in punched-card or tape form. Additional holdings include volumes of data on log sheets. The Center publishes catalogs containing data from special expeditions, accessioned publications, data available, and oceanographic data exchange.

83. Naval Oceanographic Office, Washington, D. C. This office maintains files of hydrographic charts for areas throughout the world exclusive of the United States. The office also prepares tide tables and other hydrographic data which, like the charts, are available upon request. Lists and publications include sailing directions, lists of lights, radio weather and navigational aids, current atlases, fleet guides, marine geographies, surface temperature charts, tide tables,

tidal current tables, general navigation charts, and coastal hydrographic charts.

84. Scripps Institution of Oceanography, University of California, La Jolla, California. Holdings include books, pamphlets, newspapers, periodicals, and items in vertical files. Subject matter includes physics, geology, and oceanography.

TO sources

85. Without specifying a particular TO, it is impossible to compile a detailed listing of potential sources of background information. It is possible, however, to anticipate the general availability of certain types of data and to categorize the probable sources. These are discussed briefly in the following paragraphs.

86. Governmental agencies. The governmental structure of each country of the world may differ markedly; however, the equivalent of certain major departmental offices should exist throughout the world. For instance, it is difficult to imagine any nation without the equivalent of Ministries of Agriculture, Transportation, Maritime, and Commerce or the equivalents of Departments of Mines, Weather and Climate, Drainage and Inland Waterways, Geology, Ports, etc. Several of these agencies that should hold data in their files relevant to port construction are identified as follows:

a. Department of Transportation. This department could provide information regarding the transportation network including road, rail, and inland waterways that could service the proposed port. Additional information would describe standards of construction, capacities, sources of construction materials, foundation investigations for bridges, locks, depots, terminals, etc.

b. Maritime Commission. This office should represent the source of most of the available oceanographic data available for the port area. Information would include descriptions of existing facilities; navigational data; tidal characteristics; currents; documentation of storm intensity, frequency, and damage; and hydrographic charts, tables, etc.

c. Geological Survey. This department will probably have mapped the nature and occurrence of surface rocks and the general geological structure in the vicinity of the port. Some general assessment may be available as to the suitability of local rocks for use as aggregate and their suitability for subsurface foundations. Copies of groundwater reports and well logs should be on file.

d. Department of Surveys. This department has the responsibility for all topographical surveying within the country. All available topographic, drainage, and special-purpose maps such as trafficability, engineering, intelligence, etc., should be obtainable from this office. The survey should have indexes of all aerial photography flown in the vicinity of the port area and should have the capability of reproducing desired coverages. In addition, they should hold handbooks of local topographic terms, travel manuals, guides, and route books. One of the most important holdings in the department files is topographic and geodetic control data. These may provide the necessary horizontal and vertical control required to tie in the topographic and hydrographic surveys conducted by the engineer teams.

e. Department of Agriculture. Any soils map of the vicinity of the port should be available at this agency. Since the soils will probably have been mapped for agricultural purposes, the map data will probably require conversion to engineering terms.

f. Department of Meteorology. This office should maintain records of long-period weather conditions for stations throughout the country. These should include measurements of rainfall, atmospheric pressure, air temperature, relative humidity, cloud cover, and wind. Weather summaries including normal conditions and departures from normal should be available.

87. International organizations. A number of international developmental organizations operating under the direction or auspices of the United States or the United Nations are active throughout the world. Some of the more prominent of these are listed below and discussed briefly:

a. United Nations Educational, Scientific, and Cultural Organization (UNESCO). Located in Paris, France, this specialized agency of the United Nations sponsors scientific research as a means of promoting collaboration among the nations of the world. Research is focused more on undeveloped nations and deals with such subjects as soils, hydrology, geography, etc. UNESCO consists of 125 member nations.

b. United Nations Food and Agricultural Organization (FAO). To raise levels of nutrition and standards of living by securing improvements in the efficiency of production of agricultural products, this organization, with headquarters in Rome, Italy, conducts and sponsors extensive research in soils and other related fields relevant to the production of crops.

c. Economic Commission for Asia and the Far East (ECAFE). Offices in Asian cities maintain files and libraries with general information on the various aspects of the environment. Specific references may include hydrology, soils, minerals, and forests.

d. United States Agency for International Development (USAID). USAID conducts United States overseas programs of economic and technical assistance to less developed countries. It also sponsors projects devoted to development of these nations through exploitation of natural resources and conducts inventories of undeveloped geographic areas in terms of land use, soil types and distribution, vegetation, hydrology, etc. USAID recommends programs that will promote agricultural and economic growth.

e. United States Operations Mission (USOM). Among numerous interests in principally underdeveloped countries of the world, USOM is involved in the development of both groundwater and surface water resources. They conduct or participate in groundwater investigations, damsite investigations, irrigation projects, etc. Useful well logs, soil borings, maps, and reports on investigations are on file in local offices.

88. Universities. Local institutions always represent a potential wealth of scientific data. In small countries, they may represent the only organizations involved in active research. Their libraries should contain or reference all available scientific information. Various departments such as geology, geography, oceanography, engineering, agronomy, etc., may be actively involved in studies in port areas. Academic contacts will identify other potential sources of environmental data.

89. Commercial organizations. These consist principally of engineering and construction firms that have been actively involved in projects in port areas. If existing port facilities are evident, investigation reports for foundation evaluations should be available. These should contain soil borings, groundwater and drainage information,

aggregate sources, dredging records, and soil test data connected with the construction of existing port facilities. Shipping firms, dredging contractors, commercial fishermen, bargelines, offshore construction firms, marine salvage companies, and marine surveying organizations represent additional sources of pertinent information.

90. Individuals. These would consist of engineering and geological consultants and independent researchers under contract or sponsored under the auspices of a national or international research contract who are actively engaged or have had experience in the area of interest.

91. Port Authorities. These are the administrative bodies that have overall control of the planning and operation of port facilities. Some of their functions are development planning, traffic promotion, and to own and develop independent terminals, lease facilities, and operate harbor craft. Their engineering or construction sections will normally have construction drawings of the facilities under their control.

General Site Selection

92. The collection of background data discussed in the preceding paragraphs will provide the basis for the general location of a port and its facilities. The seaport must, of course, be located in sheltered waters that may result either from natural indentations or recesses in the shoreline or from varying degrees of modification to achieve the desired setting. Generally, three distinct situations may result: (a) a natural setting along a shoreline such as a bay, lagoon, estuary, etc., that would provide suitable protection; (b) a setting where natural barriers on the seaward side of port locations such as land arms, reefs, spits, tombolos, islands, etc., are inadequate for protective purposes but have been modified by engineering methods to increase protection capabilities; and (c) a setting where the port location has no natural protection by seaward barriers and where totally artificial protective measures such as the construction of breakwaters, jetties, etc., are required. It should be pointed out that the construction of jetties, breakwaters, etc., is time-consuming and should be avoided in TO

port construction if alternative locations are available. Even if required, such structures are beyond the construction capabilities of engineer troop units and will not be discussed in this text. Such requirements, however, should represent one of the principal criteria in the evaluation of port site locations. The port must additionally be adequate to handle the volume of shipping required to sustain the theater activity and to accommodate the vessels that will transport the required cargo.

93. Although the general location of the port may have been conclusively established at this point as a result of careful consideration of background information, the precise location of the component facilities such as wharves, piers, quays, etc., must result from comprehensive topographic and hydrographic surveys. A number of factors must be considered during the conduct of each of these surveys.

Hydrographic surveys

94. These surveys must be conducted at the earliest possible time after the port area has been secured and conducted within a time frame that is compatible with the assigned completion date for the port facility. The survey will include the collection, reduction, and analysis of hydrographic data and the effective presentation thereof to permit subsequent decisions. Numerous hydrographic parameters must be considered during the survey.

95. Depth of water. Accurate bathymetric measurements must be obtained throughout the port area as well as in seaward approaches to the facilities. Water depth is critical to the operation of ships and craft that will utilize the facility. Because the maximum draft for a cargo ship is expected to be 40 ft, pier construction and location must be reasonant with suitable hydrographic conditions.

96. Bottom character. Detailed determinations must be made as to the lithographic and micro-relief character of the bottom. Foreign and random natural objects such as boulders, oil drums, and ship wreckage must be delineated to facilitate removal or ensure avoidance.

97. Tidal characteristics. These are controlling factors in the effective operation of a port. Tidal parameters requiring determination

are heights, range, interval, times, and behavior of tidal currents on a daily and seasonal basis and during periods of unusual vigor resulting from storm activity. Significant daily tidal ranges in certain parts of the world may exceed 20 ft.

98. Discharge volumes and flow velocities of rivers. Discharge volumes and flow velocities at or in the vicinity of the port are important considerations in the regulation of vessel traffic, location and orientation of structures, sediment transport and deposition, and dredging.

99. Extent, duration, and causes of flooding. Flooding at times during the year may affect inland portions of a port. Harbor routine may vary during flood season, and sediment introduced into the harbor areas may create navigation problems. Knowledge of the causes of flooding enables the adverse effects to be minimized. Examination of historical data permits reasonably accurate forecasts.

100. Tidal and river currents and velocities. Current directions and velocities are of continuing concern to navigation. These include longshore currents, wind currents, river currents, and permanent great currents. In some cases, several of these currents may be in action concurrently, and the results must be considered.

101. Shoreline data. The land-water interface must be established for the various daily and seasonal stages of the tide. Extreme tidal stages occurring during severe storms must also be established.

102. Location of landmarks as navigational aids. Location of landmarks can be greatly facilitated through the use of hydrographic and topographic maps and aerial photography. Field checks to ensure acceptable levels of visibility are required.

103. Location of structures in water and along shore margins. These would include structures being currently utilized or abandoned.

104. Subbottom characteristics. Subbottom information includes data on type of sediments, layering, bearing capacities, and consolidation.

105. All of the parameters listed above are pertinent to the construction, operation, and maintenance of a port and support facilities,

but the hydrographic survey as detailed and subsequently discussed in this chapter will deal only with those that are relevant to the construction of off-loading facilities and contiguous storage areas, e.g., DeLong and Ammi piers and adjacent POL and ammunition storage areas. However, to ideally locate the desired structures, navigable routes for cargo vessels and topographically suited storage areas covering a much broader area must be determined through surveys.

Topographic surveys

106. The term topographic is loosely used here to include all land-implemented surveys conducted in support of the construction of off-loading, storage, and connection facilities. Parameters to be considered as part of the topographic surveys are identified as follows.

107. Topographic detail at site locations. Fine detail will be required to ensure optimum layout of facilities and the transportation network required to service them. Land-water interfaces at all possible tide levels should be checked with the hydrographic surveys.

108. Pedologic parameters. A comprehensive investigation of the pedologic character of surficial materials is considered essential. The suitability of the soils to support various types of construction and suitability as construction materials must be determined. Identification of soils can be greatly facilitated by use of aerial photographs.

109. Drainage characteristics. Surface drainage patterns must be determined. Drainage can influence site selection, particularly if overflow from streams cannot be controlled and inundation of a site is possible. Streams may also provide convenient supplies of surface water for port use.

110. Surface rock. An investigation of available sources of surface rock must be conducted to determine suitability of local supplies to construction requirements.

111. Subsurface characteristics. Investigation of subsurface soil conditions is required to determine parameters relevant to pile-type construction on shore locations.

112. Vegetation types. A survey of natural vegetation in the vicinity of the port is required to determine (a) the construction

effort required to clear the area required to accommodate the port facilities, and (b) the suitability of the timber for use in the construction of certain facilities, e.g., wharves, piers, bridges, warehouses, etc.

113. Cultural features. A survey is required at and in proximity to the port area including private, business, and government buildings, the transportation network, utilities, recreation areas, and agricultural lands.

114. Ideally, the topographic and hydrographic surveys should be conducted simultaneously since the time available for the entire site investigation is limited, i.e., two weeks. A topographic survey team and a hydrographic survey team (or equivalent units) functioning under the control and supervision of the Port Engineer should have the responsibility for the collection of the field data. Coordination between these teams is imperative since certain phases of the investigations must be integrated. For instance, land-based surveys may indicate favorable locations for the construction of port facilities, but these same locations may prove completely unacceptable because of adverse hydrological considerations such as water depths, currents, exposure to wave attack, etc.

115. The following paragraphs present in detail procedures to be applied by survey teams during the conduct of the site investigations. The scope of these discussions will be devoted entirely to the investigation of sites for the construction of off-loading and storage facilities, e.g., piers, quays, slips, navigation and graving locks, jetties, transit sheds, storage and repair facilities, cargo-handling facilities (railroads, railroad yards, highways, parking areas), and marine POL facilities. So restricted, the report will not deal with the entire listing of hydrographic and topographic parameters identified during the previous discussions. Surveying techniques that adequately direct these investigations have been documented in previously published literature. Hydrologic parameters that will be addressed and for which techniques for the collection of field data will be described are: (a) depth of

water, (b) bottom character, (c) shoreline data, and (d) subbottom characteristics.

116. As stated previously, the hydrographic investigation will be restricted to the construction site areas for the off-loading facilities and the approaches to the facilities from the harbor. Obviously, surveys of the entire port region are necessary to gain an appreciation of hydrographic conditions that will have favorable or adverse effects upon various activities normally associated with port operation. For instance, longshore drift and riverine deposition may result in sediment buildup that requires periodic dredging or preventative maintenance.

Port Requirements

117. The initial step for the hydrographic survey team, closely coordinated by the Port Engineer, is to consider the marine environment in the vicinity of the proposed port location in terms of construction requirements of facilities on or immediately adjacent to the waterfront. Certain limiting criteria that must be considered in the location of waterfront facilities are:

a. 50-ft water depth (mlw) for vessels utilizing DeLong piers.

b. 20-ft water depth for LST type vessels, barges, and lighters, which will be accommodated by a pier-type structure with shallow pile depth requirements.

c. 50-ft water depth MLW within harbor of adequate area to permit vessels to maneuver.

d. Bottom soil conditions that are suitable as holding ground for anchors (soft soils or rock are unsuitable).

e. Subbottom soil conditions (to 105 ft) suitable for the driving of piles for the erection of pier and wharf facilities.

Surveying Equipment Requirements

118. Certain types of surveying equipment should be available to

the hydrographic survey team. This equipment should be selected on the consideration of the following criteria:

- a. Equipment will enable the survey team to expediently acquire the necessary field data in the required time.
- b. Equipment will provide the required level of accuracy.
- c. The equipment should be compact and as portable as possible and should be adaptable to various boat configurations that may be available for the survey.
- d. The equipment should be relatively inexpensive, and the replacement parts should be available on short notice or reparable by competent engineer technicians (modular, solid-state electronic components are relatively easy to troubleshoot, remove, and replace).
- e. Equipment must be sturdy in design to withstand unavoidably harsh treatment in the TO.
- f. The equipment should be simple in design and operation to enable efficient employment by survey personnel without electronic backgrounds and with a minimum of training.
- g. Equipment should provide direct data outputs or graphical records to avoid, if possible, time-consuming and perhaps inconvenient computer processing.
- h. The equipment must prove versatile in various types of shoreline environments, e.g., relatively straight shorelines or estuarine locations.
- i. The equipment must be operational under most weather conditions; surveying techniques requiring visual communication between ship and shore components would be seriously inhibited by fog, rain, etc. It must be considered that dramatically inclement weather would prohibit all surveying operations.

119. The equipment required for the survey is extensive, and much of it, e.g., survey vessels, generators, compasses, radios, radar, etc., may be currently organic to engineer construction elements in a TO. The systems described herein are those that are necessary for conducting the surveys utilizing techniques that are discussed in this report. Much of this equipment has been developed only in recent years, and the full potential of its capabilities has not been fully explored. Oceanographic survey equipment is currently enjoying a period of great prosperity due largely to current interest in continental shelf, estuary,

and oceanographic applications. Consequently, significant technological improvements are being introduced. Competition in this field is keen, and innumerable systems are currently available on the market, each perhaps with more effective application toward a particular requirement. The discussions here have no promotional orientations but will be expressed in terms of general operational techniques.

Hydrographic Surveying Equipment

120. The engineer element charged with the responsibility for the conduct of the survey is restricted to a period of approximately two weeks. Existing surveying techniques are incapable of providing the required data within this time frame and are inherently inadequate for providing bathymetric and subbottom data in the detail required. The following paragraphs describe the general types of surveying systems that are potentially applicable to the objectives of this study. Rationale that was used in the ultimate selection of the system utilized in the development of the investigation techniques described in this report are discussed later in the text.

Bathymetric profiling systems

121. These systems, commonly called fathometers, continuously record the distance from the water surface to the water bottom. Variations in bottom configuration are measurable in tenths of feet. In principle, the system produces an acoustic signal from a transducer installed in the hull of the vessel or towed alongside. The signal travels to the bottom below the vessel and is reflected back toward the surface. The transducer radiates the sound, receives the reflected sound, and converts it to electrical energy. The acoustic energy round trip transit time can be converted into units of depth, which are graphically portrayed on a synchronized recorder (fig. 10). Fathometers of different types are utilized in different environmental conditions and may be classified in terms of their operating frequencies. Each type is potentially best suited for certain applications.

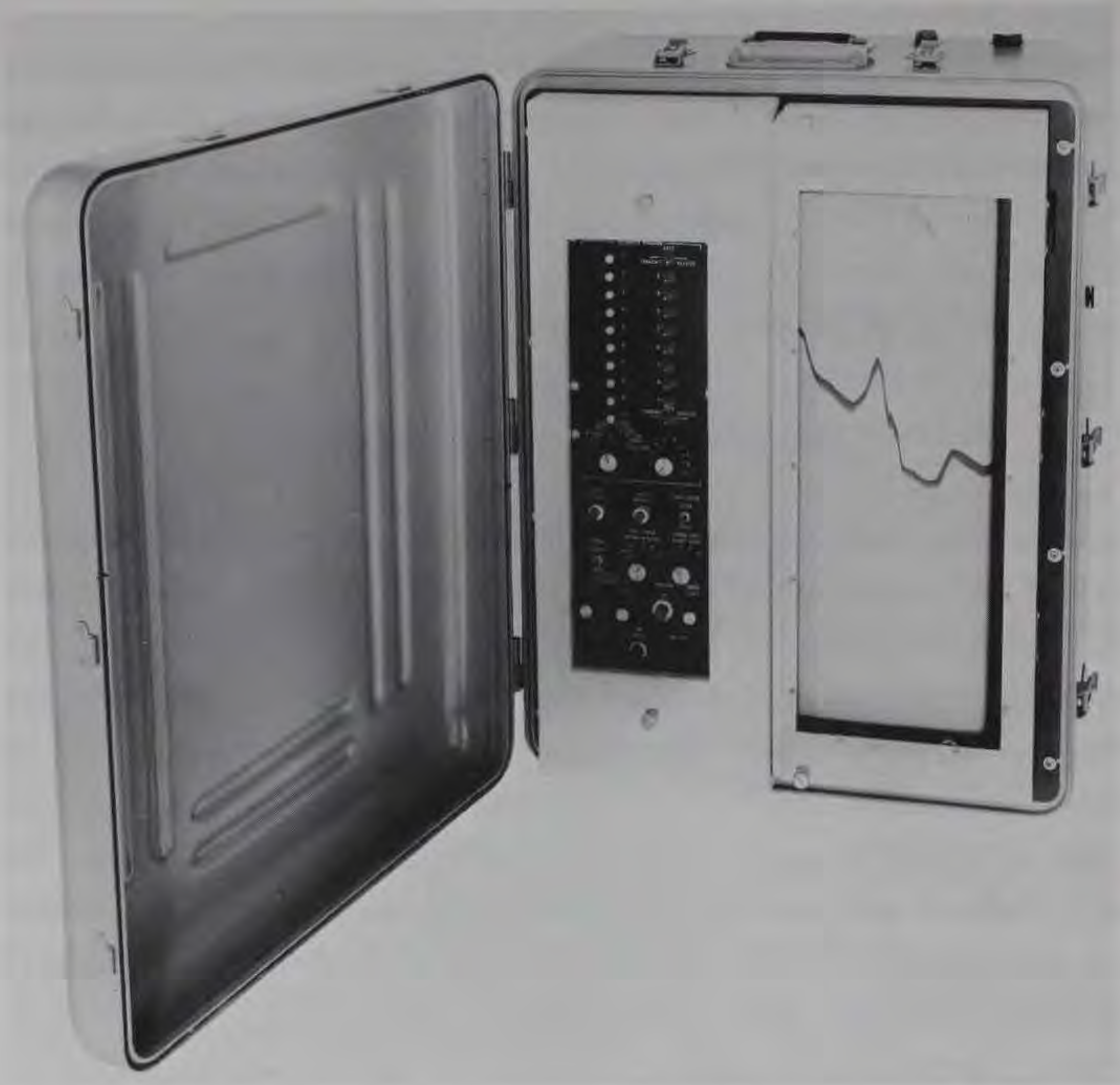


Fig. 10. Continuous graphic recorder for bathymetric profiler

122. Low-frequency fathometers. These types are the least inhibited by the transmitting media and thus are capable of achieving the deepest penetration. Unfortunately, the wavelengths utilized by these systems, 15 kHz or less, provide the poorest resolution. Low-frequency fathometers utilize relatively wide beam widths, which may preclude accurate definition of relevant bottom features. Reflection from irregular bottom features or from confining slopes in restricted waterways may create undesirable side echos that obscure bottom reflections and make interpretation difficult. Water energy and ship noises also occur within this frequency range and create spurious signals on the records. Because of minimum attenuation, fathometers of this frequency are most often utilized in deep water, i.e., over 300 fathoms.

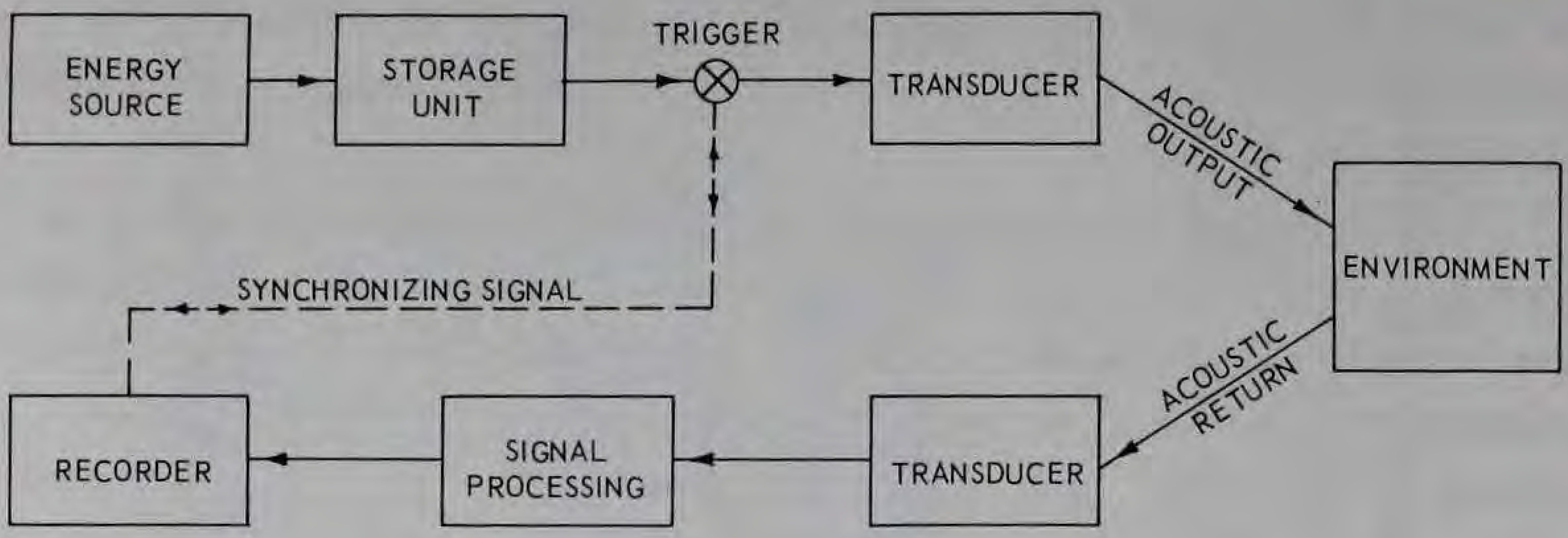
In soft bottom materials, signals at these frequencies often achieve shallow penetration, a circumstance that may inhibit accurate identification of the bottom.

123. Medium-frequency fathometers. These types are designed to operate in water depths of less than 300 fathoms, a range that includes the 10-fathom limiting operation depths of this study. The transducers required to generate the 15- to 50-kHz frequencies utilized by these fathometers are small and may be mounted without difficulty on the boat hull or in a towed vehicle, or "fish." These frequencies, unlike the low-frequency types, are not vulnerable to boat or background noises. Beams are relatively narrow within this range, providing good definition of the bottom and eliminating troublesome side echoes. There is greater attenuation of sound at these frequencies, but in the 10-fathom operating depths required by this study, this is not a factor unless considerable turbulence is evident.

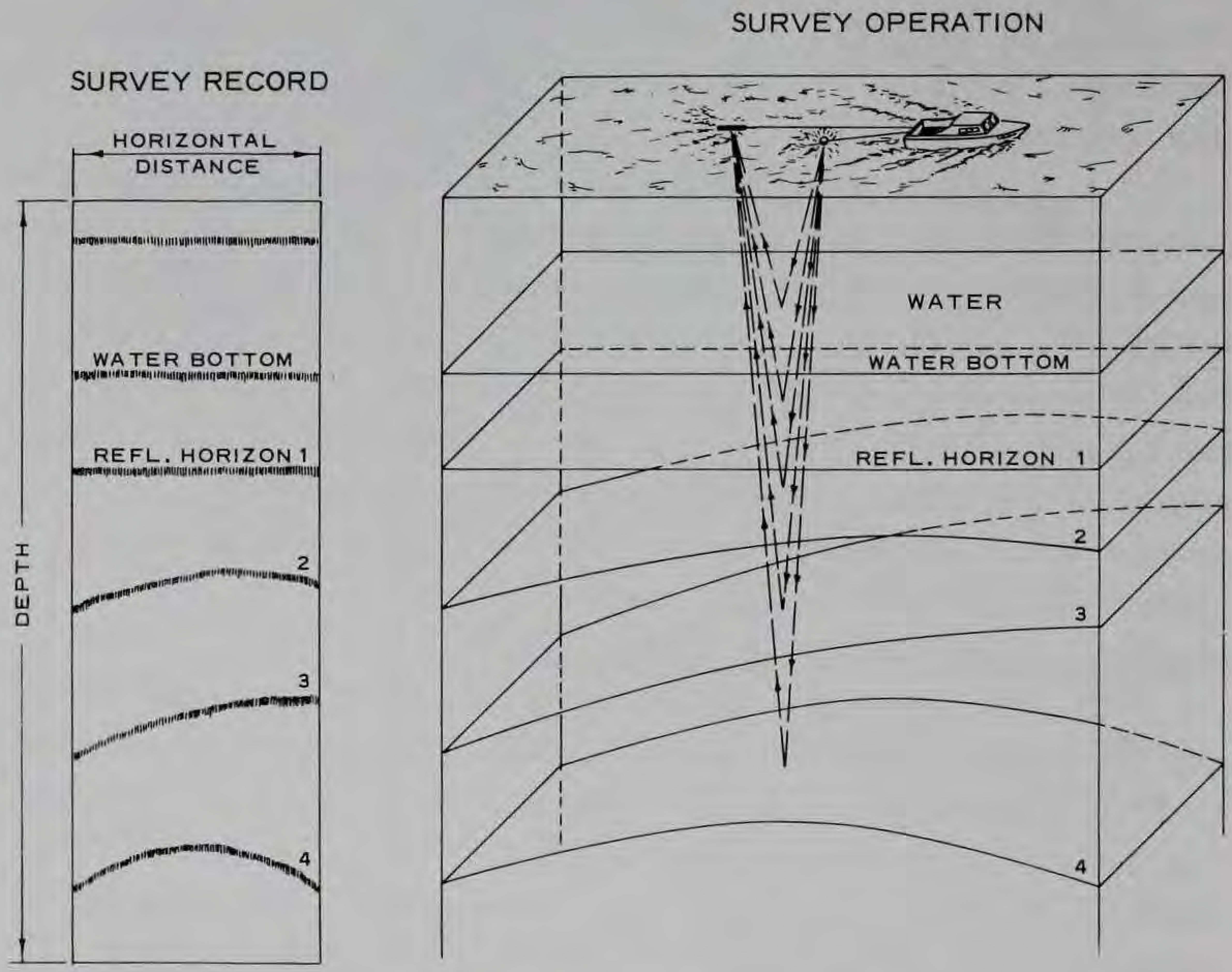
124. High-frequency fathometers. These fathometers commonly have operating frequencies between 50 and 200 kHz. They are characterized by narrow beams that provide the highest bottom resolution. Attenuation of the acoustic signals is high at these frequencies; however, operation in shallow water poses no problem. Bottom penetration is minimal, and resulting resolution is good. Unfortunately, the high-frequency signals respond to numerous discontinuities evident in the water that may be produced by turbulence, temperature gradients, density changes, suspended soil materials, or grasses and kelp beds.

Acoustic subbottom profiling (ASP) systems

125. All ASP systems depend for their operation upon the generation of controlled-frequency pulsed acoustic energy, which is introduced into the water beneath, behind, or alongside a moving vessel. The systems detect, amplify, and record signals that are reflected back from subbottom acoustic interfaces, i.e., layers of contrasting acoustic impedance. Each system consists of several basic components (fig. 11) that may vary widely in their operational capabilities. The basic operation technique of a typical subbottom profile system is also shown in fig. 11. Table 1 lists some of the relevant operational characteristics



a. Basic components



b. Basic operation technique

Fig. 11. Basic operation technique and components of a typical acoustic subbottom profiling system

Table 1

Operational and Performance Characteristics of Available Profiling Systems

Manufacturer or Operator and Name or Designation of System	Only or Dominant Frequency kcps	Intensity of Acoustic Output, db, or Stored Energy Level, J	Pulse Rate per sec	Pulse Length msec	Resolution ft	Depth of Penetration ft
		Pingers (Piezoelectric Transducers)				
Edo Western Corp., Model 185 (Navy AN/UQN-IE)	12.0	61.5 db	10	0.9-1.2	2-3	120-150
Edo Western Corp., Model 415	7.0 or 3.5	107 db	--	0.2-30.0	0.5-1.5	30-150
EG&G International, Inc., Pinger Probes	12.0 or 5.0	98 db	20(max.)	0.3-0.4	<1	45-90
Kelvin Hughes America Corp., Echo Sounder	10.0	--	--	--	3	90
Ocean Research Equipment, Inc., Subbottom Profiling System	12.0-3.5	105-112 db	--	--	2	±100
Ocean Sonics, Inc., Model OSR-119T/XD-5	8.0-3.5	--	--	0.02-1.0	±1-2	15-100±
		Pingers (Magnetostrictive Transducers)				
Brown and Ross, Inc. (Distr.), Elac Bottom Penetration Sounder	18.0	--	1-9	0.6-10.0	<1	90
Magnolia Petroleum Co., Marine Sonoprobe	3.8	250 J	12	0.5	<0.5	30-60
		Boomers (Electromechanical Transducers)				
EG&G International, Inc., High-Resolution Boomer	1.2-0.8	200-500 J	2.5	1.0	±1	20-200
EG&G International, Inc., Standard Boomer	0.6-0.4	13,000 J(max.)	0.2-1.0	0.5(min.)	±10	1,000(max.)
Lister Enterprises, Bubble Pulser	0.25	16 J	8(max.)	8.0	5-10	200+
		Sparkers and Arcers				
Alpine Geophysical Assoc., Inc., Sparker (a)	5.0-0.5	50 J	1+	--	5-15	300-400
Alpine Geophysical Assoc., Inc., Sparker (b)	0.6-0.25	100-400 J	1-16	<6	20-25	1,200
Alpine Geophysical Assoc., Inc., Arcer	--	100,000 J	--	--	--	5,000+
EG&G International, Inc., Sparkarray	0.120-0.08	105,000 J(max.)	--	--	50-100	7,000+
General Oceanographics, Inc., Seismic Profiling System	10.0-0.009	750-3,000 J	0.25-4	--	5-50±	1,000+
Huntec Limited, Mark 2A Hydrosonde System	2.3-0.1	--	4	--	--	150
Lamont-Doherty Geological Obs., Subbottom Depth Recorder	5.0-0.3	--	1-4	--	--	600
Scripps Inst. of Oceanography Arcer or Sonic Profiler	0.5-0.2	3,000 J	1-2	--	20-30	600+
Southwest Research Institute, Arcer	20.0-0.6	5,000 J	--	--	<10	3.000±
Teledyne Industries, SUBot System	1.0-0.125	5,000 J(max.)	4	8-9	10-50	300-2,000
Teledyne Industries, SSP System	0.125-0.02	160,000 J(max.)	0.25	8-23	--	15,000
Texas A&M University, Sparker	--	50,000 J	--	--	--	5,000+
U. S. Geological Survey, Sparker Systems	--	13,000-160,000 J	--	--	--	--
U. S. Coast & Geodetic Survey, Sparker	0.9-0.2	1,000 J±	0.08-8.0	--	10-25	400+
U. S. Naval Undersea R&D Center, Plasma System	4.0-0.035	200,000 J(max.)	--	--	--	5,000+
Western Geophysical Co., Sparker	--	100-400 J	0.25	--	--	1,500(max.)
Western Geophysical Co., Arcer	--	80,000 J	0.33	--	--	6,000±
Woods Hole Oceanographic Inst., Continuous Seismic Profiler	0.08-0.04	100,000 J(max.)	0.1-2	33	--	3,800+
		Gas Guns				
Lamont-Doherty Geological Obs., Repeatable Acoustic-Seismic Source	0.035	--	1-2	--	--	1,400+
Sinclair Oil & Gas Co., Dinoseis System	0.08-0.02	--	--	2	>100	20,000±
Western Geophysical Co., Continuous Seismic Profiler	--	--	0.13	--	--	12.000+
		Air Guns				
Bolt Associates, Inc., Marine Profiler	0.07-0.005	95-138 db	0.18-4	10(min.)	20-100+	400-10,000
Lamont-Doherty Geological Obs., Air Gun	--	120-125 db	0.1	--	--	2,000+
United Geophysical Corp., Shallow Water Air Gun System	0.2-0.005	--	--	<20	--	3,000±
		Miscellaneous				
Raytheon Company, Inc., Hydroacoustic Source	0.3-0.2	15 & 1,500 J	0.06	1,000 & 10	12±	2,000+

of certain ASP systems currently in use. Systems are most often grouped according to their operating frequencies and designated with appropriate names suggestive of their sound sources, such as "pingers," "boomers," "sparkers," "arcers," "gas guns," and "air guns" (fig. 12). Of these,

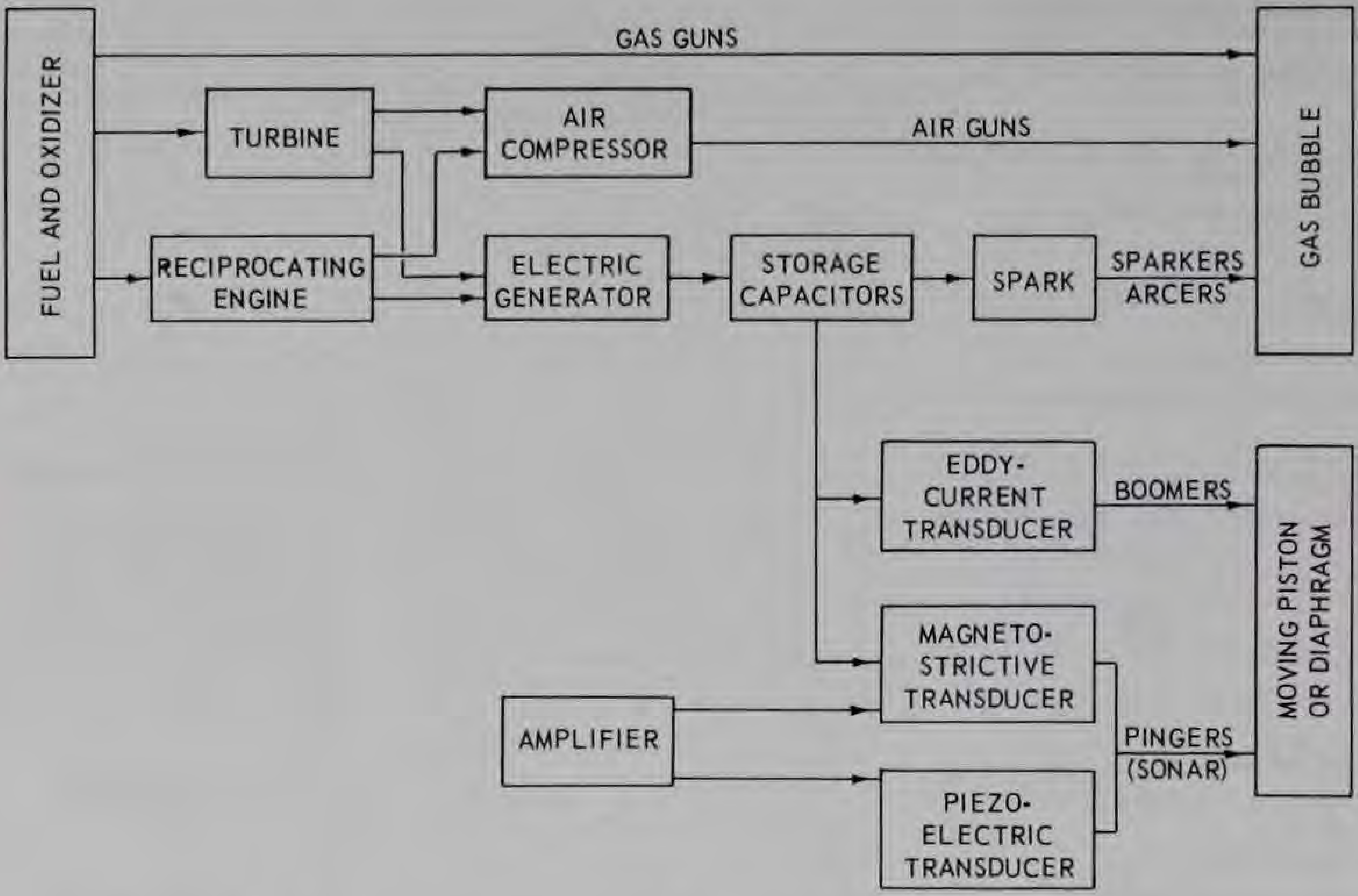


Fig. 12. Sound sources used for subbottom profiling systems

the pingers, boomers, and sparkers are the higher frequency systems and have higher resolution but shallower penetration. In a given environment, any one of the three may prove to be the superior system. The following paragraphs describe the basic components, operational characteristics, and inherent limitations of these three systems.

126. Pinger system. Most pinger systems operate within frequency ranges of 2 to 16 kHz (see table 1). The system is composed of five basic components:

a. A sound source, or transducer, which generates a relatively low-frequency, regularly pulsed acoustic signal. Transducers are mounted singularly or in combinations of two or four (fig. 13), the configurations influencing the resolution and the directionability of the system (a four-transducer array transmits a narrower beam than a two-transducer array and achieves higher resolution). Transducers may be used for both transmitting and receiving and may be mounted in an over-the-side array (fig. 13) or in a towed fish (fig. 14). The fish, although restricted to areas with 10 ft or more water depth, usually achieves better overall results and permits the vessel to travel at higher speeds. The transducers must be towed a minimum depth of 2 or 3 ft below the surface.

b. A receiving component, or hydrophone, which detects the reflected signal. In most pingers, the transducers serve alternately as transmitters and hydrophones.

c. A transceiver (fig. 15), which controls the operating frequency (in variable-frequency systems) and pulse lengths and amplifies the transmitted and reflected acoustic energy into the desired electrical signals.

Fig. 13. Over-the-side mount for four-transducer array utilized with WES "pinger" system

Fig. 14. Towed fish containing the four transducers in the array shown in fig. 13. The fish permits the transducers to be towed at greater depths, thus eliminating certain background noises and enabling the vessel to move at greater speeds

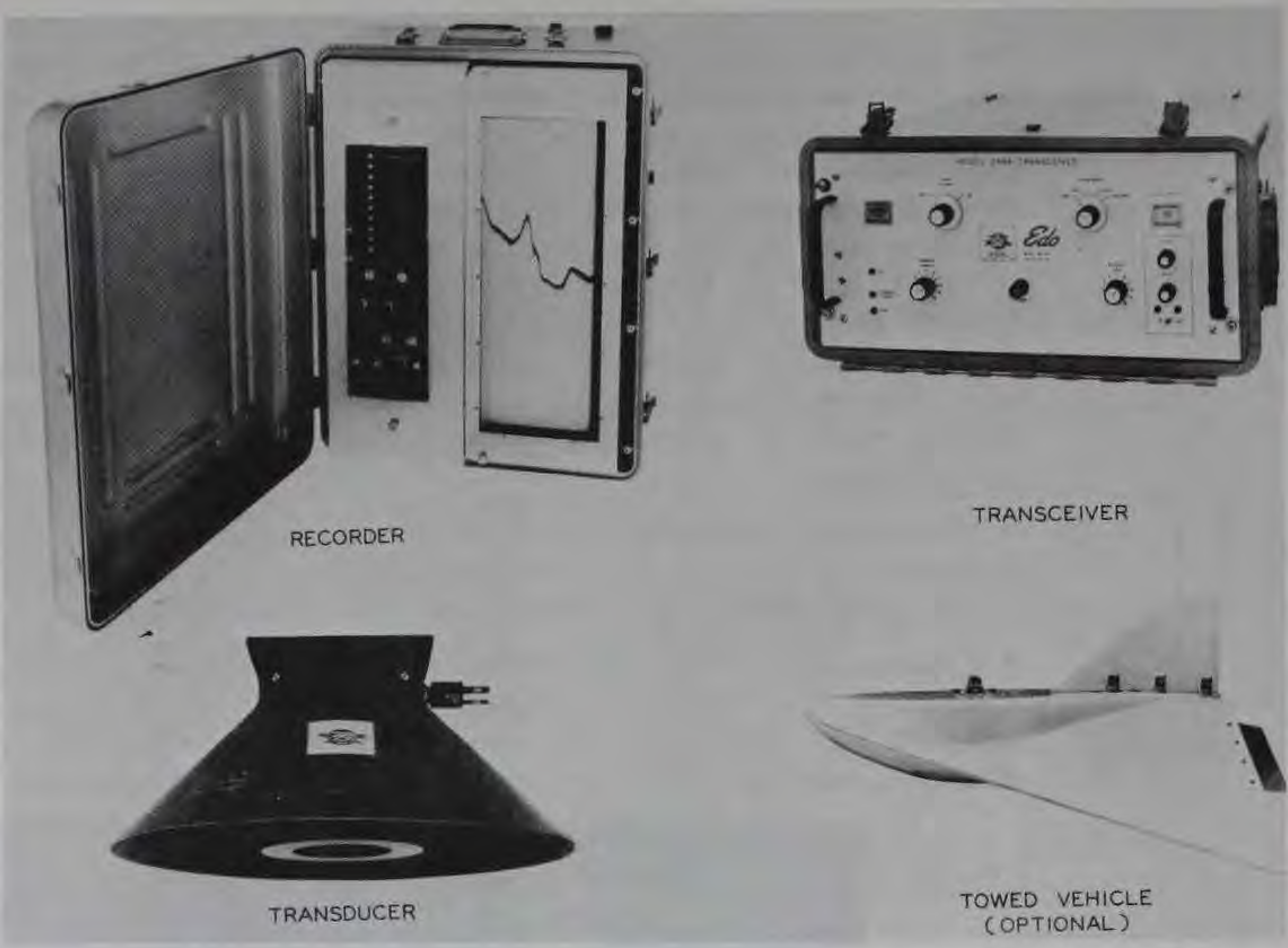


Fig. 15. Typical bathymetric profiling system

d. A graphic recorder (fig. 15), which portrays the electrical signals as continuous bottom and subbottom profiles at controllable scales.

e. A power supply consisting of a 3-kw (approximately) generator to provide a continuous 110- to 120-v a-c current.

127. Hoisting equipment must be installed on the vessel and should consist of a winch and boom or A-frame capable of raising and lowering the fish-mounted transducers. Pinger systems provide excellent resolution of subbottom interfaces (1 to 2 ft) and, in optimum operating conditions, can penetrate to depths of 100 ft or more. Unfortunately, the relatively high-frequency signal may fail to penetrate some bottom materials such as organics and certain sands.

128. Boomer system. High-resolution boomer systems operate at frequencies ranging from approximately 400 Hz to 8 or more kHz. Boomers are capable of penetrating to depths of 200 ft or more and achieving resolution of approximately 2 to 3 ft, depending upon the energy level and operating frequency. With its greater power supply and lower

operating frequency, a boomer can penetrate most bottom conditions. Boomer systems consist of the following components:

- a. A single transmitting transducer, which is mounted on a catamaran and towed at a specified distance behind the vessel (fig. 16).
- b. A hydrophone streamer array (fig. 17), which receives the reflected acoustic signal and trails the vessel on the side opposite the catamaran. The streamers may vary

Fig. 16. Boomer transducer mounted on catamaran trailing the survey boat

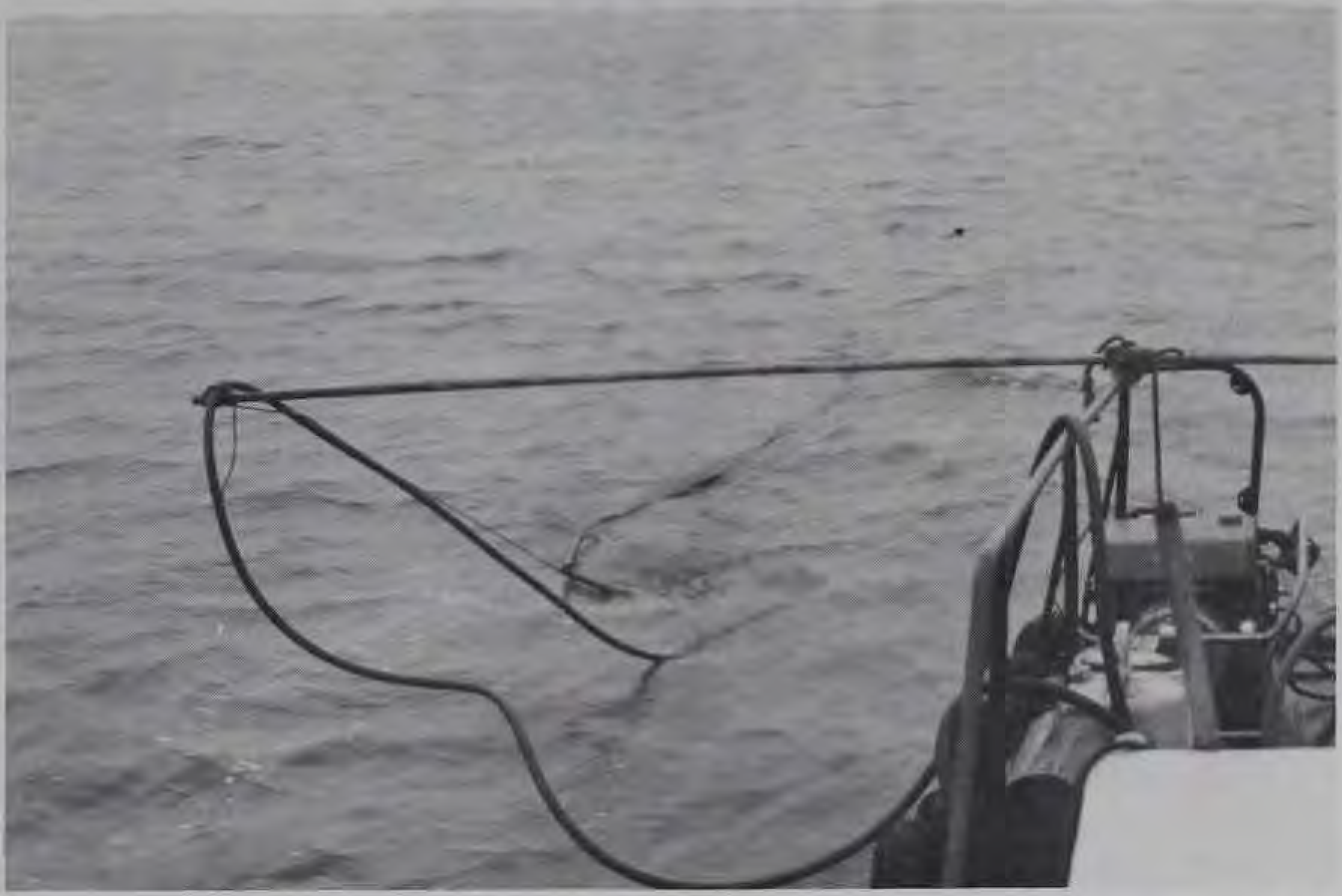


Fig. 17. Hydrophone array trailing survey boat on side opposite catamaran to avoid interference

in length from 10 to 100 ft and are composed of from 5 to 100 hydrophones that are usually piezoelectric ceramic devices.

c. A power supply, which serves as a high-voltage source for charging the capacitor banks (fig. 18).

d. A capacitor bank or capacitor banks for the storage of the required voltage to generate the high-powered

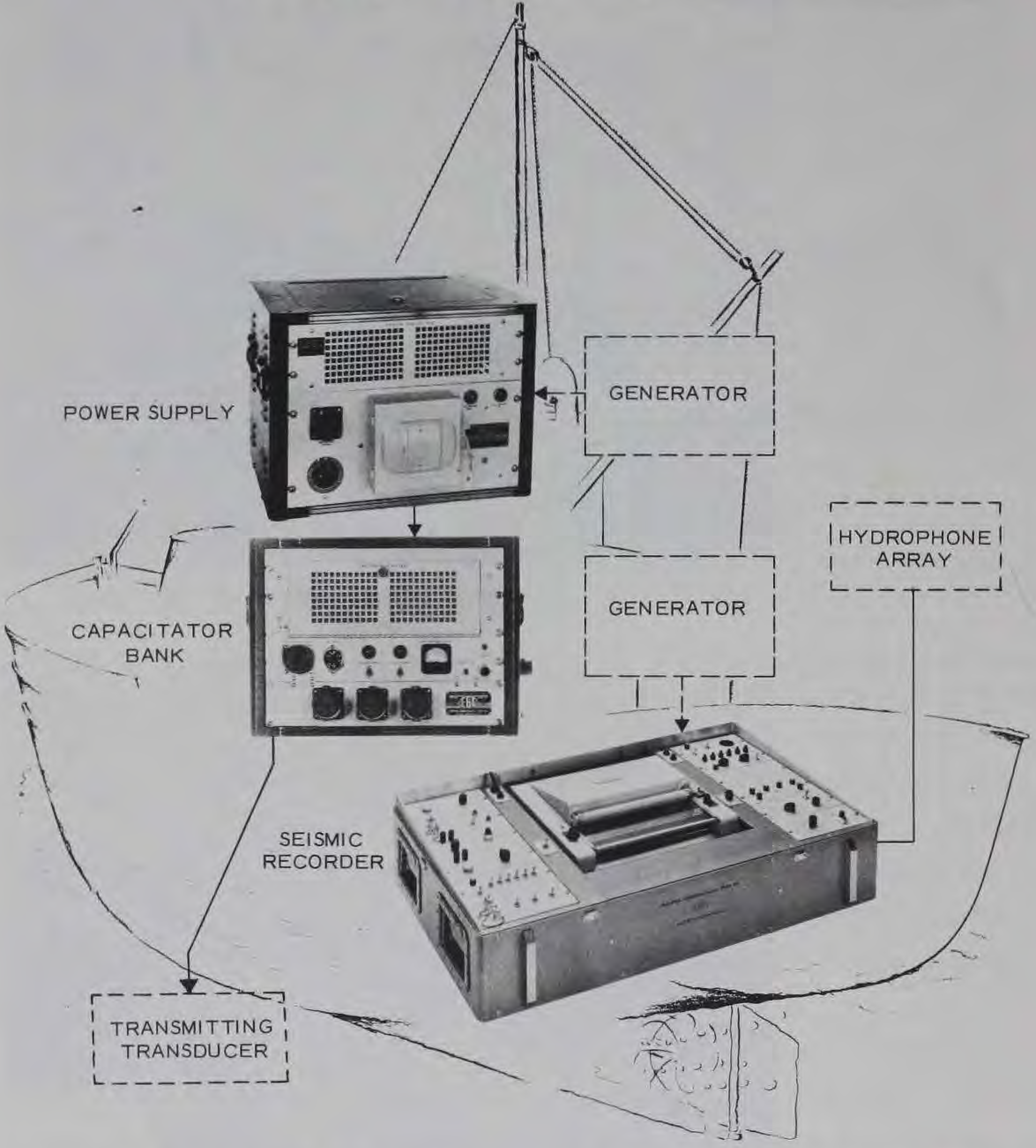


Fig. 18. Recorder and power components of the high-resolution boomer

electrical pulse that discharges into the transducer (fig. 18).

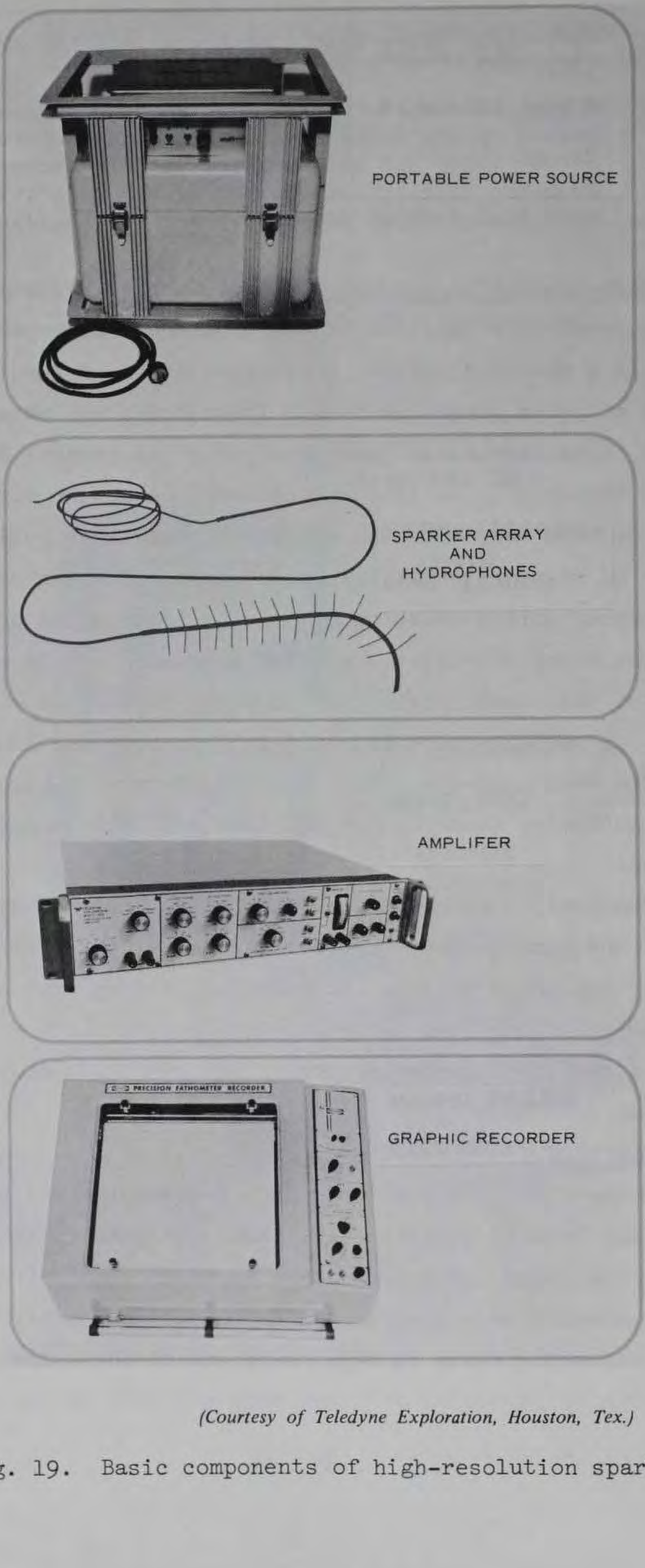
e. A graphic recorder (fig. 18), which portrays the processed return signals as a continuous record. The recorder times and triggers the outgoing acoustic pulses from the transducer. Normally, a 5-kw portable generator will provide adequate power for the system.

129. High-resolution sparker system. Sparker systems (fig. 19) are achieving growing recognition as a hydrographic surveying tool. Although normally a poor-resolution, deep-penetration system, recent models operating at lower power and higher frequencies are obtaining good resolution (3 ft in some cases) and penetration of several hundred feet. They are less affected by adverse bottom conditions than either the pinger of boomer systems, although records in the upper horizons of the subbottom may be of poor quality or washed out. The sparker is a comparatively compact unit consisting of: (a) a towed spark array, which constitutes the sound source, (b) a towed hydrophone array somewhat similar to that of the boomer system, (c) a power supply, (d) capacitor banks, and (e) a graphic recorder. A 5-kw generator should provide adequate power for most high-resolution sparker systems. Sparker systems are characteristically more compact and less expensive than pinger and boomer systems.

130. The basic components are quite often interchangeable on many ASP systems. The same graphic recorder may be utilized for all three of the previously discussed systems, although not always with equal effectiveness. The power supplies and capacitor banks are often interchangeable between boomer and sparker systems. Certain hydrophones are adaptable to several systems.

Electronic positioning equipment

131. Bathymetric and subbottom data are meaningless unless they can be precisely located geodetically. Numerous positioning systems are presently available for hydrographic surveying that offer substantial improvements over systems and techniques currently being employed by CE surveying teams in TO's. Typical of these are procedures requiring extensive surveying of lines perpendicular to the shorelines



(Courtesy of Teledyne Exploration, Houston, Tex.)

Fig. 19. Basic components of high-resolution sparker

and transit stations from which angular measurements can be taken as the vessel follows along the range line (fig. 20). Range lines are identified by a succession of flags from the shoreline inland often across landscapes and man-made structures that may seriously inhibit line of sight. At best, the operation is slow and wholly dependent upon favorable weather conditions. In addition, numerous personnel are involved, both aboard ship and ashore, a circumstance that compounds the serious inadequacies already evident in the method. Electronic positioning equipment offers a more expedient and accurate means of acquiring depth location data and requires fewer personnel. Positioning systems that are potentially applicable to the conduct of this study are classifiable into three basic types:

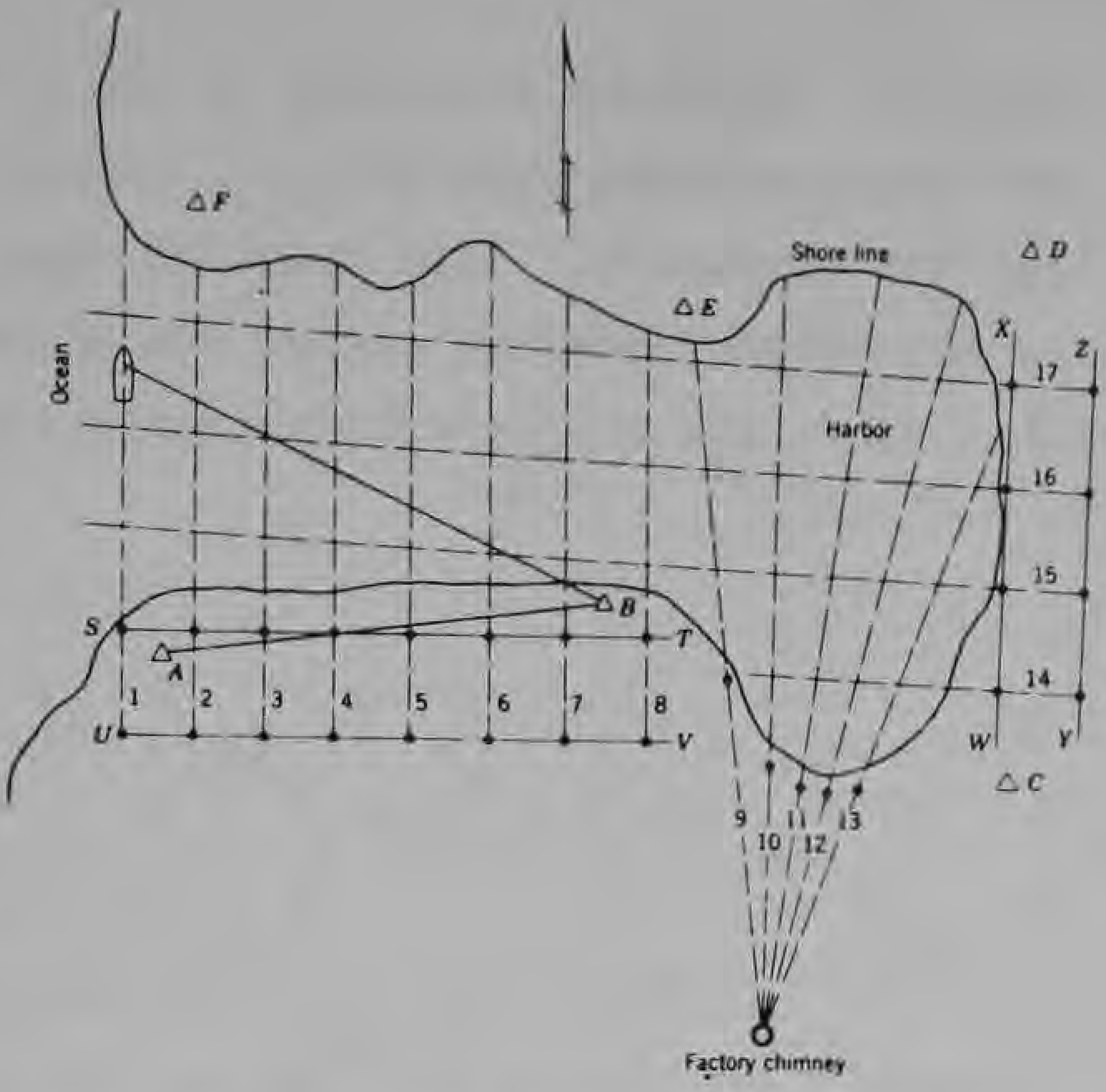


Fig. 20. Simplified sketch of range-azimuth procedure of hydrographic survey in a harbor

- a. Range-range. Distances to two surveyed shore stations are electronically measured from the moving survey vessel.
- b. Range-azimuth. An azimuth is measured from a known reference (line A-B, fig. 20) and the distance determined from a surveyed control station (point B) to the moving vessel.
- c. Azimuth-azimuth. Two transits are used to track the moving vessels.
- d. Doppler-sonar. A system that requires no shore stations; the distances are determined in relation to known or arbitrarily selected reference points, and angles are computed in relation to the preselected courses.

132. Range-range, range-azimuth, and azimuth-azimuth systems are widely used in hydrographic surveying throughout the world. All of these systems, however, are dependent for their accuracy upon surveyed shore

station. With the exception of radio-frequency range-range types, all are line-of-sight systems i.e., limited by physical obstacles or the earth's curvature. This requires that stations be relocated as required by the length, configuration, and elevation of the shoreline to ensure that operative ship-to-shore geometries are maintained (fig. 21). Over

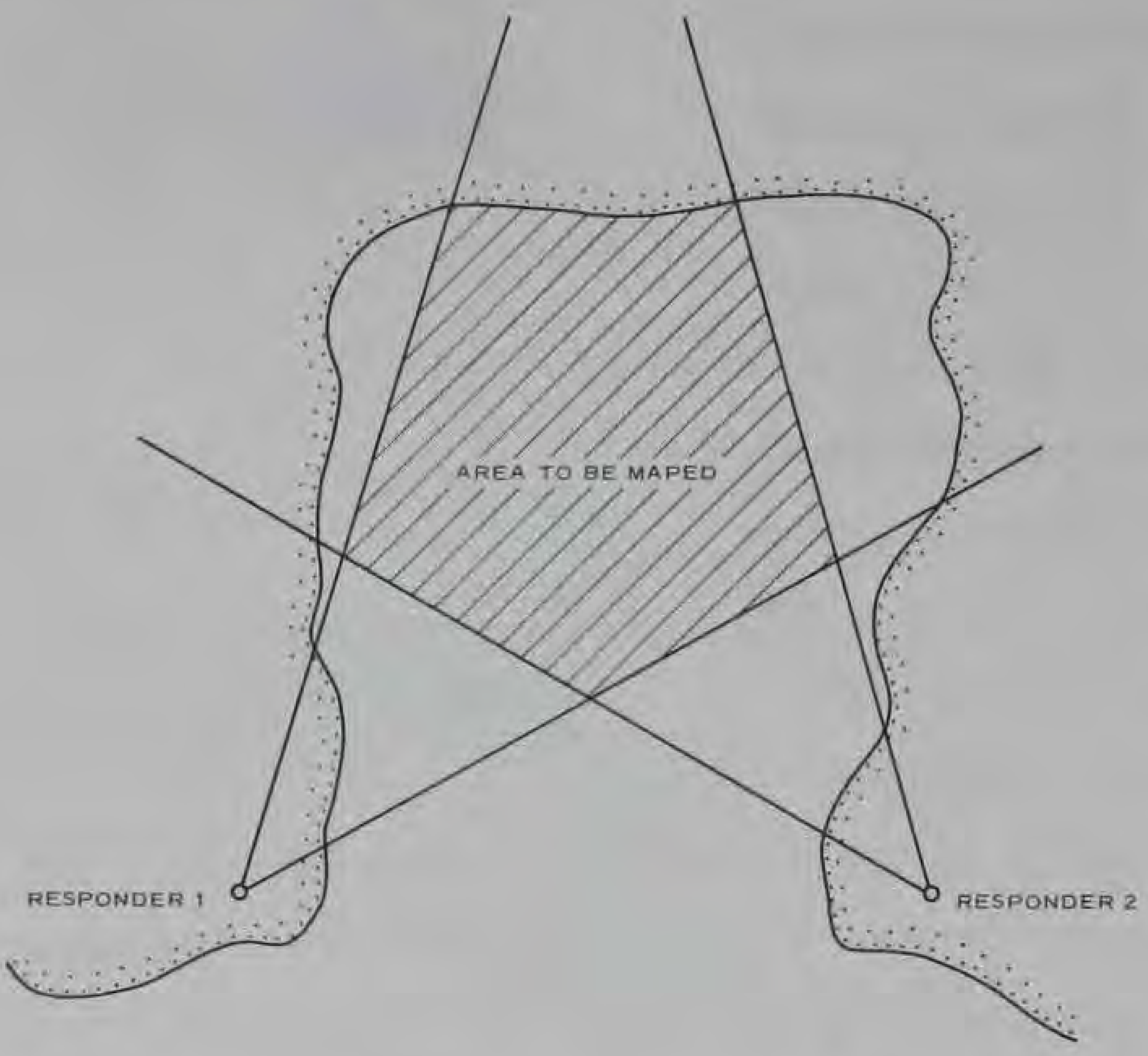


Fig. 21. Area of coverage provided by shore-located responders for a particular shoreline configuration.

a lengthy, irregular stretch of shoreline, numerous shore station setups would probably be required. Range-range systems provide instantaneous digital displays of the distance to the two shore stations that, when the exact baseline distance between the stations has been determined, enable precise location of the ship (fig. 22). These distances can be manually recorded, recorded on magnetic tape, or visually displayed on an X-Y plotter. Desirable elements of such a system are a hydrographic or electric clock and a data formatter. The data formatter interrogates both the position system and the fathometer and interfaces with the clock. As a result, a continuous record of depth, position, and time is recorded on magnetic tape for later reduction to a visual plot or directly onto an X-Y plotter where the exact position is known throughout the survey and timely adjustments can be made to course direction.

Fig. 22. Typical range-range ship-to-shore geometry

(Courtesy of General Electric)

Doppler-sonar systems are neither line-of-sight restricted nor dependent upon surveyed shore stations and have proven acceptably accurate (error of 1/1000), reliable, and relatively simple to operate. Certain commercially available types are equipped with solid-state circuitry that is removable and replaceable without calibration. The system (fig. 23) consists of a control unit that computes both on- and off-course velocities in knots (00.00) and on- and off-course distances in nautical miles (000.000), an interfacing gyro compass that provides instantaneous bearings, and a 300-kHz transducer that is normally mounted in the hull but can be placed on an over-the-side mount. The system may interface with an X-Y plotter and a digital electronic clock. The principal advantage of the Doppler system is that no shore-based instrumentation is necessary for its operation. Starting from a known or arbitrarily selected point, continuous computations are made of on- and off-course velocities and distances in reference either to magnetic north or to an arbitrarily selected course. The system is compact, relatively simple to operate, all weather, and not dependent upon line-of-sight. This system cannot be used in rivers or bays where the currents are moving a significant amount of bedload material as this may introduce an unacceptable velocity error.

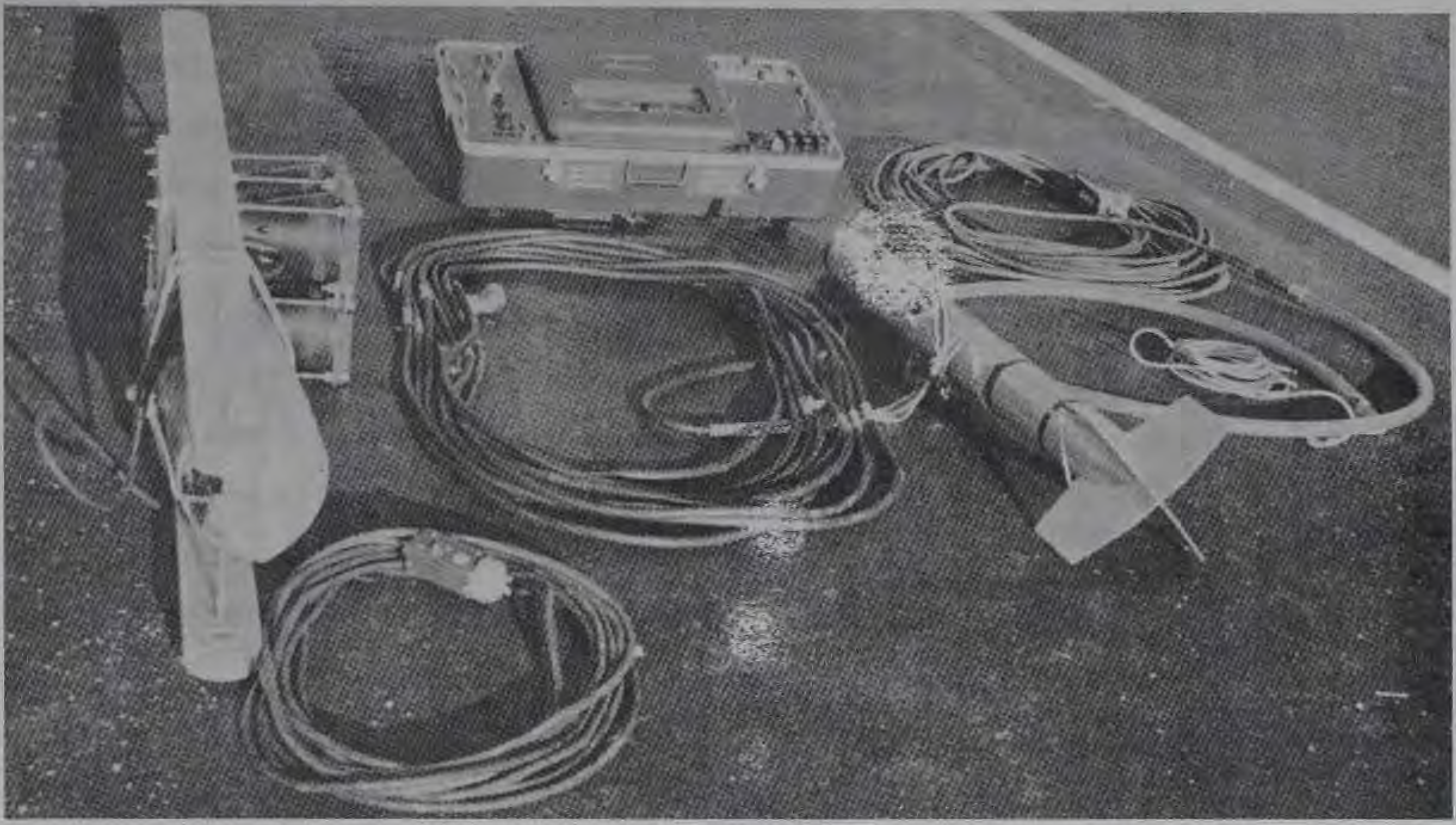
Side-scan sonar system

133. A valuable complement to the bathymetric and subbottom surveying systems in an expedient type survey as described in this report

(Courtesy of Edo Western Corp., Salt Lake City, Utah)

Fig. 23. Basic operational components of the Doppler sonar system

is a side-scan sonar system (fig. 24). The basic system consists of: (a) a transducer (100 ± 10 kHz) mounted in a hydrodynamically designed towed fish, (b) a transceiver, and (c) a graphic recorder. The system can be operated entirely on batteries or from the vessel's power system. Certain systems have the ability to scan both to port and starboard distances of 1000 to 2000 ft, portraying both records simultaneously on the graphic recorder. Resolution is achievable in centimeters. Used with the bathymetric profiler, the side-scan sonar system provides a means of gaining a complete and accurate picture of the harbor bottom. The system not only discriminates natural configurations of the bottom but detects foreign objects such as debris or mines that represent potential hazards to navigation and thus require removal. The system enables identification of bottom materials and structures that are correlative with subbottom records obtained by the ASP system, thus facilitating interpretation.



(Courtesy of U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Va.)

Fig. 24. Side-scan sonar transducer, pinger probe set, and hydrophone

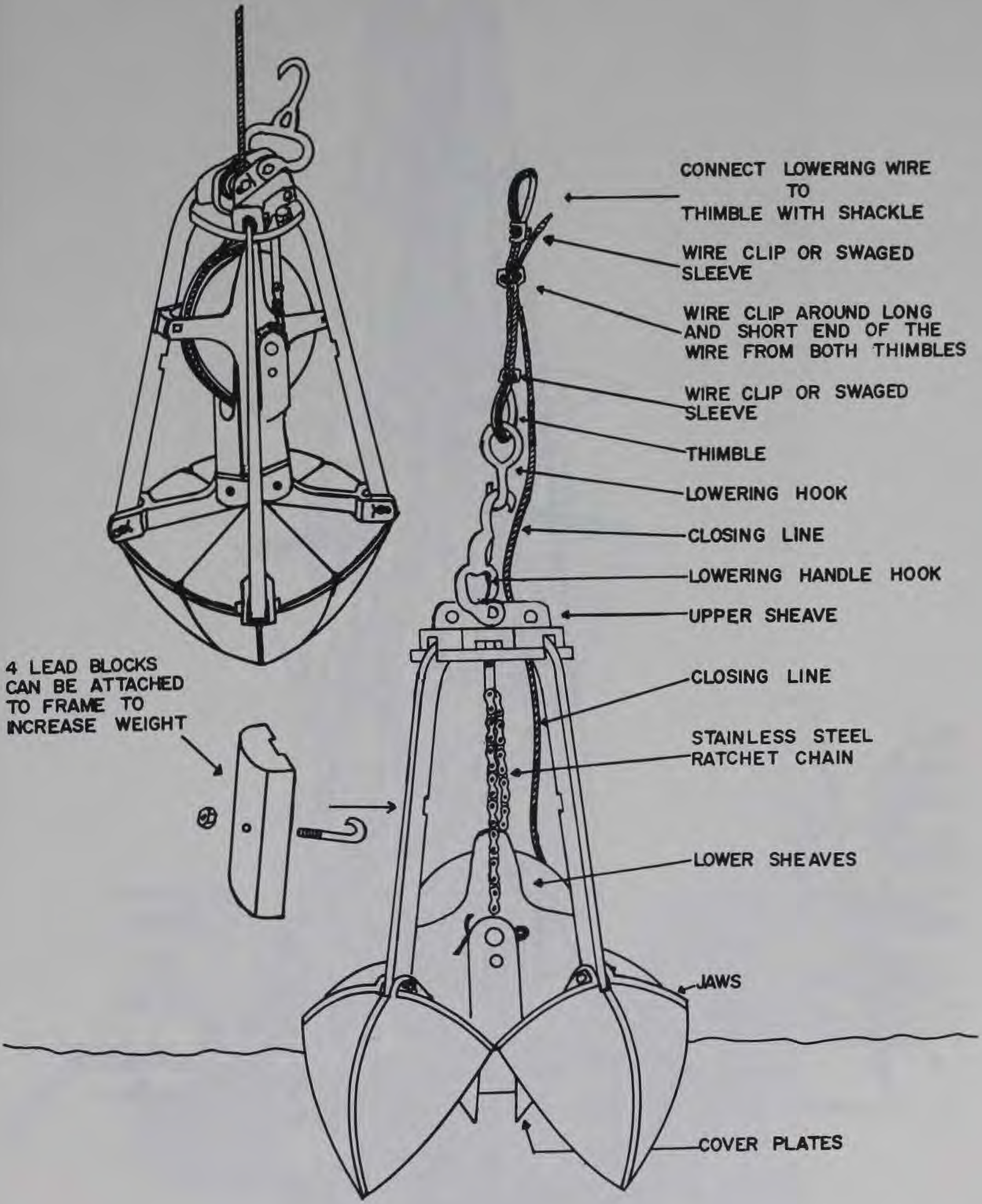
Bottom samplers

134. It is necessary during the conduct of the bathymetric survey

to identify the materials that compose the bottom in areas of anticipated construction or dredging where navigation is required. There are numerous sampling techniques that are currently employed dependent largely upon the requirements of the particular survey. There are three general methods for the collection of bottom samples: (a) coring, (b) dredging, and (c) grab sampling. Each has definite advantages dependent upon the type of investigation, nature of the bottom and shallow subbottom materials, water depth, and equipment required for the lowering and raising of the samplers. For the purposes of this investigation, the clamshell or orange peel grab sampler (fig. 25) was selected largely because of its ability to operate from a moving vessel. These samplers are also relatively light, easy to operate (they can be raised and lowered manually), relatively simple mechanically, and require little or no maintenance. Bottom penetration using these systems, however, is limited to 1 decimeter or less.

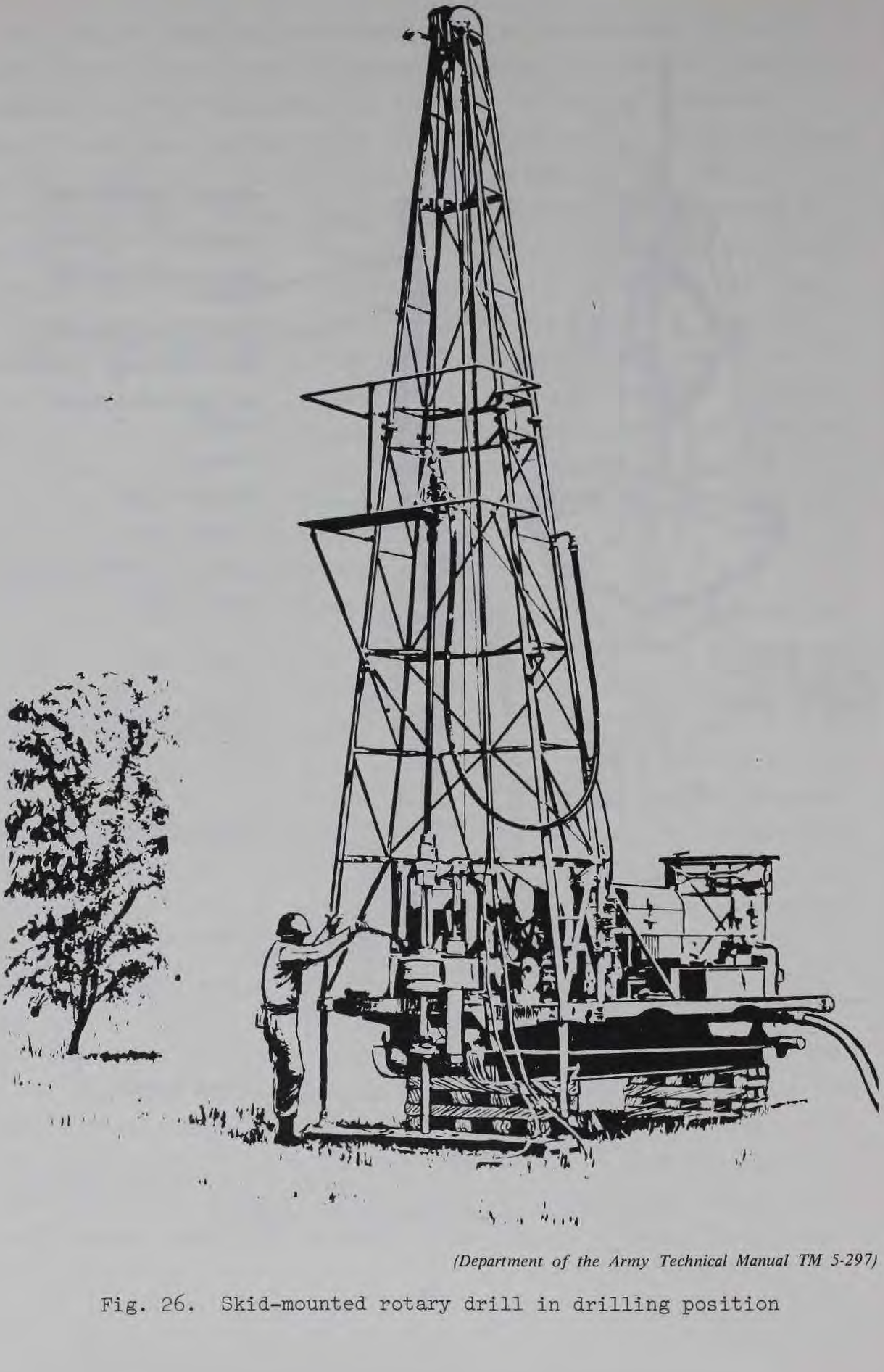
Subbottom sampling and coring

135. Interpretation of the subbottom profile records enables selection of potential sites for pile-supported construction and areas requiring dredging to meet navigation requirements. Subbottom sampling is required at these locations to depths required for classification of the materials to be removed by dredging or to support near-shore facilities. The sampling can be performed either by drilling or coring techniques, both requiring the use of heavy equipment and significant expenditure of time. Since the sampling will be located on land as well as water, the equipment must be versatile. Either skid- or truck-mounted rotary well drilling rigs (figs. 26 and 27) could be effectively utilized. For water locations, a self-propelled and self-elevating spud barge would be required as a drilling platform. For coring operations, a wire-line core barrel can be lowered through the drill pipe to the bottom of the hole. One type of core barrel is equipped with a driving mechanism that enables it to penetrate several feet into the bottom of the hole. The core is then retrieved using a wire line and reel. In the absence of a rotary drill rig in the TO, hammer drill systems could be applied that would provide comparable results. These drills utilize double-walled



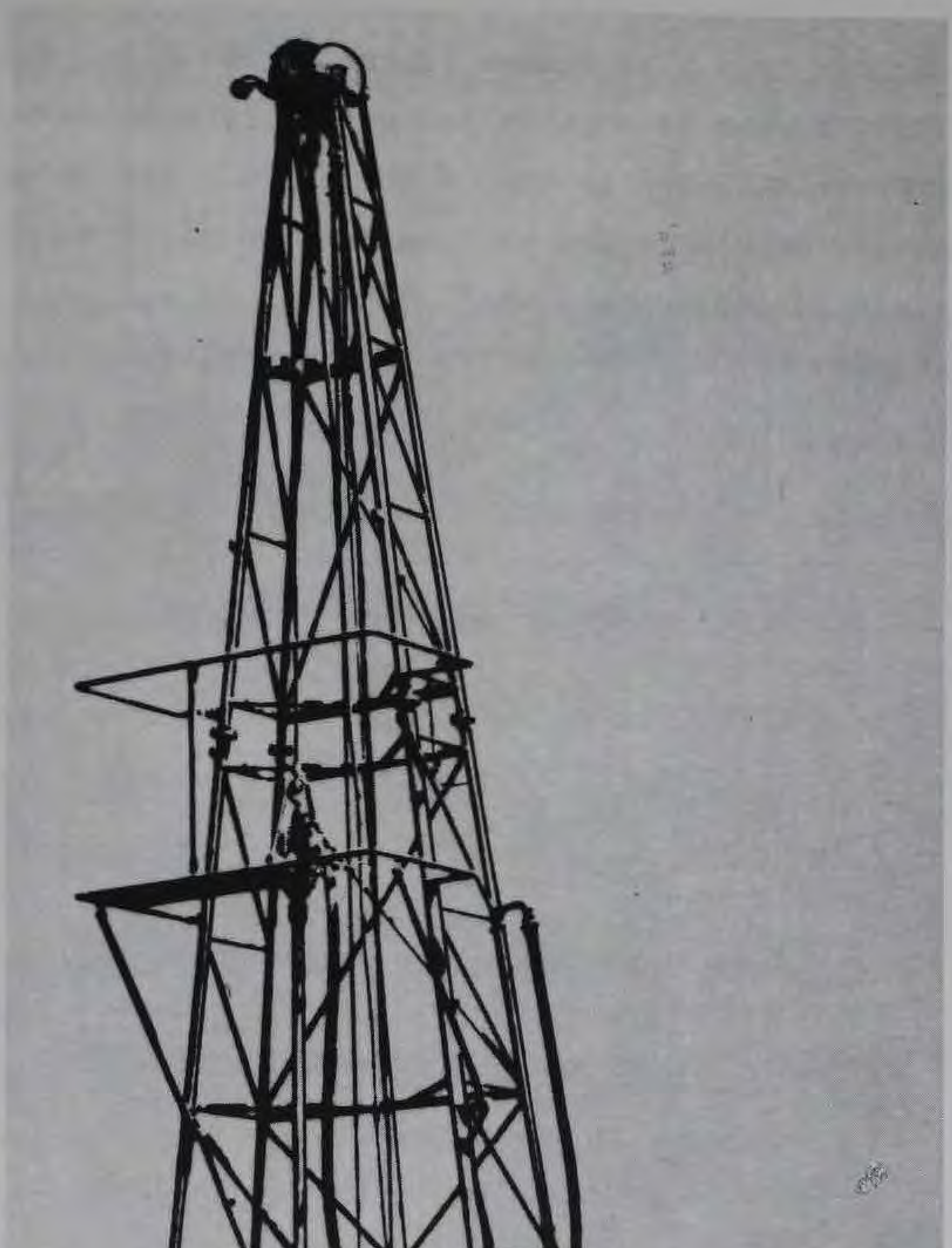
(Courtesy of U. S. Naval Oceanographic Office)

Fig. 25. Orange peel bucket sampler



(Department of the Army Technical Manual TM 5-297)

Fig. 26. Skid-mounted rotary drill in drilling position



(Department of the Army Technical Manual TM 5-297)

Fig. 27. Rotary drill mounted on low-bed trailer

pipe that is driven by a pile hammer (figs. 28 and 29). The principal advantage of this system is that it can be easily adapted to conventional pile drivers utilized by the CE in the TO. Air or water is forced through the annular space between the two pipes to transport the drilled materials to the surface where they can be analyzed for specific soil mechanics parameters. The center of the drill pipe remains clear, permitting use of test equipment such as penetrometers, Shelby tubes or split spoons, shear vanes, or static load testers.

Hydrographic Surveying

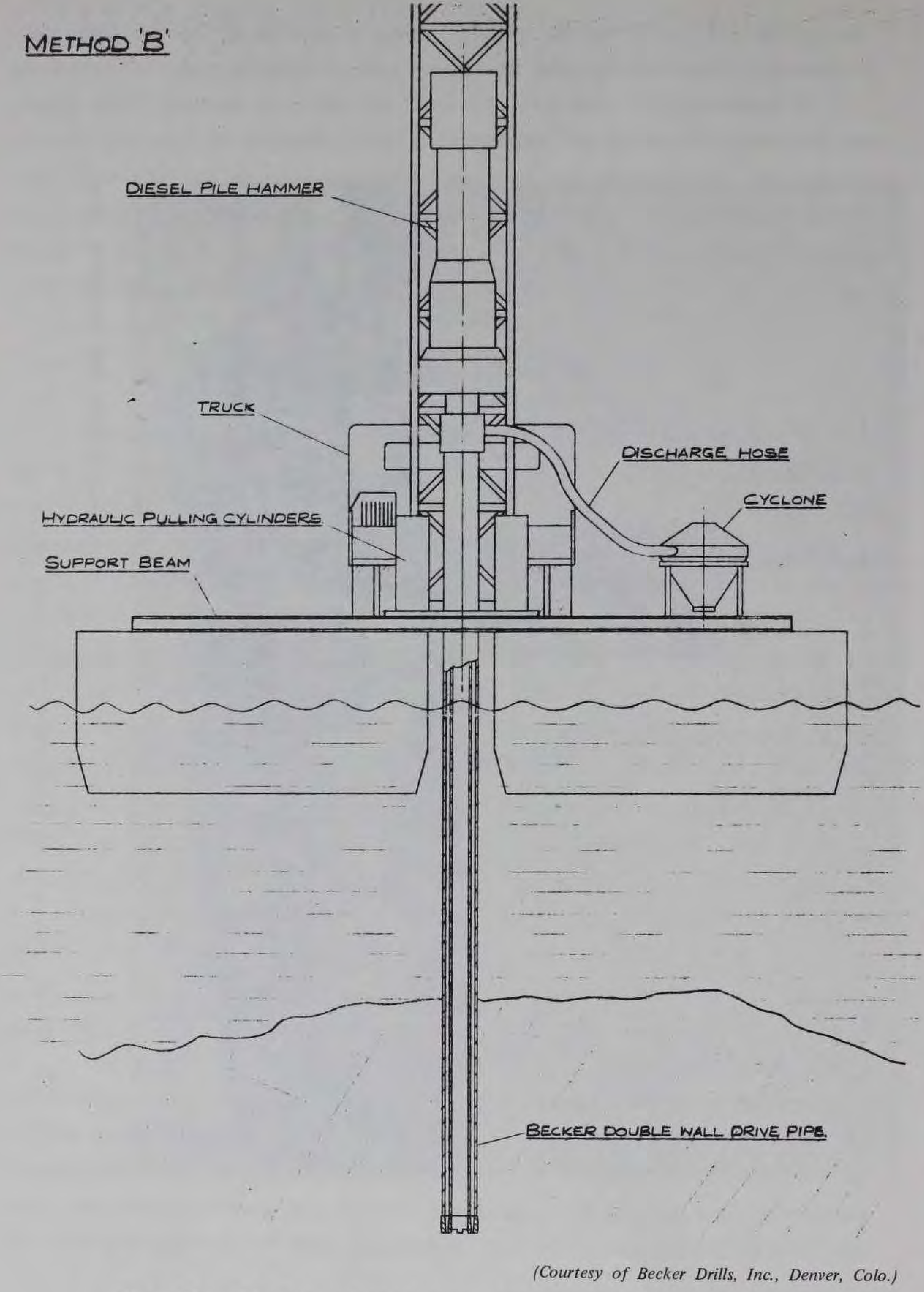
136. It is the purpose of this report to describe procedures that can be utilized in conducting a hydrographic survey that will provide the minimum information required to make the ultimate decision as to the location of pier facilities and to determine dredging requirements in TO ports. It is not within the scope of the study to detail procedures for hydrographic surveying. Conventional surveying techniques are well documented,[10-13] and continual reference throughout field operations, regardless of the nature, will always be a necessity. However, consideration is not given to situations for which expedient surveying is required and less precise results are acceptable. In addition, standard surveying techniques are operative only during favorable weather conditions and are restricted to line-of-sight configurations. The techniques described herein are designed to be operative during weather conditions that would render normal procedures inactive, i.e., wind, sea state, fog, rain, etc.

Selection of hydrographic surveying equipment

137. Numerous types of equipment have been discussed that are considered applicable to the procedures described herein. The selection of the combination of systems which provide the basis for the techniques developed to accomplish the objectives of this study cannot be defended with the benefit of actual field experience. Study has been performed on the capabilities of each component, and field demonstrations of the

(Courtesy of Becker Drills, Inc., Denver, Colo.)

Fig. 28. Truck-mounted, pile-hammer-driven core drill



(Courtesy of Becker Drills, Inc., Denver, Colo.)

Fig. 29. Diagram of marine coring operation with barge-mounted hammer drill

performance of each have been observed. Based on these observations and recommendations of individuals active in the field of hydrographic surveying, the components of a survey package capable of providing the type of data required as the basis for site selection of port facilities were generated.

138. In the selection of the surveying components, a number of factors were considered:

a. Efficiency of operation, as assurance that acceptable levels of accuracy could be obtained.

b. Simplicity of operation, because CE field personnel lack the electronic expertise to effectively operate some of the more complex systems.

c. Simplicity of design, i.e. systems for which maintenance is minimal and little or no calibration is required.

d. Cost of systems, which should not be the predominant criterion for selection, but, by necessity, must be considered, especially in instances in which competitive components with comparable capabilities cover a substantial price range.

e. Compactness of design, because even on a 40- to 50-ft survey vessel, numerous systems operating simultaneously and manned by required personnel can adversely affect the overall efficiency of the operation if consideration is not given to arrangement and dimension.

f. Compatibility of systems during periods of operation because operating frequencies too similar in range can create noise levels that in some cases prohibit the reception of clear signals. Configurations should also be compatible with boat geometry and the installation of the other systems.

g. Ability of the systems to operate during inclement weather and on a 24-hr-a-day basis.

139. Based on these seven criteria, the following components were selected and are considered optimum for the conduct of the site investigation. A brief defense of each component based on its primary advantages is also given:

a. Survey vessel. Should be 40-50 ft long, have a draft of 5 ft or less, have a cabin, and be diesel-powered (fig. 30). The vessel should be equipped with a 110- and 220-v, a-c power system as well as adequate d-c power systems, e.g., 12 and 32 v. These systems are required to furnish power for the operation of the positioning equipment, the fathometer, and various components of the acoustic subbottom profiling system if required.

Fig. 30. Diesel-powered survey boat operated by the New Orleans District, Corps of Engineers. The vessel is approximately 50 ft long and has ample cabin space for the accommodation of all required surveying equipment

b. Power supply. A portable generator of 3.5- to 5-kw output will be required (fig. 31). This is considered adequate for the operation of the sound source for the ASP and normally the other components, i.e., recorder and transceiver.

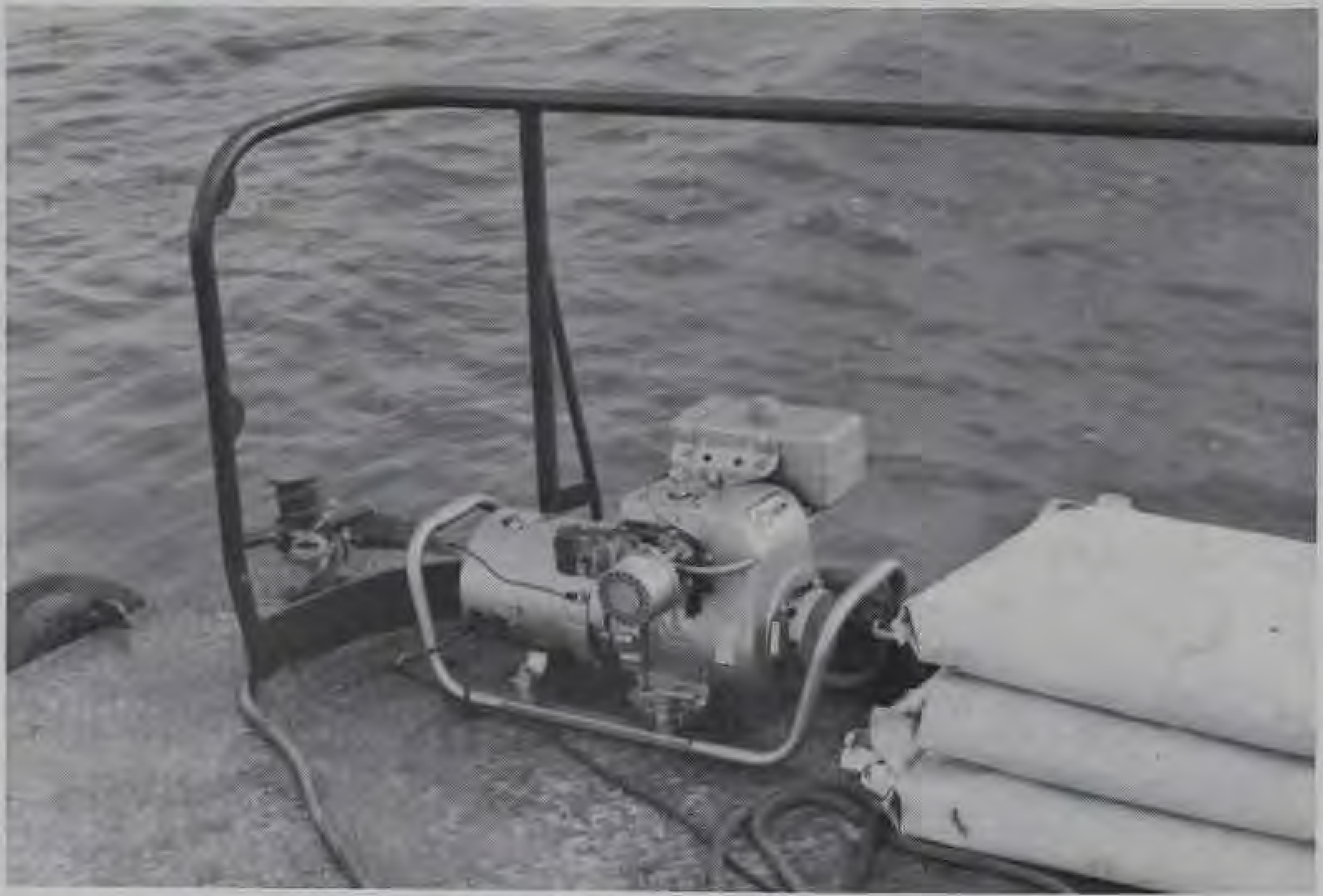
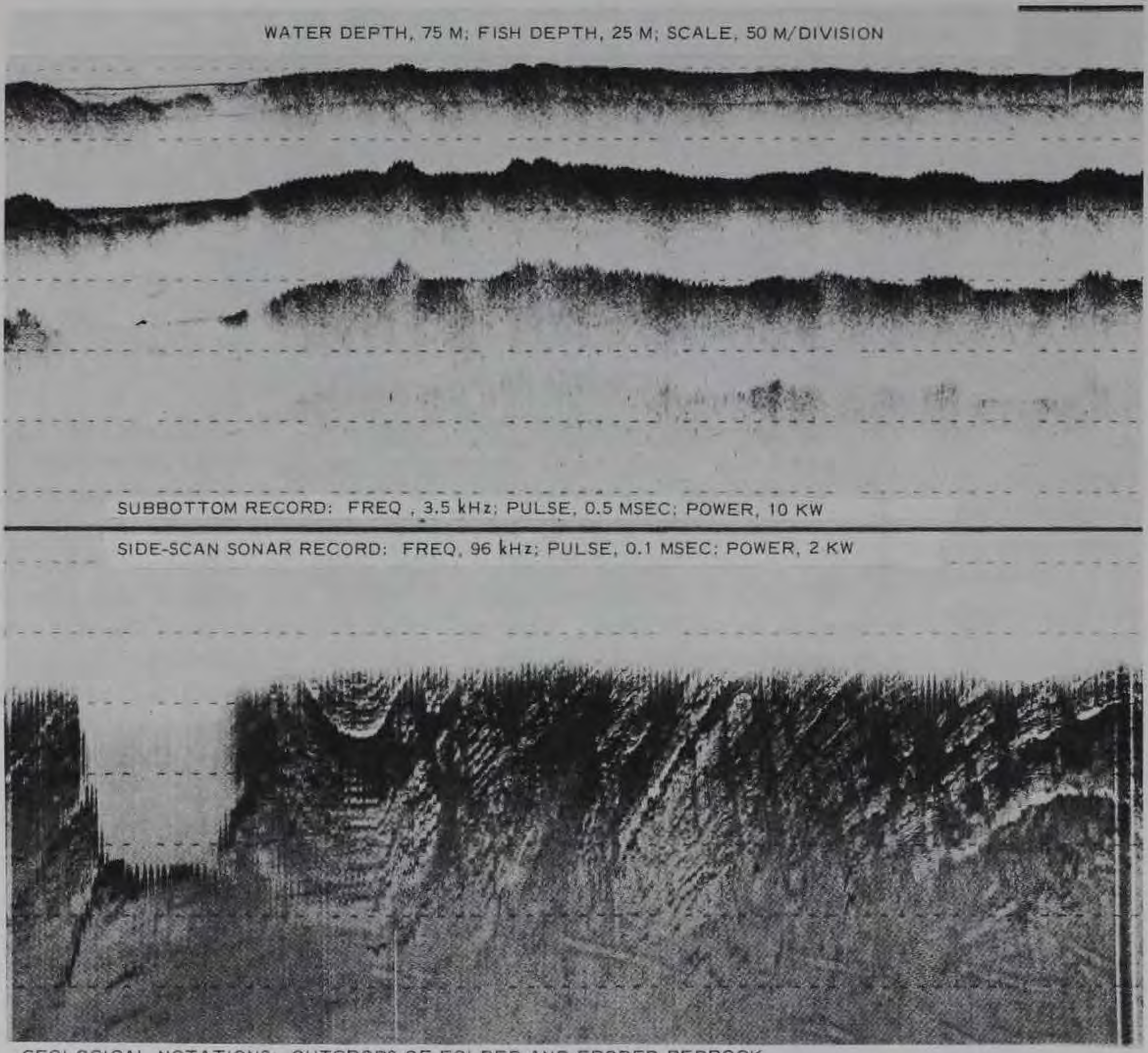


Fig. 31. Portable generator on rear of survey vessel. The generator provides power for the operation of the subbottom profiling system

c. High-resolution sparker. This system was selected over the pinger and boomer primarily on the strength of its superior penetration capabilities in a wide variety of bottom conditions. Although the resolution of this system may be slightly inferior to that of the other two (approximately 3 ft is achievable in the higher frequency operating ranges, i.e., 200 to 1000 Hz), it has been determined to be adequate for the requirements of this study. Resolution can be most simply considered as the inherent ability of generated signals to discriminate or resolve subbottom layering. However, this should not preclude the superiority of the other two systems in a given application. The system is relatively inexpensive and comparatively simple to operate, and is potentially operational under more severe sea states than the other two types. Additionally, the unit is compact, and its configuration does not inhibit the functioning of the other survey system.

d. Fathometer and bathymetric equipment. A fathometer is required for continual reference by the boat operator during navigation in shallow waters. A fathometer with an operating frequency of approximately 50 kHz should be adequate for this purpose. The boat fathometer need not be operative in deeper waters where navigation is obviously no problem. The bathymetric system should be a medium-frequency type, e.g., 35 kHz, to provide good definition of the bottom and experience minimal attenuation effects. Each system should be equipped with a graphic recorder which could include a digital display for the boat operator. The transducers for both the fathometer and the bathymetric profiler should be permanently installed if possible (permanent survey vessels may not be available) in the hull of the vessel at points where water turbulence will have minimal effects.

e. Side-scan sonar. A system with side-scan transducers mounted in a small, towed fish that trails alongside the survey vessel is desirable. The side-scan system should have an operating frequency compatible with those of the other systems (approximately 100 kHz is recommended) and should interface with the recording unit of the ASP, i.e., the records of both the ASP and the side-scan sonar can be graphically portrayed simultaneously on the same recorder (see fig. 32). The side-scan sonar should be capable of scanning a path of 1000 to 2000 ft both to the left and right of the survey line, or, if restricted to a single path, the sonar should be equipped with a selection switch that would permit the operator to choose the direction of scan. A selectivity switch on



GEOLOGICAL NOTATIONS: OUTCROPS OF FOLDED AND ERODED BEDROCK.
SAND AND SILT FILL THE DEPRESSIONS.

Fig. 32. Subbottom and side-scan sonar records portrayed simultaneously on a dual recorder

the recorder would enable the operator to simultaneously portray both the port and starboard records of the side-scan or the ASP record with either the port or starboard side-scan record.

f. Doppler sonar. This positioning system was selected largely on the strength of its all-weather capability, lack of dependence upon shore-established survey control, simplicity of operation and maintenance, and lack of calibration requirements. Doppler systems operate at frequencies from 150 to 300 kHz and thus create no interference problems with the other surveying systems. The small transducer should ideally be installed permanently in the hull of the boat at a point where it will experience minimal turbulence from the movement of the vessel and where it will have a fixed orientation. However, the transducer can be installed on an over-the-side mount fixed as securely as possible to ensure desired angular orientation. Alignment errors can be compensated for through the interfaced gyro compass. The system interfaces with most commercial gyro compasses that provide instantaneous computations of magnetic bearings. The control unit computes and visually portrays velocity and distance values along or at right angles to the preselected courses. Documentation of the entire survey can be permanently recorded on an interfacing digital plotter that provides an instantaneous record of the position of the vessel in reference to the preplotted traverses.

g. Short-wave two-way radio. The vessel must be equipped with an adequate ship-to-shore radio communication system to monitor weather conditions, gain navigation information in the survey area, and receive, if needed, survey instructions from shore-based units. In addition, a small military channel unit is required for communication between units operating in the area.

h. Ship radar. Radar is vital to the all-weather capability of the survey vessel. It also provides protection from collision with other vessels in the port vicinity, especially since the survey vessels will be repeatedly crossing navigation channels. All survey vessels of the dimensions required for this investigation are equipped with adequate radar units.

i. Clamshell grab sampler. This type of sampler seems adequate for obtaining shallow samples of the bottom material. The jaws on these samplers are held open by an external spring arrangement and snap shut immediately upon striking the bottom, enclosing a representative quantity of material. The effectiveness of the sampler varies according to bottom materials; it is not operative on rocky bottoms, is unreliable on gravel bottoms, and is most effective in fine materials and sands. Grab samplers are available in various sizes with capacities varying from 15 to 500 cc; the smallest is deemed adequate for the needs of this survey.

j. Coring equipment. The subbottom coring will be a separate operation from the site surveying and is discussed in more detail later in this report. A survey of available coring type equipment revealed no significant innovations in recent years insofar as obtaining core samples at depths up to and exceeding 100 ft. Therefore, it was decided that a conventional drill rig with a capability for penetrating to depths of 100 ft or more and equipped with a wire-line coring assembly will be mounted on a spud-barge, towed to the site, and elevated to a height sufficiently above surface water turbulence. To minimize the effects of sea state on the towing and coring operation, a site will be selected, when possible, close to the shore.

k. Sample analysis equipment. Cores from various depths will be taken at each site. An engineer soil test laboratory at the Engineer Command or Brigade Headquarters should have the capability of performing the laboratory tests required. Soil parameters of relevance will include shear strengths, consolidation characteristics, density, void ratio or porosity, and grain-size distribution. Equipment for running these tests is standard and should be organic to any well equipped laboratory. The procedures for performing these tests are also standardized and need not be discussed in this report.

Hydrographic surveying procedures

140. The hydrographic surveying phase of the port construction site investigation can be best discussed in a sequence of phases. These are discussed briefly in the following paragraphs.

141. Presurvey data examination. Previous portions of this report have discussed sources and types of information. These data should be collected from both United States and TO sources and provided to the engineer theater unit performing the investigation. Careful examination of these data should allow tentative selection of locations along a shoreline for the construction of a port facility based on a comprehensive examination of available topographic, hydrographic, and oceanographic data coupled with such vital considerations as the port facility

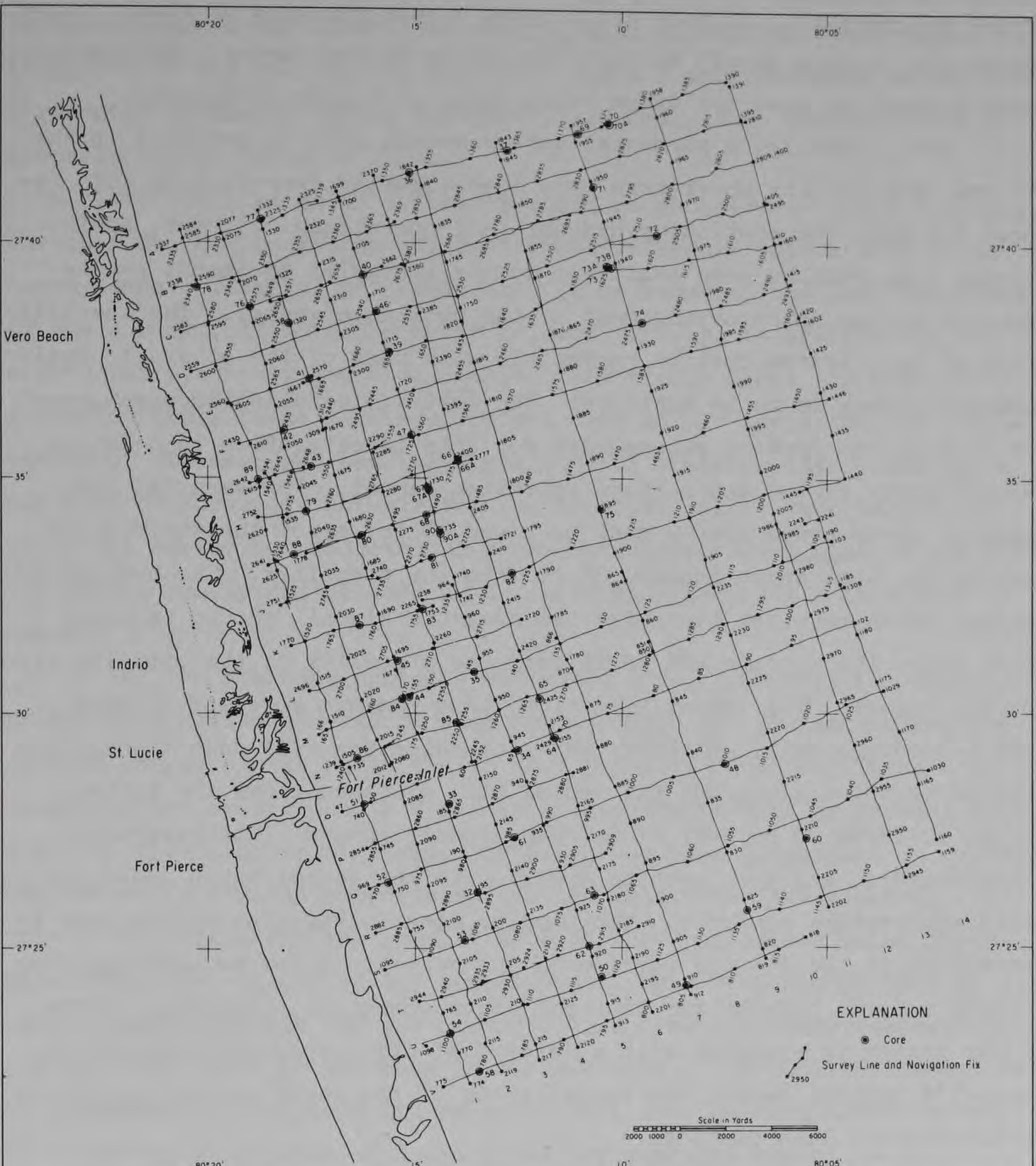
requirements, proximity to existing transportation networks, and utilization of existing port facilities. Inevitably, numerous compromises must be involved in the ultimate selection of the most likely locations. Once specific locations have been delineated, however, the topographic and hydrographic survey teams can actively pursue the required field operations that will provide the basis for final selection. It should be borne in mind that final selection of the port site will consider the composite investigations for all component facilities, i.e., ammunition dumps, POL storage, warehouses, road networks, wharfs, piers, quays, etc.

142. Once the selection of potential port sites has been made based on the numerous criteria previously cited, topographic and hydrographic site investigations should be immediately initiated. The physical and cultural considerations to be surveyed by the topographic survey team have been discussed in paragraph 50 and will not be reiterated here. There must be a continuing rapport between the topographic and hydrographic teams during the entire survey. Critical or limiting data generated by one team can exert profound influence on the field activity of the other. Inadequate POL storage or ammunition dump locations or impossible transportation tie-ins to locations determined as optimum by the hydrographic survey team would force relocation. Conversely, ideal shore arrangements coupled with inadequate water depths or severe current activity would also probably force relocation.

143. The hydrographic survey team will first consider the offshore areas for which surveying will be required. If they are numerous, a priority should be assigned based on port requirements and assiduous examination of all available information. If the locations are geographically remote, it may be necessary to select additional ports from which to stage surveys. The staging ports must have adequate docking facilities; supply depots to provide fuel, water, rations, etc.; and the capability for providing necessary repairs to the vessel and to components of the electronic systems requiring routine and relatively unskilled maintenance. A schedule should be established that will permit the surveying to progress from the highest to the lowest priority areas within the time allotted for the field phase of the investigation.

144. Data for each of the priority areas should be assembled and examined in detail. Large-scale topographic maps, hydrographic charts, tidal data, depth soundings, foundation data resulting from construction of existing facilities, aerial photography, navigation data (particularly aids and deterrents), and well logs are among the most useful types of data. Based on the size of the priority areas, available map and chart coverages, apparent hydrographic complexity of the area, and the time available for the survey, a base map scale should be selected. This will probably be 1:10,000 or larger. Based on the geometric configuration of the shoreline of each priority area, a series of survey traverses should be plotted on the base maps in a fashion designed to satisfy both the bathymetric and subbottom data requirements. Normally these will be laid out in roughly rectangular grid fashion, with dip lines running approximately perpendicular to the shoreline at designated intervals and strike lines running approximately parallel to the shoreline and, of course, intersecting the dip lines approximately at right angles (see fig. 33). The number of dip and strike lines cannot be specified in advance and must result from consideration of surveying time available, complexity of the priority survey area, and the degree of detail required. Simplicity of navigation and maneuverability of the survey vessel should always be important considerations to bear in mind when laying out the survey lines. Significant hydrographic and navigational data obtainable from the reference material should be plotted on the base maps.

145. The positions of potential navigation hazards become of paramount concern when operations are conducted during periods of inclement weather. Also, the positions of navigation aids and hazards indicated on existing maps and charts should be resurveyed to ensure that they are precisely located. The positions of transient navigational hazards such as shoals, mud flats, debris, kelp beds, etc., can only be noted at the time of survey and must be rechecked periodically to determine location and extent. The position of the shoreline, as determined from the most recent and reliable sources, should be plotted on the base map with reference to its outline at a specific tidal stage. The



(Courtesy of U. S. Army Coastal Engineering Research Center)

Fig. 33. Typical grid pattern of hydrographic survey plot, with dip lines perpendicular to shore and strike lines intersecting approximately at right angles

locations of tidal stations within the priority areas should be determined and plotted. If none are located within the area or within close proximity, a gage should be installed prior to the survey. Bathymetric data without an accurate datum would prove virtually worthless.

146. Ideally, a permanent survey vessel will be provided in the TO not only for the short-term type investigation described in this report but also for continuing hydrographic operations. If not, additional time must be made available so the surveying equipment can be adapted to the space arrangement of the available vessel. The installation of each system must be compatible with that of the others if optimum efficiency is to be achieved. The desired installation arrangement of each of the systems recommended for this investigation is detailed specifically in the appropriate operation manual. For example, the sparker array sound source must be towed 18 in. below the surface and behind the boat approximately 35 ft from the propeller. The hydrophone array, which receives the reflected acoustic signal, should be towed 8 ft below the surface and 70 ft from the propeller on the opposite side of the vessel. The vessel is limited to a maximum speed of 5 knots. The hydrodynamically designed fish containing the side-scan transducers should be towed alongside the vessel at a distance above the bottom equal to 10 to 20 percent of the range scale in use. The recorder, transceivers, and gyro must be operated in the vessel cabin under specified temperature controls. The Doppler sonar navigation system must be installed in the forward portion of the cabin in order to maintain continual rapport between the boat and sonar operators. However, if the sonar system is equipped with a left-right off-course indicator on the vessel's control panel, the installation of the sonar system inside the cabin becomes less critical.

147. Prior to the actual survey, the traverses are manually transferred to the plotter chart. Scale is an important consideration because the plotter sheets are restricted in size. It may be that several plot sheets will be required to cover a priority survey area, but a single sheet should suffice for a day's operation. The scale factor must be correlated with the bathymetric profiler since it is desirable

to make direct correlations and transfers of information from the record of one system to the other. An electrically stimulated event marker is triggered by the positioning system to place a vertical mark at desired horizontal intervals on the bathymetric record. Care must be taken to properly orient the plot sheet.

148. Doppler sonar systems require no shore-based control points, but they do require accurately positioned reference points within the survey area. Ideally, this control will be known at the starting point of the survey. If not, the point of departure can be arbitrarily assigned and precisely positioned at a later time. Since the Doppler system utilizes these reference points only as the basis for the computation of distance and bearing, knowledge of their precise locations at the time of survey is not a vital requirement. Either the dock from which the survey is conducted or permanent navigational aids in the survey area normally can be used as the reference points for this type of survey.

149. As the boat proceeds along the line of survey, the Doppler positioning system constantly computes velocity and distance along the desired course and at right angles to the desired course. These measurements are synchronously fed into an interfaced data processing unit, e.g., a calculator or mini-computer which has been programmed to convert the values to digital coordinates for the interfaced X-Y plotter. The plotter in turn marks the graphic plot at the appropriate point determined from the calculated X-Y coordinates. Points can be plotted at a rate of approximately one per second, but during a reconnaissance type survey, this level of accuracy is not required. The positioning system is programmed to instruct the recorder unit for the bathymetric profiler to record an event mark at a specified horizontal interval, e.g., 100 ft. This makes it possible to correlate directly between the two systems at any chosen time during the survey and also provides a simplified means of correlating the data during the subsequent office analysis phase of the study.

150. Under ideal operating circumstances, it is desirable to spend at least a full day checking the various systems under survey area

conditions to ensure that they are functioning at peak efficiency and that they are calibrated for optimum sensing of the operational environment. For instance, water depths, bottom composition, salinity, and bottom configuration may individually or in concert impose various effects upon the operationability of the surveying systems. The sparker's operation is dependent upon the discharge of stored electrical energy in salt water between electrodes evenly spaced on a line array or streamer. A spark is generated and creates a high-intensity pressure pulse resulting in an acoustic signal that travels through the water and into the subbottom formations at a given frequency. The magnitude and duration of the initial pulse are functions of the voltage level and stored energy in the capacitor banks. By varying the voltage and stored energy levels, it is possible to achieve various degrees of penetration and resolution. The sparker must be operated in salt or brackish water having a minimum salt concentration of 15,000 parts per million (ppm) to generate the required spark between the electrodes. In water bodies such as estuaries where the salt concentration may be less, modification of the sparker array is required. The sparker is modified by enclosing the entire array in a brine-filled, sealed polyethylene hose. The modified array may prove hydrodynamically more cumbersome than the unencapsulated version, but it should not exert any appreciable inhibiting influence upon the towing operation. These adjustments, as well as those to the other systems, should be made prior to the initiation of the survey to ensure compatibility of the systems with the operational environments.

151. Since it is important that all phases of the hydrographic survey be related in time, a digital electronic clock should be utilized. In addition to providing a means of accurate synchronization between surveying systems, the clock also provides the means of relating the surveying to relevant physical changes in the environment, viz. tidal fluctuation. In some areas of the world, tidal ranges within a 24-hr period may exceed 20 ft. Inability to relate bathymetric data to tidal readings in real time could result in highly inaccurate depth computations. Hydrographic clocks can be automatically timed to give signals at specified intervals or even interfaced with the bathymetric

recorder to produce an event mark at regular intervals. For less demanding surveys such as the type described in this report less sophisticated means of determining time, such as the manual transfer of time values to the graphical records, are adequate. A simple consecutive numbering system can be utilized whereby the records of the various systems can be manually marked periodically with identical digits. However, because this places an additional demand on available personnel, an automatic electronic device should be utilized if possible. Electronic or manual time provides a means of correlating the various survey records.

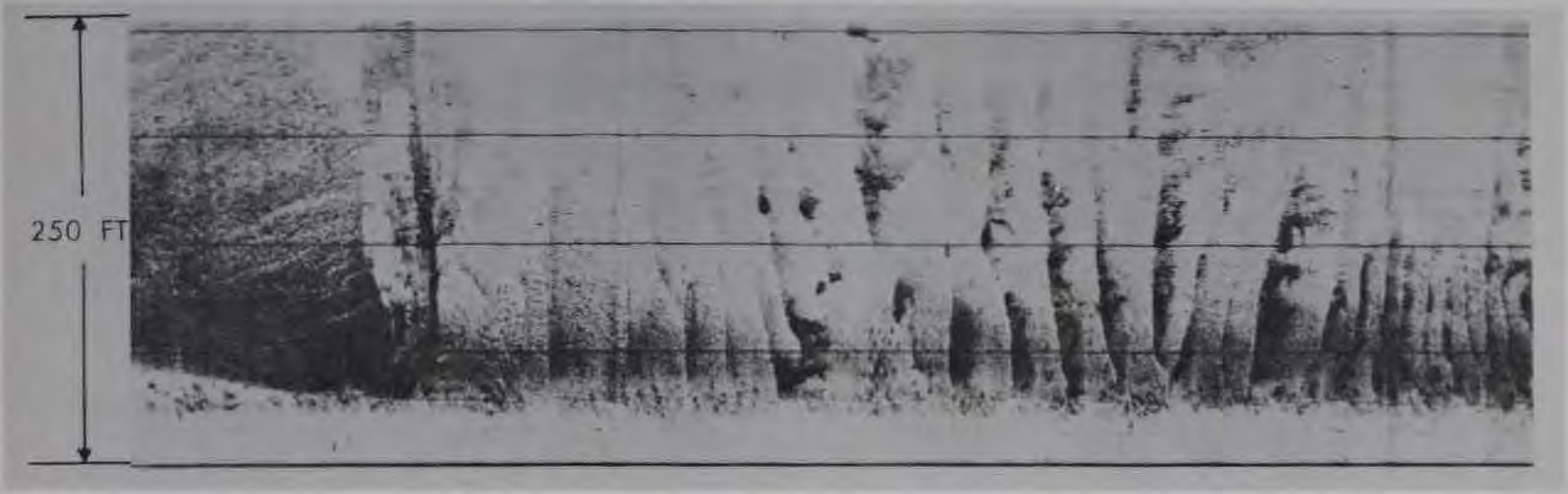
152. In conducting the survey, it would seem most advantageous to run the strike lines first, i.e., those that parallel the shoreline to depths out to 50 ft or more of water. From a navigation standpoint, running these lines is relatively simple, as all that is required is to keep the vessel approximately on course. An advantage in running the strikes first is that it permits the ASP operator (the operator need not be a geologist but must have at least a working knowledge of the local geomorphology to enable interpretation of the acoustic records) to examine the records and gain a general impression of the complexity of the subbottom stratigraphy. Examination of the strike records will quite often dictate shifting or relocation of the dip lines, i.e., those perpendicular to the shoreline, to ensure coverage over questionable or anomalous features or sequences. Such features, for example, might later be identified as filled channels, faults, boulders, relict mangrove swamps, or shell and coral reefs, all of which would represent questionable locations for pier construction. It should be stressed that the dip and strike lines are not to be considered sacred. When local and current intelligence gained during the survey dictates that relocation would prove advantageous to the conduct of the investigation, then necessary changes should be made. These changes, e.g., relocation of profile lines or shore-based positioning equipment, will undoubtedly impose additional navigational hardships upon the vessel personnel, but experience has demonstrated that major changes in the survey format are quite possible. The number of strike lines must remain flexible because

the dip of the bottom may vary significantly from one locale to another. In some instances, the water may be 50 ft deep at a distance of less than 1 mile from the shoreline, while in others, distances of 5 miles from the shoreline may be exceeded before the 50-ft depth is evident. The spacing of dip lines is almost equally uncertain, with the apparent homogeneity of the subbottom stratigraphy the controlling factor. Obviously, in seemingly unchanging conditions, a maximum spacing, e.g., 1 mile or greater, should suffice. However, in highly complex or uncertain subbottom configurations, dip lines should be spaced no greater than 1000 ft apart. A more leisurely and comprehensive examination of the acoustic records in the office may indicate that it is necessary to run additional lines for several reasons: (a) to ensure that the previous records are directly attributable to stratigraphic conditions rather than to an electronic irregularity in the system or background noise in the water during the survey; (b) to delimit the subaqueous extent of any questionable or anomalous horizon that proves to be authentic; and (c) to acquire additional stratigraphic knowledge to enable more confident and definitive selection of sites for later coring. In running the dip lines, the draft of the survey vessel rather than inherent limitations in the surveying systems is the controlling criterion as to minimum operating depth. If the vessel draws 5 ft of water, it should cautiously negotiate depths of less than 10 ft due to the presence of offshore bars and shoal. Determining the turning point of the dip traverses is the responsibility of the vessel pilot who by referral to the vessel's fathometer is continuously aware of decreasing water depths.

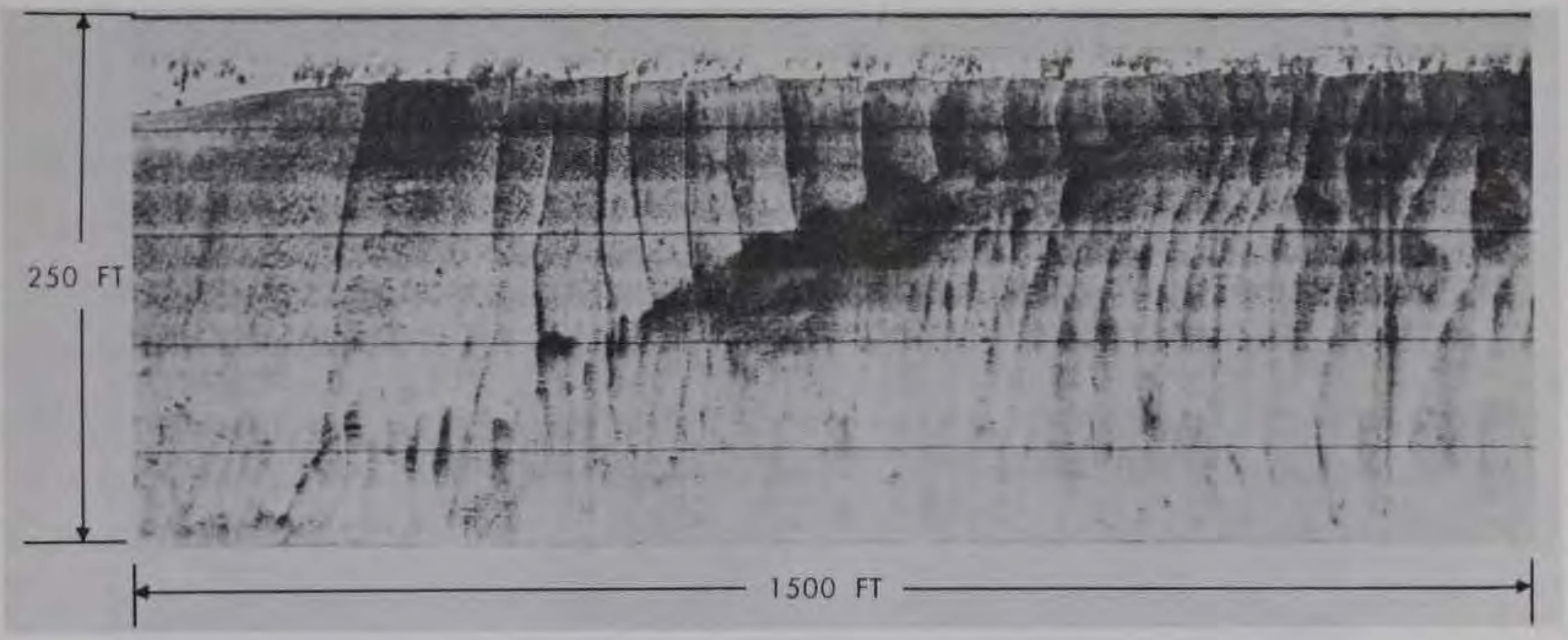
153. It is highly desirable that the side-scan sonar be operational along both the dip and strike traverses. The side-scan sonar is capable of scanning both to the port and starboard sides of the vessel simultaneously. The records from both can be portrayed simultaneously on a single recorder. This arrangement would require an additional recorder for the ASP system. An additional recorder is undesirable and actually unnecessary because the ASP and side-scan records can be synchronously portrayed on a single record, although loss of either the port or starboard side-scan records is necessary. A directional switch

on the side-scan sonar permits sensing in either a port or starboard direction, leaving the option to the discretion of the operator. Continual scanning to starboard, for instance, on both ingoing and outgoing dip lines spaced 2000 ft apart should provide complete bottom coverage.

154. The side-scan system is capable of resolving minute (less than 1 ft) bottom features. Thus, in many instances it provides information not only as to the physical configuration of the bottom but also as to compositional variations. Sandy bottoms revealed by repetitious ripple patterns (see fig. 34), bottoms littered with boulders and rock



a. Port side



b. Starboard side

(Courtesy of EG&G International, Inc., Geodyne Division)

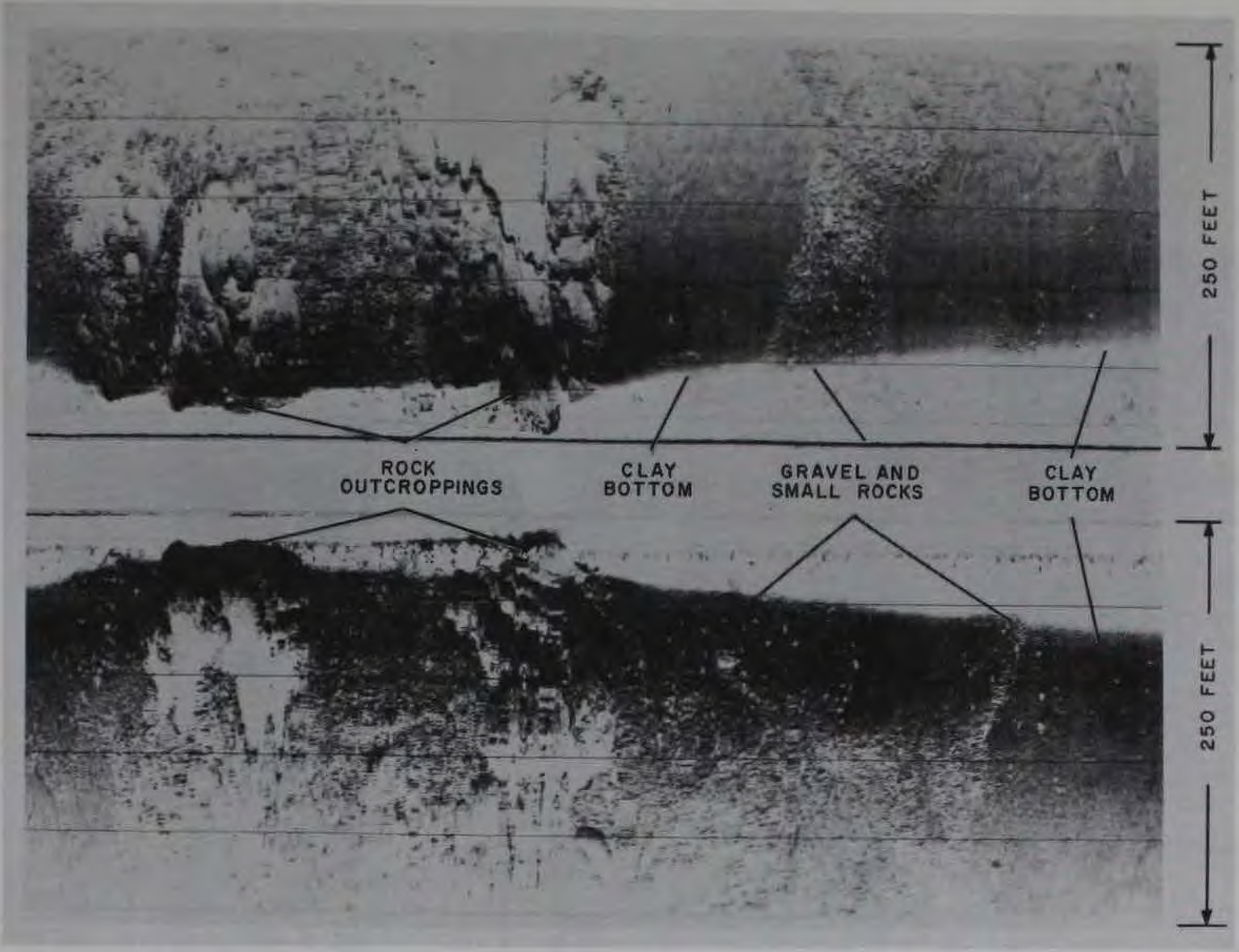
Fig. 34. Large sand ripple patterns revealed on both the port and starboard channels of a side-scan sonar system

fragments, bedrock bottoms, and shell and coral surfaces are all discernible on side-scan records. The reliable prediction of rock or soil conditions on the bottom minimizes laboratory analysis and provides a more comprehensive picture of the full compositional range of bottom conditions.

155. An equally important role of the side-scan sonar is the detection of debris, rock pinacles, large boulders, reefs, and relict man-made structures that represent serious hazards to navigation and that, in many cases, are not sensed by the bathymetric profiler. The side-scan records should be monitored during the surveying operation and significant features noted. Additional passes should be made over bottom features not readily identified. Bottom conditions revealed on the side-scan records often provide useful clues that facilitate the interpretation of the subbottom acoustic records. Figs. 35-38 are examples of typical side-scan records of various natural and man-made features.

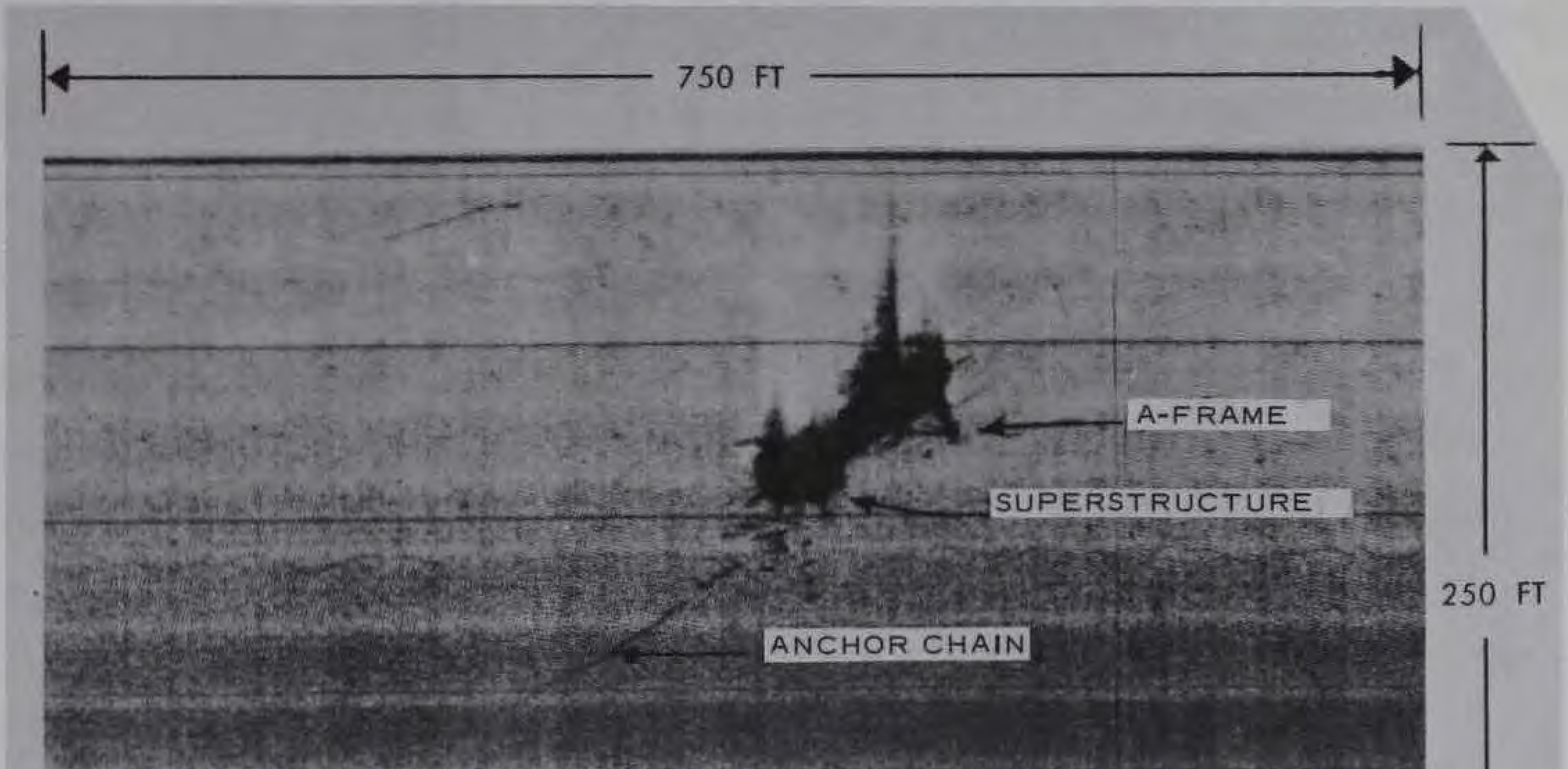
156. Sufficient bottom samples should be taken along the survey to positively identify bottom composition. As stated, assiduous examination of the side-scan records during the survey can provide valuable clues and thus reduce the required number of samples to a minimum. Samples should be stored in glass jars or plastic containers and their origins marked at the appropriate point on the bathymetric profile.

157. It should be stressed that the procedures for the conduct of the site investigation described in this text are not in adequate detail for performing any but a reconnaissance type of survey. Hydrographic mapping, establishing survey control, and detailed descriptions of standard items of hydrographic equipment are discussed in required detail in previously cited references (paragraph 136). The procedures must remain flexible due to changing environmental conditions. Surveying equipment unique to this report has been discussed in general terms to include numerous competitive commercial types. Certain systems have been selected that represent at least the equivalent of the best available systems. The requirements of the site investigation discussed in this text are restrictive, necessitating the generation of a hydrographic systems package that should be considered as unique to this study and thus not



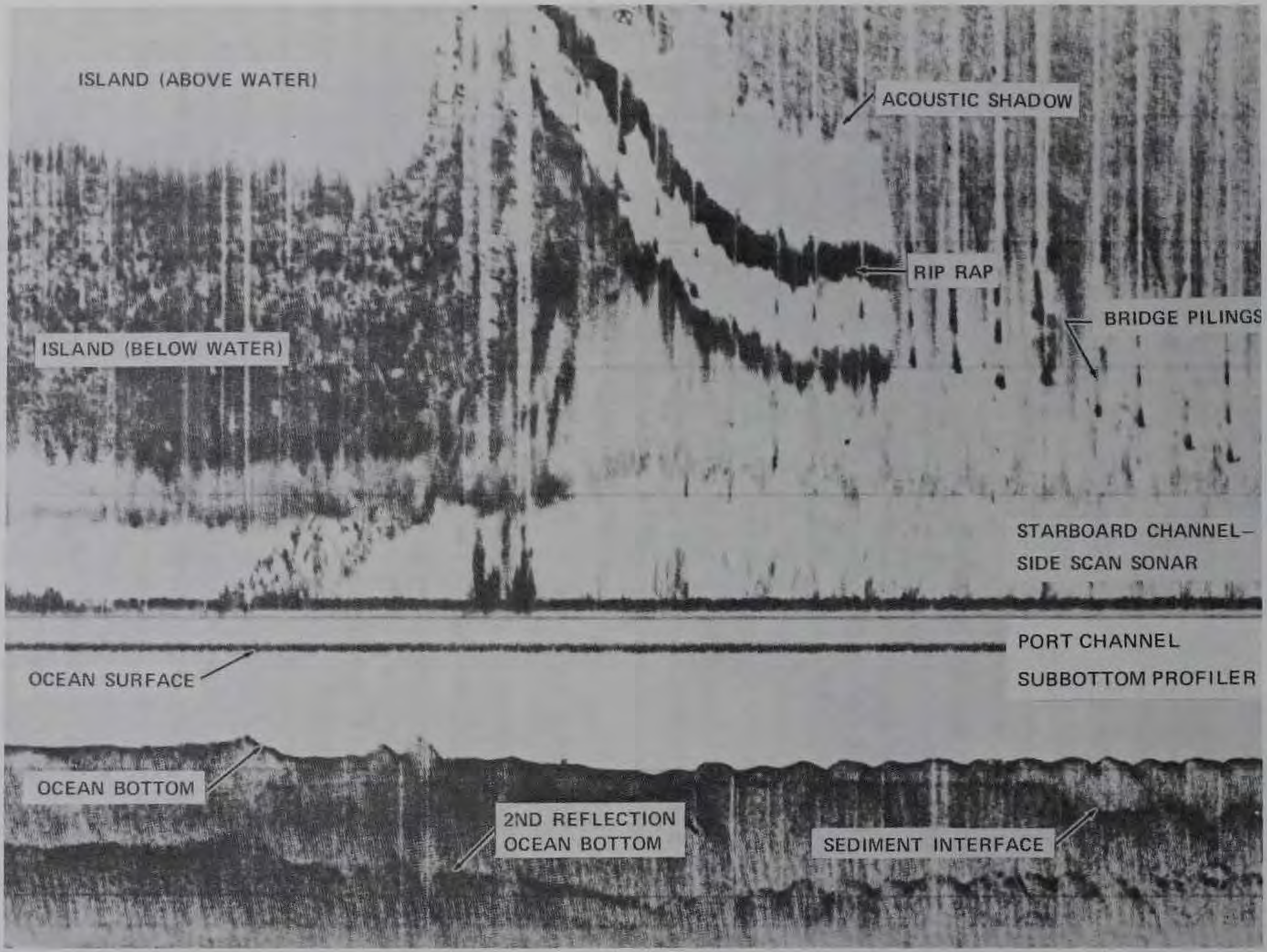
(Courtesy of EG&G International, Inc., Waltham, Mass.)

Fig. 35. Dual side-scan records of typical natural bottom conditions



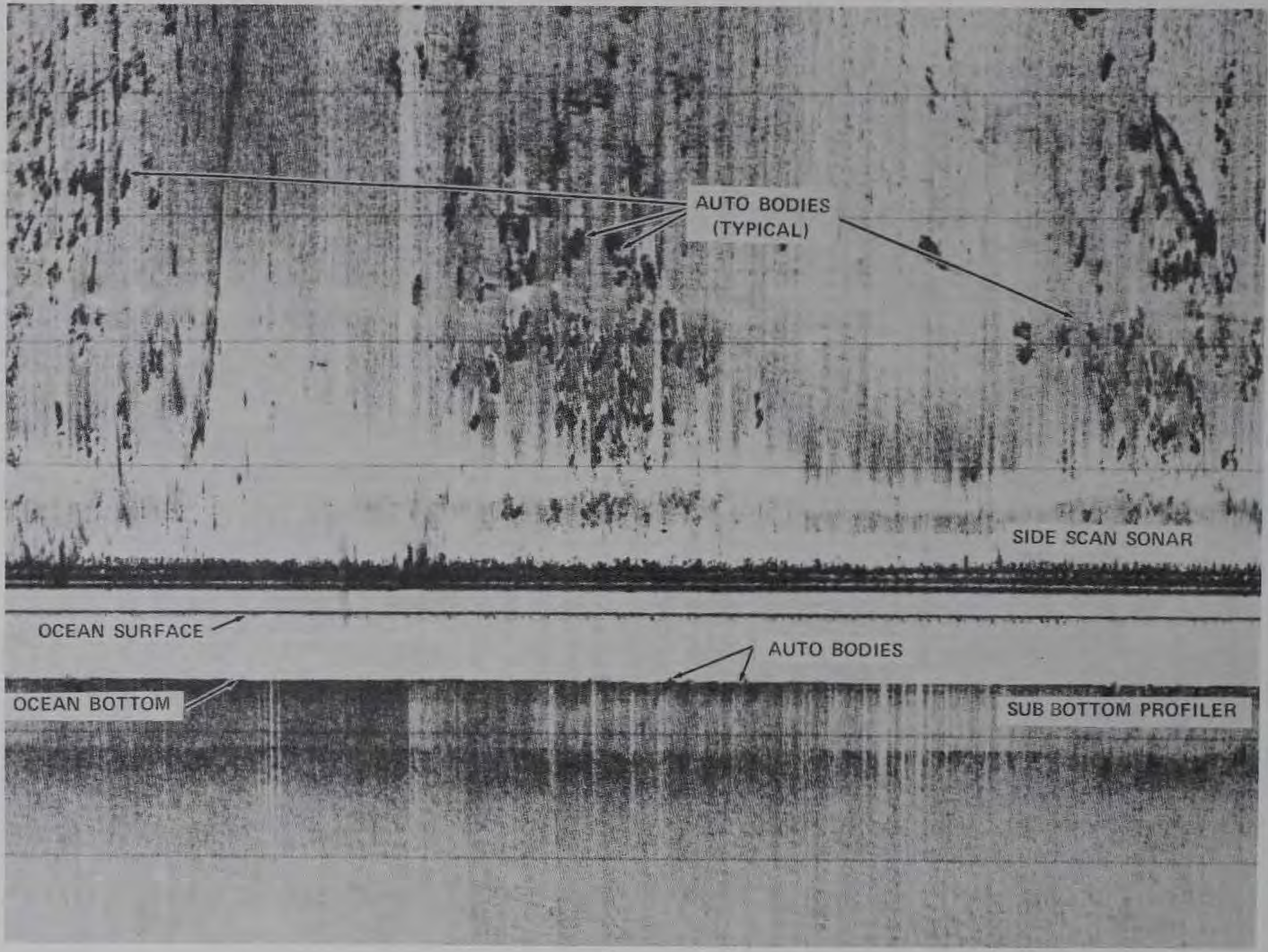
(Courtesy of EG&G International, Inc., Geodyne Division)

Fig. 36. Side-scan sonar record of sunken barge



(Courtesy of U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Va.)

Fig. 37. Simultaneous side-scan and subbottom records portrayed on a dual-channel recorder



(Courtesy of U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Va.)

Fig. 38. Automobile debris revealed on side-scan sonar and subbottom profiler records and portrayed simultaneously on a dual-channel recorder

necessarily applicable to other types of investigations.

158. Interpretation of survey data. Interpretation of the hydrographic records should be initiated during the actual survey and concluded a short time after the survey is completed. The following paragraphs discuss some of the procedures that are considered of primary relevance to the investigation:

a. Survey routes. All significant features representing an aid or a hazard to navigation either existing and confirmed or not before recognized should be noted and transferred to the base maps. The actual routes of the survey, i.e., the dips and strikes, as well as additional traverses should be transferred to the base maps. The adequacy of coverage within the priority area should be immediately determined. Deviations from preplotted routes due to navigation difficulties or to judgments made from examination of the records during the actual survey may result in areas inadequately covered. However, any decision for additional surveying should benefit from a comprehensive examination of the records.

b. Correlation of records. Subbottom, bathymetric, and side-scan records should be accurately located in relation to the survey routes protrayed on the plot sheet. The three survey coverages should be accurately correlated with each other and indexed in terms of the dip and strike survey lines. Points of intersection of dip and strike traverses should be noted and cross-indexed to facilitate comparisons of records during the interpretation phase of the study.

c. Interpretation of records. The investigation in its simplest terms can be divided into separate surveys, i.e., the bottom investigation and the subbottom investigation. The purposes of each have been previously discussed in sufficient detail. The bottom investigation is principally for the purposes of navigation and determination of suitability of sites in terms of bottom materials, water depths, and bottom slopes for the construction of port facilities and the determination of dredging requirements. The subbottom investigation is devoted exclusively to the adequacy of the soils underlying the bottom for pile-supported structures or removal by dredging. The bottom investigation is accomplished through the comprehensive examination of background information, the reduction and interpretation of bathymetric and side-scan records, and the analysis of bottom samples. The subbottom investigation must consider the historical data coupled with the acoustic subbottom records, the core samples, and, indirectly, the side-scan sonar records. Both investigations are limited in accuracy to the effectiveness of the positioning equipment.

d. Bottom investigation. Reduction of the bathymetric profiles and adjustment to tidal readings at the time of surveying provide the basic data requirements for the preparation of a bathymetric map of the priority area. Depth determinations are made at intervals selected along the survey grids and at locations established from the navigation plots. These data are then transferred to the base map of the area. Bathymetric contours can be generated at desired intervals, with the amount of detail being dependent upon the time available for preparation and precision necessary for site evaluation. The side-scan records are then examined to determine the existence of bottom features or debris in the areas between the bathymetric profiles. The presence of all features with an order of magnitude greater than the selected contour interval must be located and identified as accurately as possible. Direct height determinations cannot be made from the side-scan records, and features of significant proportions may require resurvering. Heights of repetitive or extensive natural features should be incorporated into the bathymetric contouring. Natural features, areally restrictive, should be identified on the map as point or closed contours. Debris should be identified, if possible, and its extent and height above bottom determined. Locations of debris should be included on the final site map unless removed by salvage operations. The type of material composing the bottom should be determined and delineated as accurately as possible. The side-scan records provide valuable clues to bottom compositions, e.g., ripple patterns denote sandy material. Ideally, sufficient bottom samples should have been taken to permit verification of compositional interpretations; however, questionable areas that will require additional sampling will almost certainly occur. Accurate positioning is vital to the effectiveness of supplementary sampling. The nature of bottom materials is a vital criterion in the selection of a site for pile-supported construction and determination of the feasibility of dredging operations. The presence of rock or coral may preclude pile-driving operations, whereas very soft, organic materials may dictate additional piling footage to ensure adequate foundations. Details for the preparation of hydrographic survey maps are included in reference 10. It should be reemphasized that the techniques described in reference 10 are precision mapping techniques for the preparation of published hydrographic charts and should be modified to the extent necessary to satisfy the requirements of this study.

e. Subbottom investigation. The specific purpose of the subbottom investigation is to provide the basis for the evaluation of the soils underlying the priority area in terms of their physical properties relevant to pile-type construction. The interpretation of the ASP records coupled with the analysis of bottom characteristics revealed by the bathymetric and side-scan records and grab samples and all other hydrographic data collected in support of various requirements of the port construction will enhance the selection of an optimum site for pile-supported construction. The final step in the investigation and the final basis for the site evaluation will be obtaining cores from the anticipated foundation depths at each location.

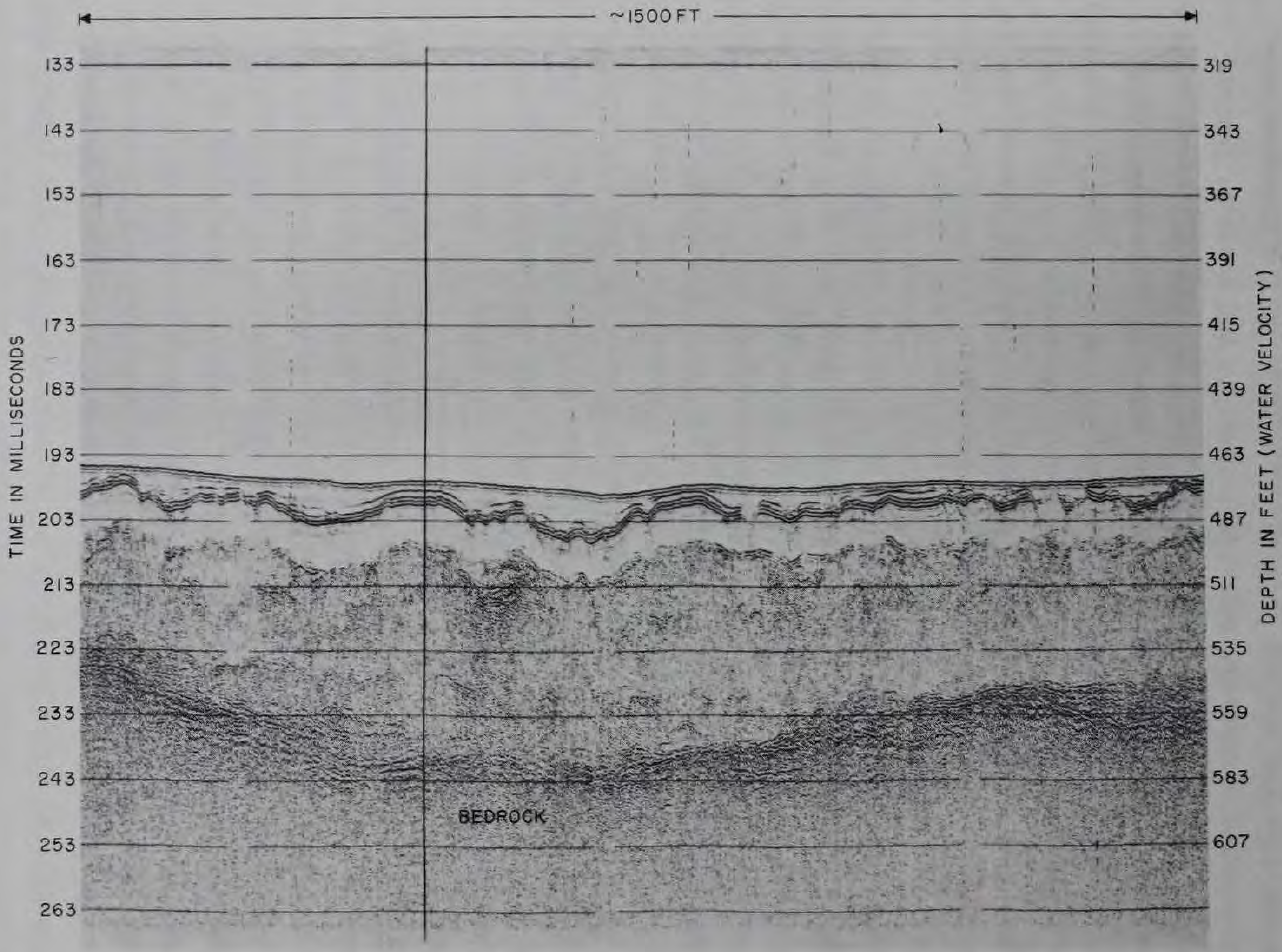
159. It should be stressed that the current state-of-the-art of subbottom acoustic profiling has not yet reached the point that direct values of the soil mechanics values relevant to offshore construction are measurable or even infallibly deducible from acoustical records. The ASP system, in this case the high-resolution sparker, generates an acoustic signal that penetrates the subbottom and reflects from subbottom horizons within the resolution capability of its signal, i.e., approximately 3 ft in thickness. Unfortunately, the reflecting horizon does not always represent a dramatic change in lithology, e.g., clay to sand, sand to bedrock, etc., but rather a change in acoustic impedance. Acoustic impedance, an inherent property of the material to reflect sound, is primarily a function of density, and subtle changes in density may result in subbottom reflections which have little or no relationship to the lithologic nature of the sediment transmitting the signal. Grain size and shape, water content, temperature, salinity, and porosity may also influence acoustic contrast and result in acoustic reflections on the ASP records. In addition, the number and thickness of the sediment horizons in which one or more of these variables is evident may result in acoustic contrast. Thus, the soil properties that are relevant to pile-supported construction may or may not produce acoustic contrast on the records. A change from sand to clay may not produce a reflection, whereas the contact between dense sand and a thicker layer of

less-compacted sand may produce a strong reflection.

160. A further difficulty arises when attempting to correlate a core log with an ASP record. Sharp contacts indicating changes in soil type on the core log are not necessarily evident on the acoustic records. Conversely, apparent layering evident on the acoustic records quite often does not appear on the core log. For general interpretation purposes, it is accepted that many of the physical and compositional properties that differentiate between sediment and rock and are relevant to this investigation will produce acoustic layering. One of the primary advantages in the utilization of continuous subbottom profiling is that it enables the interpreter to recognize bedding planes and follow them over considerable distances.

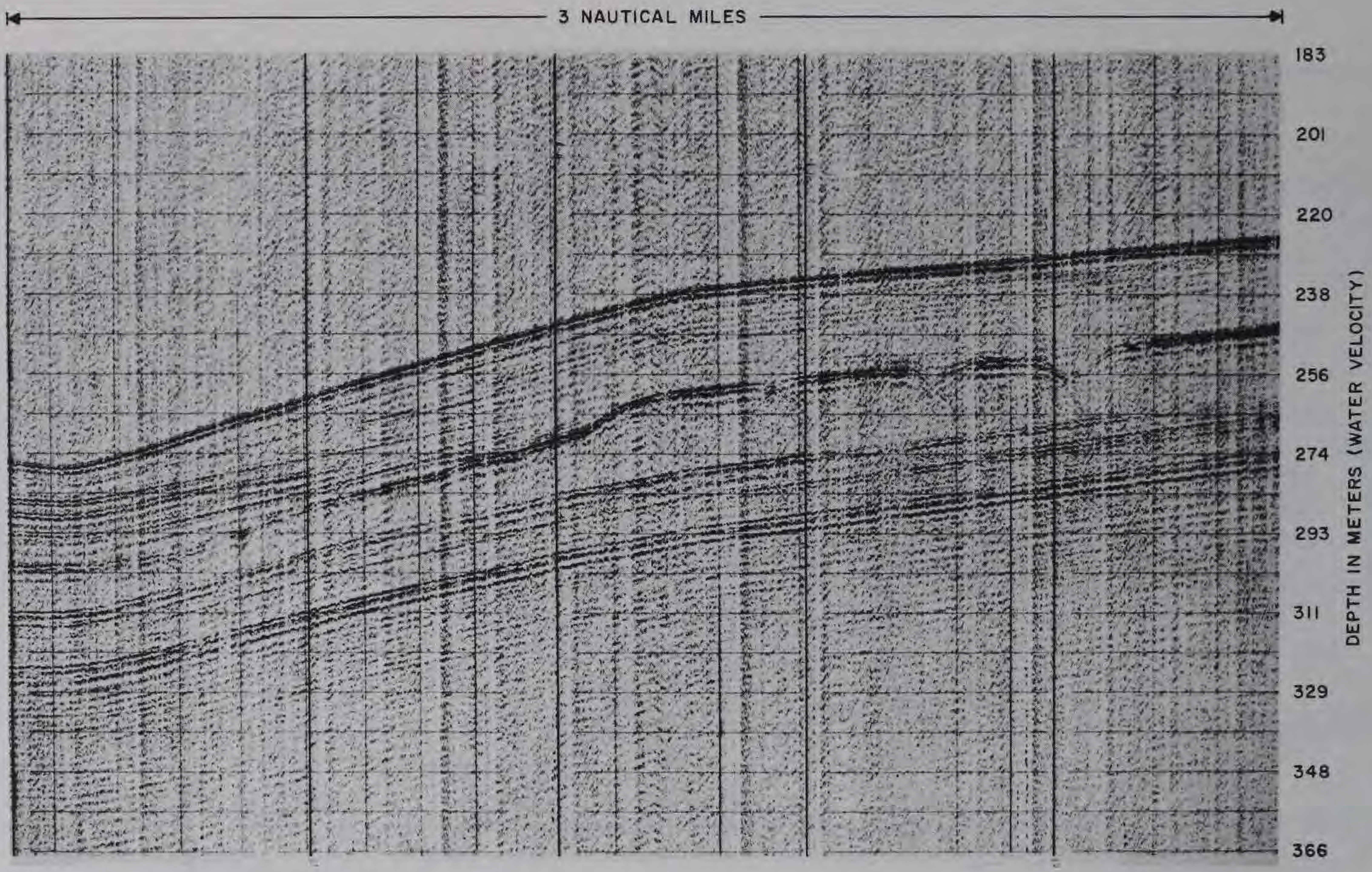
161. Through the identification of subbottom bedding, it is also possible to recognize micro or regional geologic structure. The horizontal or gently dipping top of a bedrock (fig. 39) or an erosional surface normally produces a strong reflecting surface that can be followed over considerable horizontal distances (fig. 40). Dramatic vertical offsets in otherwise consistently layered sediments provide valuable evidence of faulting. Horizontal offsets in bottom features, as revealed on the side-scan sonar records, offer additional evidence of faulting, and the two records examined simultaneously add additional credence to interpretations. The bulging of parallel layers to form a domelike structure often provides evidence of intrusive activity (fig. 41). Parabolic reflections (figs. 42 and 43) usually identify the existence of large boulders or oyster or coral reefs. Ancient filled channels (fig. 44) occurring within erosional surfaces (Pleistocene) can be readily identified. Lenticular deposits of sand, gravel, or shell are normally readily discernible on the acoustic records. Thus, although no techniques have been developed that permit the classification of layering revealed on the acoustic records in terms of the soil parameters pertinent to this investigation within acceptable levels of competence, it is possible to infer the lithology of the layering by the interpretation of the stratigraphic sequences and the morphological configurations.

162. The effectiveness with which acoustic records can be



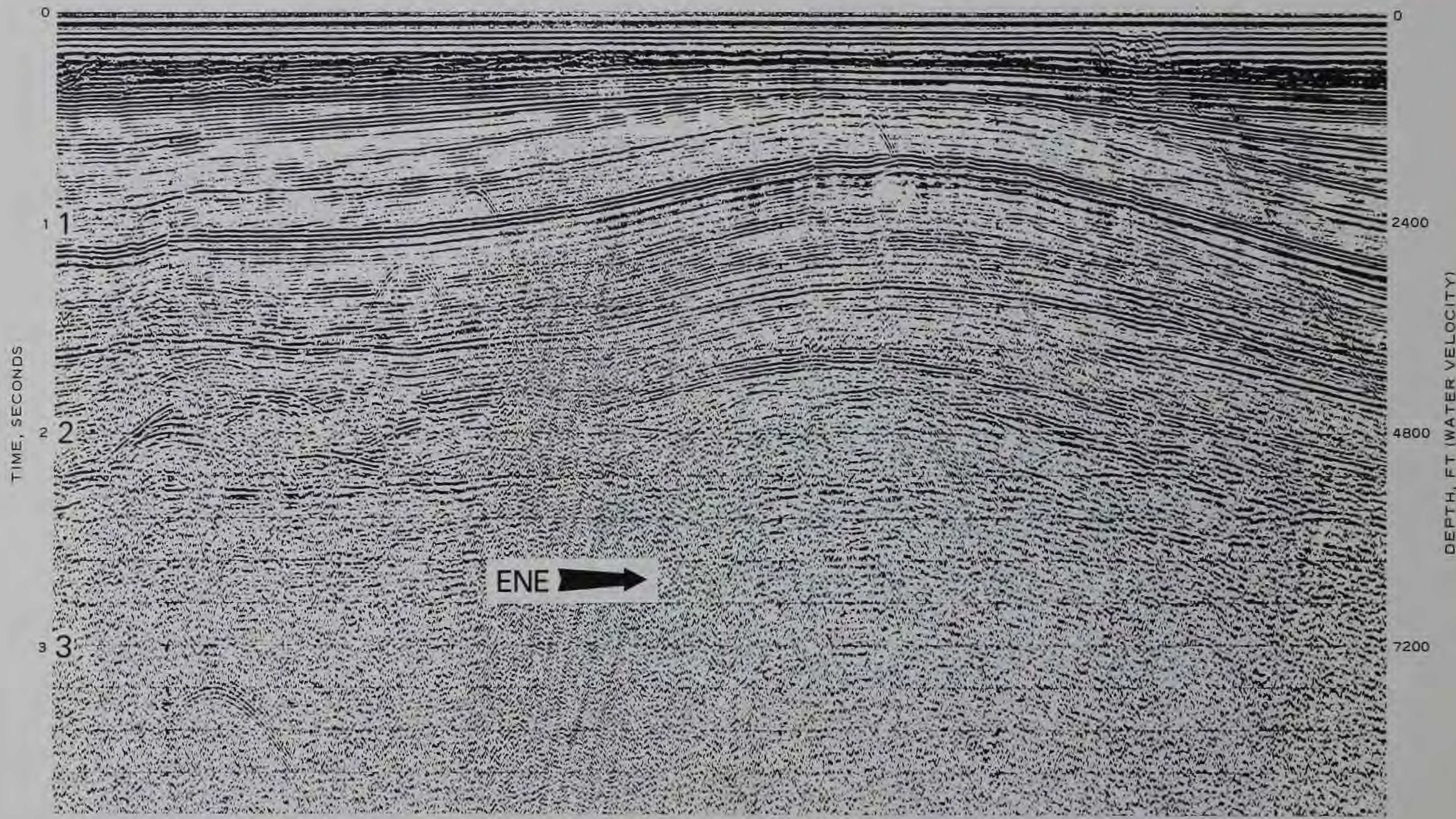
(Courtesy of EG&G International, Inc.)

Fig. 39. Top of bedrock horizon, which is a strong acoustic reflecting surface



(Courtesy of EG&G International, Inc.)

Fig. 40. Continuous more or less parallel acoustic reflecting surface extending over a distance of 3 nautical miles as revealed on an ASP record



(Courtesy of Teledyne Exploration (Geotech))

Fig. 41. Possible diapiric structure revealed on ASP record

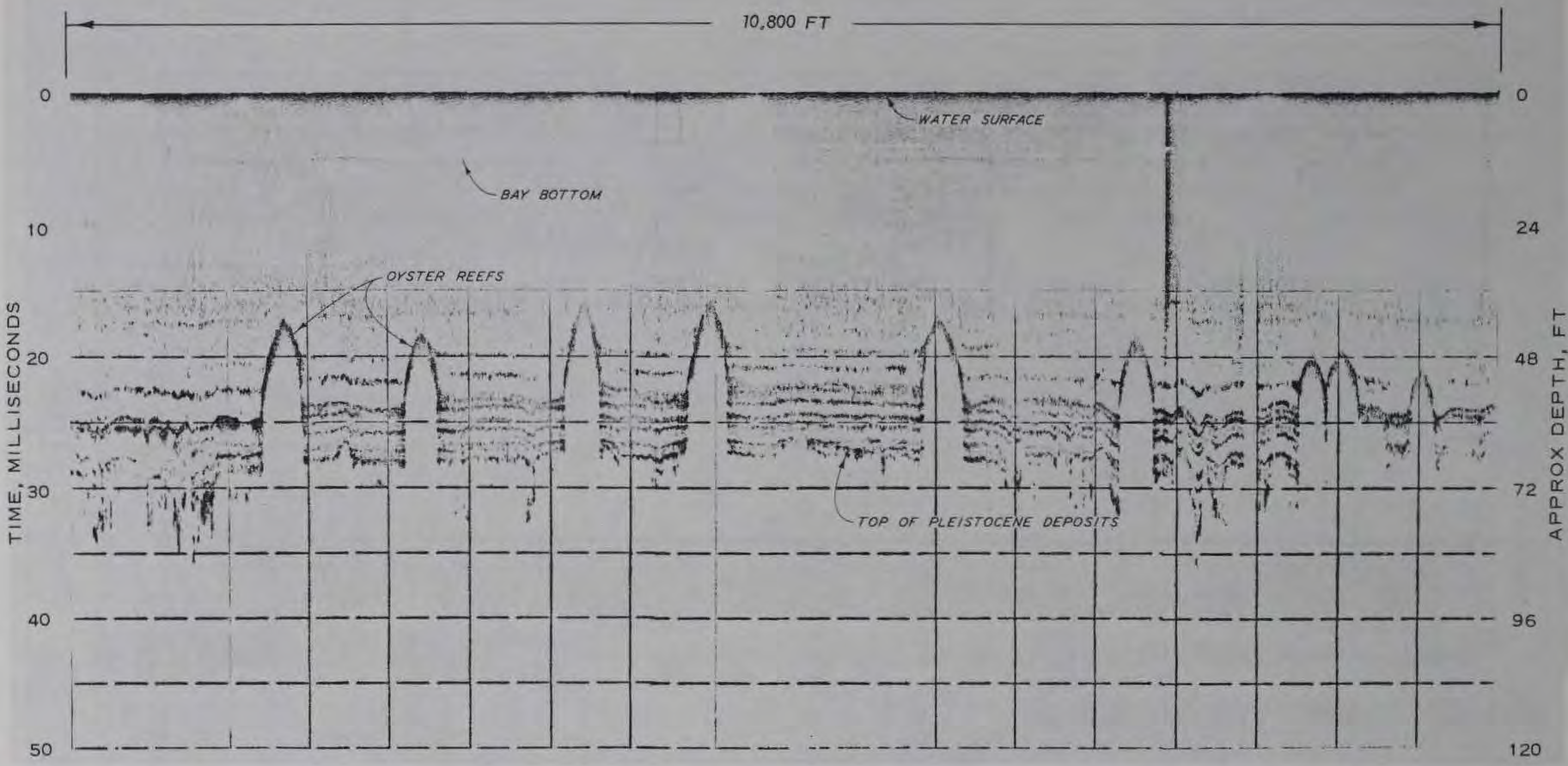
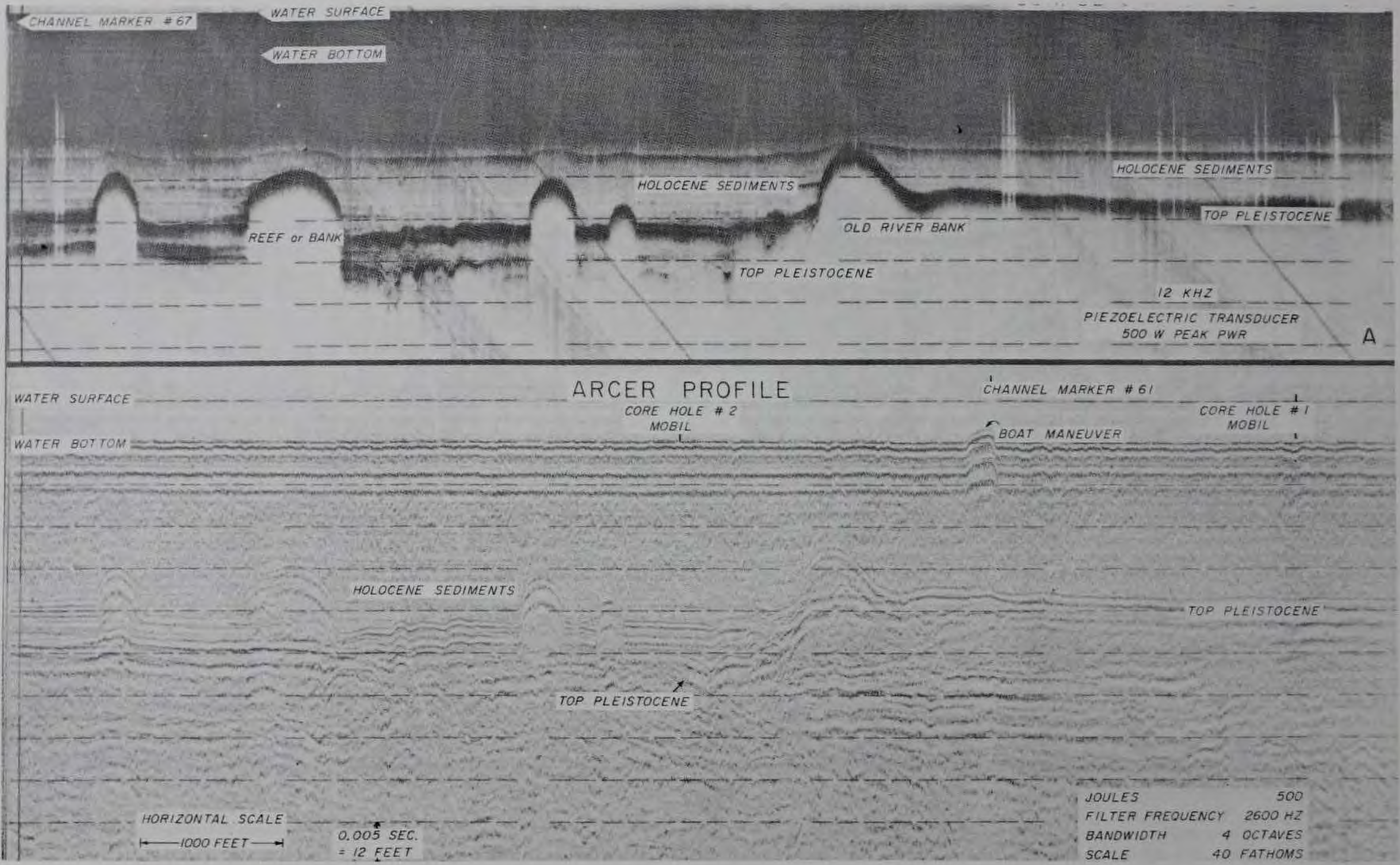
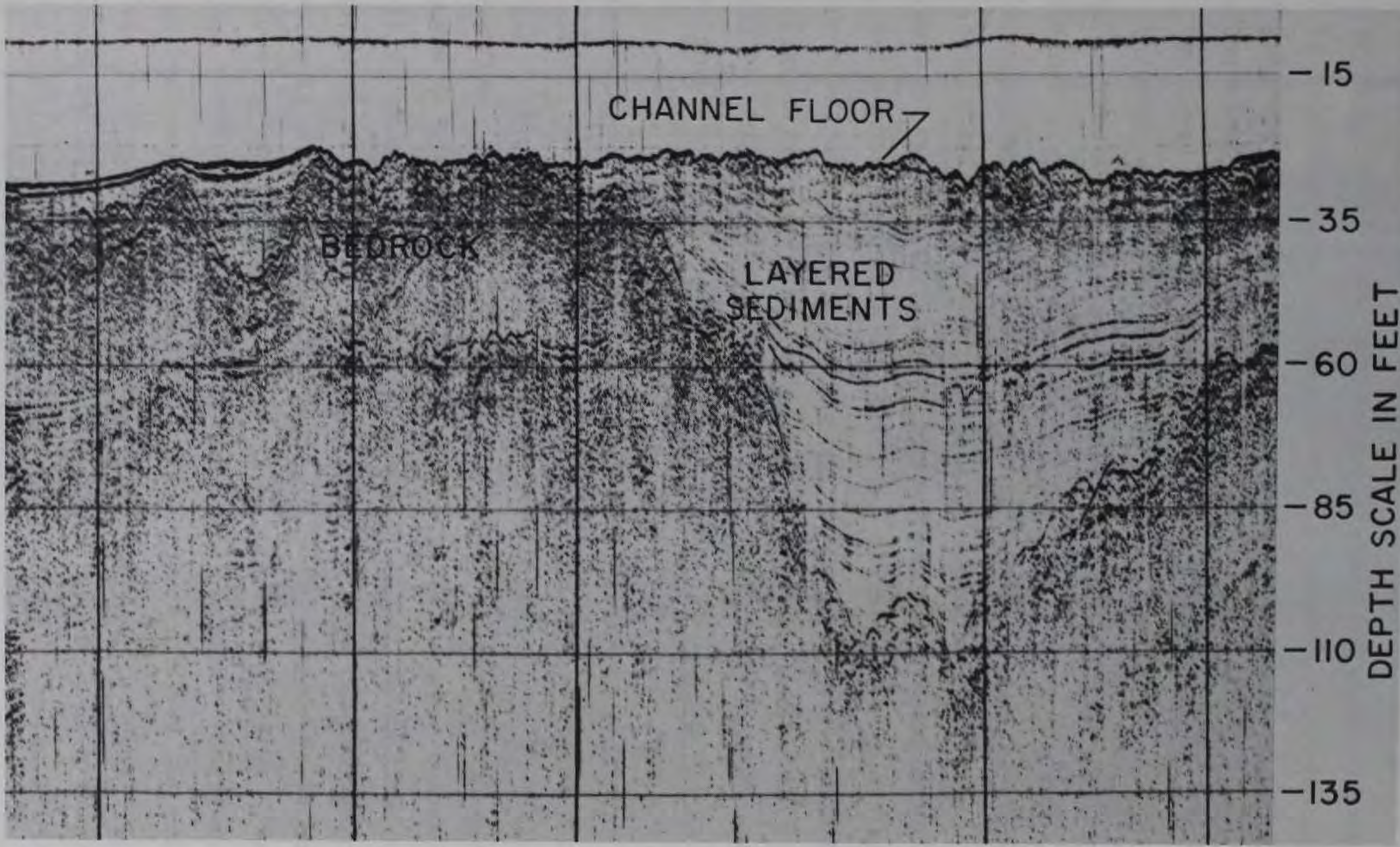


Fig. 42. Series of oyster reefs overlying Pleistocene sediments as revealed on ASP record



(Courtesy of Southwest Research Institute, Corpus Christi, Tex.)

Fig. 43. Parabolic subbottom reflections revealed on two separate ASP records taken simultaneously

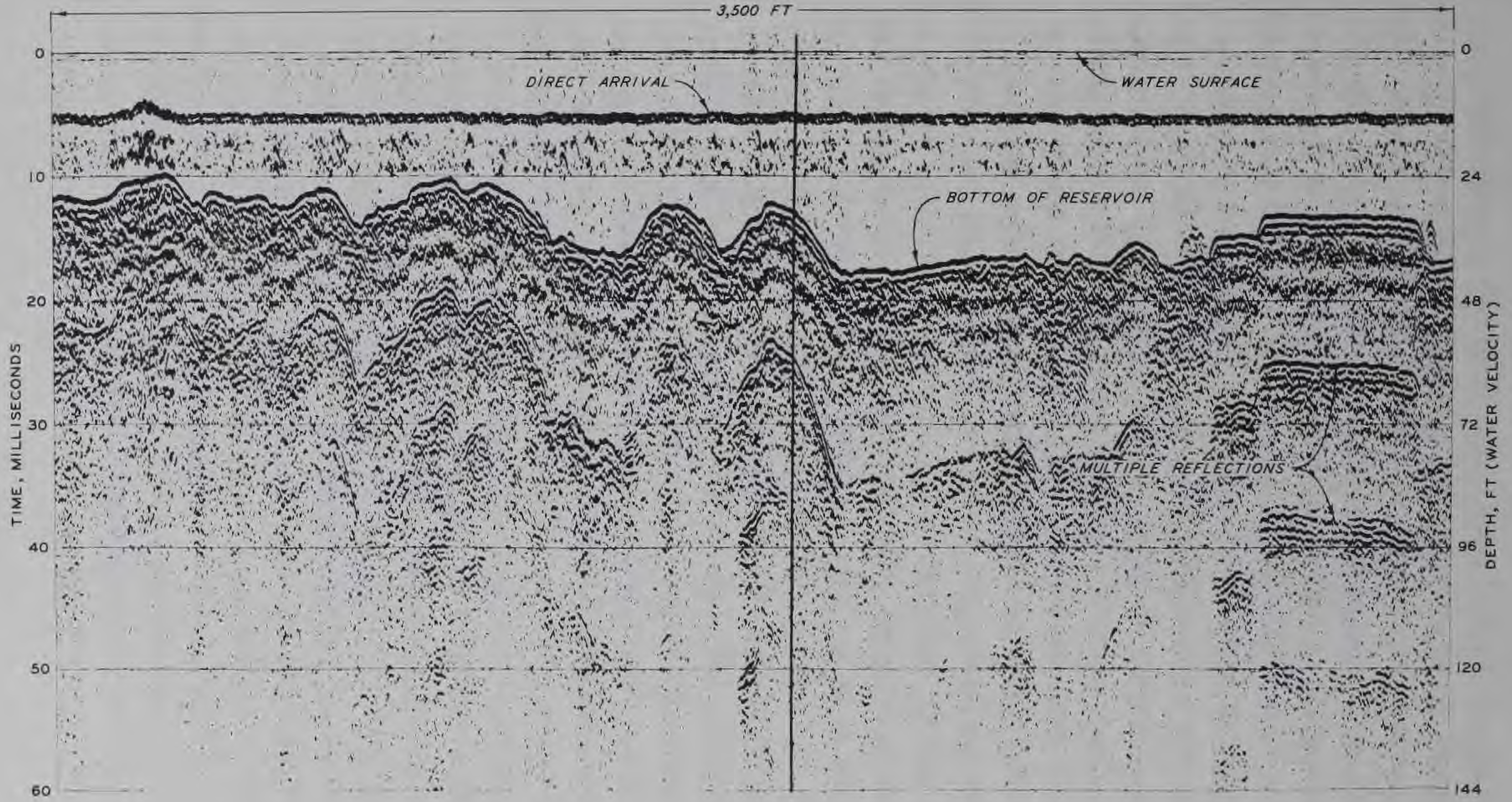


(Courtesy of EG&G International, Inc.)

Fig. 44. Layered sediments in ancient river channel flanked by bedrock

interpretated must be at least partly attributed to the expertise of the interpreter. Apparent layering may be discernible on acoustic records to all who examine them, but the significance of this layering requires at least a fundamental knowledge of the recent geological history of the area being surveyed. This historical information should be provided as part of the background information collected prior to the initiation of the survey. All coastal environments may be classified in terms of their geomorphological development. Each type, such as a prograding shoreline overlying shallow Pleistocene sediments, is characterized by a classical sequence of landforms and associated soils. These landforms can be described in terms of their geometry, soils, distribution, and association with other landforms. These landforms are ultimately destroyed or buried under more recent sediment with the passage of time. Many, such as beach ridges, shell and coral reefs, entrenched valleys, lagoons, and mangrove swamps, can sometimes be recognized on the acoustic records. Since each landform is characterized by a specific soil type or an association of soils, e.g., beach ridges may be sand or shell or mixtures of the two, it is possible to make reasonably confident predictions of its lithologic character.

163. Care must be taken in the interpretation of acoustic records not to confuse multiple reflections of the bottom (see fig. 45) with subbottom layering. Multiple reflections occur when the acoustic signals encounter the bottom, are reflected back to the surface, and then reflected downward again. This process may be repeated, with as many as six or seven reflections of the bottom appearing on the record. The multiple reflections may result from a number of factors such as water depth, nature of the bottom material, and power levels acting singularly or in concert. Multiple reflections are readily recognizable in crudely parallel arrangement downward from the initial signal. The first appears at twice the depth and slope of the bottom, and each succeeding reflection is displaced downward a distance equal to the depth of the water. Successive reflections may completely mask the shallow subbottom layering. Quite often, adjustment of power levels, gain controls, and transducer depths may eliminate or partially remedy the problem, so



SOURCE: REFERENCE 29
SYSTEM: EG&G HIGH-RESOLUTION BOOMER
LOCATION: WALTER F. GEORGE RESERVOIR, ALA.-GA.

Fig. 45. Multiple reflections of the bottom appearing on ASP record

remedial measures should be initiated at the earliest opportunity.

164. No amount of discussion can prepare the interpreter for all of the possible acoustic signatures that may appear on the records. Instruction and experience should enable the interpreter to make almost immediate evaluations as to whether the signals appearing on the records are responses from natural conditions or are the result of some inherent operational malfunction of the system itself. Recognition of acoustic layering does not necessarily imply changes of relevant significance in soil properties. However, the sequences and attitudes of the layering often identify geologic structure and landforms, thus allowing reliable predictions of soil characteristics. Anomalous features on the records not definitely attributable to natural or mechanical causes must be identified if they are within the site area. Poor-quality and questionable records may dictate resurveying of certain areas if time permits.

165. Coring operations. The final field activity associated with the site investigation is the coring operation. Each potential site for the pier facility must have a minimum of one core to provide a conclusive means of evaluating the soil properties, i.e., shear strengths, density, porosity, consolidation characteristics, grain-size distribution, organic content, moisture content, etc. Since one core hole per site appears to be the limit within the time frame imposed for the investigation, utmost care must be taken to ensure its most advantageous location. The ultimate selection of the core hole site must result from a comprehensive examination and evaluation of all the data that have been collected and assimilated during the investigation. These include not only the hydrographic data but topographic, climatic, and logistical data in support of port facility requirements. The examination of the hydrographic and acoustic records represents merely the final step in establishing the core location after all of the other site requirements have been satisfied.

166. Unfortunately, there are apparently no expedient innovations in the art of offshore coring that can be applied to the requirements of this investigation. However, refinements have been made in techniques that can be applied to coring operations. These will be incorporated,

where practicable, in the brief discussion that follows.

167. It should be reemphasized that the selection of the core site should result from an examination of the survey records. Since only one site per priority area is considered practicable within the time frame of this study, it is of paramount importance that available intelligence has been utilized as comprehensively as possible. In certain instances in which interpretation of the acoustic records has indicated that the subbottom stratigraphic and lithologic conditions are relatively homogeneous, a greater option may be exercised as to the choice of the site. This becomes important when water depths may vary in tens of feet, as coring operations should encounter far less difficulty on or near shore than in 50 ft of water.

168. A standard Army rotary drill rig capable of drilling to depths of several hundred feet may be utilized for the coring operation. The rig may be either the skid- or truck-mounted type (figs. 26 and 27). Drill pipe may be used in standard lengths of 10 ft with sufficient inside diameter to accommodate the necessary sampling tools. Bits may be either cone-type or fishtail and equipped with a center hole that will likewise pass the coring tools. A mud circulation system consisting principally of a pump, drilling fluid, and mud tanks is required. In marine operations, surface casing extending from the drilling platform into the bottom materials is required to keep sea waters from invading the hole.

169. For offshore operations, a spud-type, self-elevating barge 40 ft or more in length will be required as a stable platform for the coring operations. Either three- or four-legged types may be used, with each leg equipped with a jacking mechanism for leveling purposes. Each leg should be equipped with adequate footing to provide support under varying bottom conditions. The barge would desirably be of the self-propelled type; however, this is not essential.

170. Coring is accomplished by alternately drilling to desired depths and then lowering the coring system to the bottom of the hole on a wire line. The coring device is composed of a cylindrical sampler or core barrel attached to a driving mechanism on the wire line or cable

(fig. 46). The driving mechanism consists of weights or jars that may weigh more than 500 lb and are alternately lifted and dropped a distance of 3 to 5 ft until the barrel has been driven the required depth. Retrieval by wire line permits immediate resumption of the drilling operations. Care must be taken to accurately determine depth from the drilling platform to the ocean floor to ensure coring at the desired depths. It is wise to start the coring 1 or 2 ft above the horizon or interface to be sampled in order to avoid the possibility of drilling desired samples.

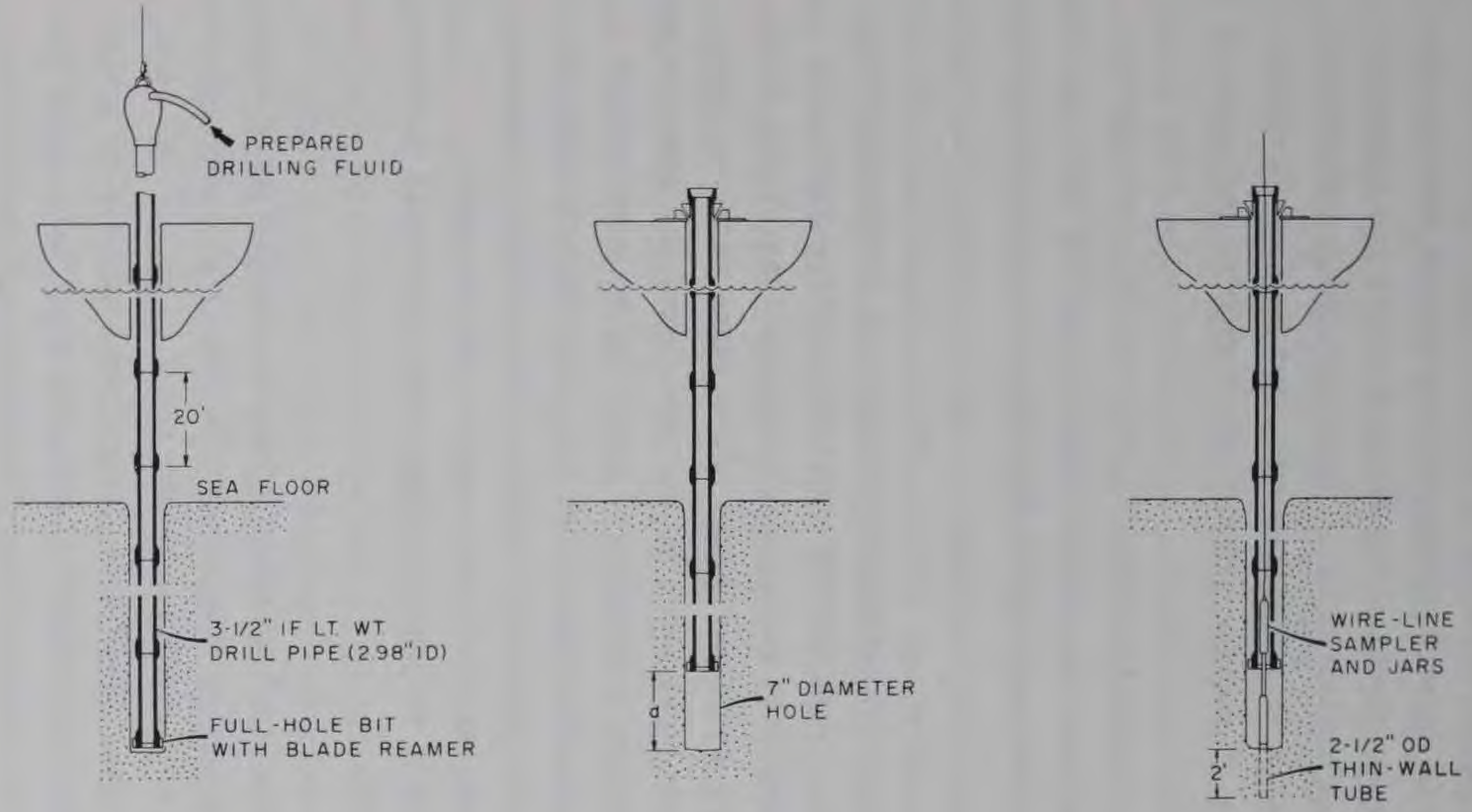
171. It should be pointed out that although cores from desired depths for laboratory classification and tests represent in-place samples, they do not represent undisturbed samples. Adequate values can be derived through laboratory tests for such parameters as grain-size distribution, moisture content, plastic and liquid limits, density, and organic content. However, the derivation of accurate shear strength values from disturbed samples is impossible since the percussion coring technique induces significant structural modification. The extent of this modification is not presently determinable, nor is the laboratory-derived test value necessarily reliable. Still the values offer valuable if not conclusive insight regarding the ability of the cored horizon to withstand pile-supported construction. Soils laboratories equipped to handle these samples are normally organic to an Engineer Command in the TO.

172. The results of the coring operation provide the final basis for selection of the construction site. These results must be evaluated along with the data resulting from the other investigations and compared with similar data from the other priority areas before final selection is possible.

Consideration of Waves in Selecting Sites

Water waves

173. This section attempts to present the problems arising from all types of water waves, problems that must be considered in the



① DRILLING

- Rotary drill pipe, partially supported by draw-works line, moves vertically with drill boat.
- Drilling fluid and cuttings exit at seafloor.
- Continuous re-supply of drilling fluid maintains a clean hole.

② BEFORE SAMPLING

- Drill pipe is set in slips at boat deck, with bit held off bottom a distance, d, which varies as boat moves with sea. Mean value of d is usually about 5-ft.
- Hole diameter is about 7 in. Some cuttings accumulate at bottom.

③ SAMPLING

- Sampler is lowered to rest on bottom, its depth monitored by wire-line revolution counter.
- Sample tube is driven to desired penetration, usually 18 to 24 in., by wire-line operation of jars attached to sampler head.

(Courtesy of McClelland Engineers, Houston, Tex.)

Fig. 46. Wire line coring operation conducted inside drill pipe

selection of a marine facility location. A discussion of the wave climate is followed by a brief indication of the effect of each type of wave on the operational characteristics of a port.

174. One portion is devoted to explosion-generated water waves, an extremely important consideration for military ports and a nonexistent problem for a normal civilian port. This phenomenon must not be overlooked in the selection of a military port that is in a TO where there is any possibility of nuclear weapons being used in the event of conflict.

175. Finally, a summary is presented that includes recommendations for work units that must be accomplished in order to make the necessary information for rapid and intelligent decisions of site selection available.

Wave climate

176. A major item of importance in selecting a marine facility location is wave climate. Wave climate consists of three types of waves: wind waves, long-period waves, and extremely long-period waves such as tsunami waves and hurricane surge. Wind waves refer to those waves generated by either local winds or distant storms and comprise the majority of the wave climate. Long-period waves may be generated by several mechanisms and are important since they have periods that may coincide with the resonant modes of a harbor or the resonant frequency of a moored ship. Tsunami and hurricane surge waves are self-explanatory. Each of these components of the wave climate is discussed in the following sections.

Wind waves

177. The wave climate of an area (primarily consisting of wind waves) is represented by a directional spectrum that yields the percentage of time that waves of a specified height range (e.g. 4-6 ft) in a specified period range (e.g. 10-12 sec) occur from a certain direction in deep water. Deep water is defined as water of sufficient depth that the bottom topography has a negligible influence on wave propagation. This depth is defined as a depth that is greater than or equal to one-half the deepwater wave length, L_o, which is $5.12T^2$ (T = wave period).

Usually, the wave climate is given on a monthly basis and summarized in yearly statistics.

178. Two methods are available for determining the wave climate of an area. The first method consists of measuring waves and computing the wave statistics. However, this really is not very practical since (a) data for several years are required to obtain reliable statistics, (b) it is difficult to measure waves in deep water due to the lack of a stable platform unless an expensive system is designed, (c) it is extremely difficult to compute an accurate directional spectrum over the entire wave climate due to the vastly different optimum spacings between wave sensors, (d) sensor reliability almost precludes an attempt to measure the wave climate over such a long period of time, and (e) the management and analysis of such a volume of data would be extremely expensive and time-consuming. Thus, it is really impractical to attempt to obtain deepwater wave climate information through a measurement program. The second method used to define the deepwater wave climate is called wave hindcasting. Through a combination of analytical and empirical techniques, one can start with weather maps (depicting atmospheric pressure distributions over the open ocean), compute the waves generated by local winds and distant storms, and then compute the characteristics of these waves as they propagate to the desired deepwater area. Thus, the wave climate is built up as these computations are made on a yearly basis. In compiling wave statistics, a minimum of three years' hindcast data is usually used; the common practice is to choose a severe storm year, a mild storm year, and a typical or average storm year.

179. There is a third method of computing wave statistics, i.e., use of visual ship observations, but data compiled using this method are not considered as reliable as data obtained using the hindcasting method. The National Oceanographic Data Center compiles ship observations as a function of location of the ship. The ocean is divided into 1-deg squares (1 deg latitude and 1 deg longitude) called marsden squares. These data are not as reliable as those obtained from hindcasting due to the limited accuracy of visual observations taken from a moored platform (the ship). It has been shown that an observer tends

to see only the highest one-third of the waves present; thus the underlying reason for a commonly used parameter in wave statistics, $H_{1/3}$, which refers to the average height of the highest one-third of the waves present.

180. In order to obtain the type of wave data needed at a proposed marine facility location, the deepwater wave statistics must be converted to a wave climate at the location in question. This involves computing the effects of a decreasing water depth (wave shoaling), the effects of the bottom topography (wave refraction), and the effects of bottom friction (usually negligible except for extremely long-period waves and shallow continental shelves).

181. The shallow-water climate can then be used to design a protective structure (breakwater) for a proposed harbor, to calculate wave forces on structures, and as input for a hydraulic model to ascertain the characteristics of the harbor itself.

182. Determination of the wind wave climate is quite an involved and time-consuming task. Deepwater wave climate data are available at sufficiently spaced stations to cover the West Coast of the United States, and wave climate data are available to slightly lesser degrees of reliability for the East and Gulf Coasts of the United States. Data are available from various sources for the European countries and to lesser degrees of reliability for coastal areas in Africa and Asia. Thus, in order to evaluate the wave climate at a proposed location for a marine facility, it is necessary to evaluate the reliability of existing wind wave data on a worldwide basis and to supplement these data with additional hindcast information. If an existing port site or harbor is being investigated, then information relative to that site can be obtained by interviewing port personnel; in some instances, recorded data may be available at the port.

Long-period waves

183. Long-period waves are commonly referred to as waves having periods ranging from approximately 20 sec to several minutes. Long-period waves comprise a very small percentage of the total energy in the wave spectrum, which includes waves with periods ranging from fractions

of a second through the astronomical tidal period of approximately 24 hr. These wave periods are important at a port because most harbors have resonant frequencies in this range, and, even though the incident amplitude of the long-period wave is small, it may be amplified several times depending upon the tendency of the harbor to resonate. The resonant frequencies of the harbor are a function of its depth, geometric shape, bottom topography, and the bottom friction.

184. Long-period waves can originate from several different sources. A few of these are: (a) they can be the leading waves from a distant storm (due to wave dispersion); (b) they can be waves generated by large-scale atmospheric pressure variations; (c) they can be the result of nonlinear interaction of two shorter period wind waves, which can produce a long-period wave with a frequency equal to the difference in the frequencies of the shorter period waves; or (d) they can be waves generated by the resonance of an offshore underwater canyon, a continental shelf, or a bay. From a practical standpoint, how long-period waves are generated is not so important. However, it is important to determine if the long-period waves persist to any degree of regularity. A long-period wave with an amplitude of 0.2 ft or more will, in general, cause a severe problem of ship surging if the resonant frequency of the moored ship is of approximately the same period (20 sec to several minutes, depending on the ship size, load, and mooring conditions).

185. Information on the long-period wave environment is practically nil everywhere in the world. The best information is probably available for the West Coast of the United States where long-period waves do persist. The East Coast of the United States has very little if any problem resulting from a long-period wave environment. Long-period waves in other parts of the world are even less well documented. Since no statistical information exists for the long-period wave environment, the best method of obtaining such information is to survey the existing ports and harbors, catalog their first several natural frequencies of oscillation, determine which are most likely to be susceptible to long-period wave problems, and then interview port personnel in an effort to establish the occurrence of ship surging.

Tsunamis and hurricane surge

186. Tsunamis are very long-period waves (usually 5 to 30 min in period) that are caused by a displacement of the ocean bottom due to seismic activity. Ports around the entire Pacific Ocean are susceptible to tsunami waves; however, the effects at different harbors vary considerably due to the local bathymetry from the continental slope shoreward and to the direction of approach by the tsunami. Although tsunamis occur rather infrequently, there is probably enough documented evidence in the more populated areas to ascertain if any area is suceptible to tsunami damage. Ports and harbors bordering the Atlantic Ocean have practically no problem from tsunamis due to the lack of active seismic régions around the periphery of the Atlantic Basin. Analytical methods are being developed to determine the susceptibility of an area to tsunami damage. It is anticipated that in the very near future such computations can be made with a relatively high degree of confidence.

187. Hurricane surge (or typhoon surge) is more common than tsunami surge and presents a problem on the East and Gulf Coasts of North and Central America and the Eastern and Southeastern Coasts of Asia and islands in that area of the Pacific. The occurrence of hurricanes and typhoons is fairly well documented (especially in the United States), and the frequency of occurrence of various intensity hurricanes and the resulting waves and hurricane surge can be calculated. It would be considerably beneficial to the site selection process to catalog all existing data on hurricanes and typhoons in order to assess the probability of operational downtime for each year and the probability of extensive damage from both hurricane surge and winds.

Effects of waves on operational characteristics of a port

188. Ports and harbors are built to provide protected locations for ships to load and unload cargo. The current trend toward larger ships and tankers has posed new problems to many harbors. Container ships have more stringent restrictions on their movement for optimum operation during loading and unloading than do break-bulk vessels. Deep-draft vessels require deeper entrance channels, which allow more

wave energy to enter a harbor. Although larger ships can utilize the harbor, its total capacity may be decreased by a deterioration in the wave environment.

Damage to breakwaters

189. It is not normally practical to design breakwaters to withstand major storm conditions without suffering damage. Usually, breakwaters are designed to withstand some design storm (e.g., a 50- or 100-year storm) with limited damage (e.g., less than 5 percent). Should damage occur to a breakwater, it is anticipated that sufficient time would be available to repair it before another severe storm could damage exposed inner harbor facilities. The selection of design storm conditions for breakwaters at military port facilities is very difficult. If the breakwater were designed for a relatively common storm (i.e., a 6-month to 1-year storm) and a 50- to 100-year storm occurred, there would be a good possibility that both the breakwater and port facility would be effectively destroyed instead of suffering minor damage. Such a situation occurred during the invasion of Normandy during World War II. Since design criteria for breakwaters are now existent, it would be prudent to develop designs covering a variety of wave climates. A specific design could then be selected on the basis of required design life, tactical importance, and construction resources.

Damage to ships and port facilities

190. Damage to piers, wharves, storage areas, and cargo handling facilities can occur from each component of the wave climate discussed in paragraph 176. A tsunami wave that inundates an area occupied by such structures will destroy or seriously damage most of them. However, the small probability of occurrence of tsunamis plus the fact that most areas are not subject to tsunami inundation make the probability of damage from a tsunami relatively unlikely. Of considerably more concern are hurricanes or typhoons (in areas where they occur). Design criteria for buildings are available to prevent extensive damage from the winds; however, damage from the hurricane surge itself (sometimes erroneously called a tide) is practically impossible to prevent unless the storage facilities are built at a sufficient elevation. This elevation should

be established from the wave statistics (recommended to be compiled) for the area under consideration.

191. Piers and wharves can be constructed to sustain limited damage under hurricane surge conditions. A prime consideration is not to design a pier with long continuous spans if the possibility exists that it will be exposed to waves that will reach the underside of the deck. Pressures from waves striking the underside of a deck have been found to exceed 1400 lb/sq ft. Because it is not practical to design decking to withstand this magnitude of load, provisions should be made in the design for breakaway components that will prevent damage to major structural elements.

192. Although long-period waves are seldom high enough to reach the underside of a pier or wharf deck, damage may result from wave-induced movement of a ship. In such circumstances, a properly designed fender system is an important factor in limiting damage to both the ship and pier facilities.

193. The probability of major ship damage from natural causes within the harbor itself is extremely small unless a tsunami, hurricane or typhoon, or deterioration of the breakwater occurs. Modern communication should provide sufficient warning for ships to head for the open ocean should a tsunami, hurricane, or storm threaten a harbor.

Explosion-generated water waves

194. Selection of a marine facility location for a military operation without consideration of explosion-generated water waves would be incomplete if not completely foolhardy. It is well-established that the detonation of a nuclear weapon in or over the ocean produces an explosion-generated train of water waves. It is also extremely well-established that in some cases these waves can be quite large and can travel long distances.

Characteristics of explosion-generated water waves

195. Explosion-generated water waves exhibit the same characteristics as any waves produced by a local disturbance in deep water. A train of waves is generated where the maximum amplitude wave always has

the same period (regardless of distance of propagation). The amplitude of this wave decreases as 1/R (R being the distance propagated from the source). There are several envelopes of waves. The number of waves in each envelope is relative to the distance from the source to the envelope, i.e., the farther the envelope is from the source, the more waves that are in the envelope. The longer period waves appear at the front of each envelope. The initial waves travel at $\sqrt{gh}$ (g = acceleration due to gravity, and h = water depth), and the energy travels at the group velocity of the maximum amplitude wave. The wave envelopes are well described by a third- or fourth-order Bessel function that modulates a circular function describing the individual waves themselves.

196. If the explosion occurs in shallow water, the first wave is usually the largest, regardless of propagation distance due to a very slow rate of dispersion.

197. The amplitude and frequency of the largest wave are functions of explosion yield, height or depth of burst, distance from the explosion, water depth, and bottom topography.

198. Because an explosion is an inefficient method of generating water waves, a relatively large-yield nuclear explosion is required to create waves of appreciable height. It can also be stated that a tsunami cannot be generated by an explosion unless it triggers an earthquake. The area affected by explosion-generated waves is extremely localized when compared with the several-hundred-mile-wide area affected by a tsunami. The periods of nuclear-explosion-generated waves can roughly be classified as being between that of wind waves and tsunami waves, i.e., they are in the long-period wave region but can have amplitudes considerably greater than those of normal long-period waves found in the open ocean.

Effects on ports

199. Before considering the concept of small, dispersed military harbors or ports, explosion-generated waves must be considered. Depending on the bottom topography, a properly placed large nuclear explosion might produce a breaking wave environment over a considerable length of shoreline and beginning in relatively deep water.

200. Although explosion-generated waves are in the long-period wave category, their effect will probably be more dramatic than that of naturally produced long-period waves since their amplitude is normally larger. However, a port that is well protected from long-period waves will probably offer good protection from explosion waves.

Effects on ships

201. The effects of explosion-generated waves on surface ships and submarines is not well known. However, should a ship be subjected to severe breaking waves, it can be expected to sustain major damage and possible destruction. The effects of airblast and underwater shock waves are discussed in reference 14.

Summary

202. A brief discussion of the wave conditions to be considered in the selection of a marine facility location has been presented. Although most of the information necessary for a rational selection is within the state-of-the-art, it is apparent that synthesizing this information is a major task. Because this task is time-consuming, it should be accomplished well in advance of a survey and included in the theater base development plans. It is doubtful that sufficient resources will be available to accomplish the task after contingency plans have been implemented. Thus, the following recommendations are made in order to obtain the necessary data for a rational decision in selecting a marine facility location:

- a. Compile deepwater wave statistics similar to those existing for the West Coast of the United States for wind waves in all contingency areas. This will involve hindcasting for areas where data are nonexistent or where existing data are unreliable.
- b. Compile data on the long-period wave environment in various contingency areas to determine if long-period wave problems exist. The data in some cases may involve only verbal descriptions obtained for existing ports.
- c. Compute frequencies of occurrence for hurricane surge and typhoons for areas where such data are unavailable. Also pinpoint locations likely to suffer tsunami inundation.
- d. Predict the effects of explosion-generated water waves for sites designated in contingency plans.

PART III: SHIP DISCHARGE FACILITIES

Discharge Facilities and Design

203. Ship discharge facilities are normally named after the type of vessel that will be using the facility. General cargo, landing craft, and petroleum facilities have been dealt with by military engineers in the past. The introduction of container ships and commercial roll-on/roll-off systems requires that two more types of facilities be considered.

204. A dock is a general term used to describe a discharge facility for unloading and loading the cargo that a vessel transports. Usually a dock is referred to as a pier or wharf, depending on its characteristics. A wharf is a facility that usually parallels the shore. The number of linear feet at the face of the wharf is the length of the berthing accommodation. A pier generally is a structure that projects into the water. It usually provides berthing on both sides of the structure and is perpendicular to or at an acute angle with the shore.

205. A discharge facility is usually constructed to serve one type of ship. Many factors must be considered in the determination of the actual design of the facility to be constructed. Some of these factors are the (a) design life of the installation; (b) sizes of ships that will use the facility; (c) types of cargo to be loaded and unloaded; (d) directions of waves, winds, and currents; (e) foundations conditions; (f) construction time available; (g) availability of construction material and construction equipment; and (h) economics of the structure.

Construction types

206. Discharge facilities generally fall into two construction classifications: (a) structures of open construction with their decks supported by piles, and (b) structures of closed or solid construction, such as sheet-pile cells, bulkheads, and gravity walls.

207. Structures of open construction can be further divided into high-level decks and relieving-type platforms. The relieving-type platform is designed with the main structural slab below the finished

surface, and the space between the two is filled with aggregate to add stability and distribute concentrated wheel loads over a greater number of piles in the foundation. This type of structure is suitable for heavy deck loads. A high-level deck design is usually adequate for light loading conditions. High-level decks can be constructed quickly and are well suited to prefabrication.

208. The solid type of construction can be used when the soil conditions are suitable for gravity-type structures and the water depth does not exceed 35 ft. Solid construction units require a thorough understanding of the physical properties of all the materials being used. Steel sheet-pile walls require an extensive tieback system and are difficult to repair when damaged.

Materials

209. Structures can be constructed of wood, steel, or concrete. Timber does not require highly skilled labor and is relatively inexpensive. It usually can be procured relatively close to the construction area. Its disadvantages are limited load capacity and susceptibility to fire and marine organisms. Wood pilings do not normally come in lengths greater than 90 ft and are difficult to splice.

210. Steel has the advantage of a high strength-to-weight ratio but requires skilled labor and special equipment and is susceptible to corrosion and galvanic action.

211. Concrete is being more widely used in commercial ports due to its low maintenance cost and ability to carry heavy loads. The problem of producing and curing large quantities of concrete in the field is a major disadvantage.

212. Prestressed concrete piles can now be produced in lengths up to 100 ft and shipped to the theater on LASH and Seabee barges. Their low maintenance cost while stored at depots makes them suitable for prestockage. Although concrete piles are difficult to splice, displacement piles longer than 100 ft are seldom necessary.

Structure design

213. A structure can be designed in two ways: (a) as a rigid structure in which the lateral forces are absorbed by batter piles or

by rigid frame action, or (b) as a flexible structure in which deflection allows the structure to absorb a portion of the impact of berthing ships. The behavior of a structure under lateral loading must be considered in the design of a fendering system. Fendering is discussed separately in Part V of this report.

214. A pier or wharf structure must be designed to resist lateral loads, vertical loads, and loads imposed on it due to berthing impact.

215. Lateral loads consist of the forces caused by the mooring lines pulling a ship into or along the structure or holding it against the forces of wind and current. The design wind forces should equal the exposed broadside area of the ship in its light condition multiplied by the wind pressure to which a shape factor of 1.3 has been applied. The shape factor takes into consideration a reduction due to height and an increase for suction on the leeward side of the ship. Usually, the wind forces are assumed to be not less than 10 or more than 20 lb/sq ft (reference 7, page 294). In designing a pier with berthing on both sides, allowances must be made for ships berthed on the leeward side. As can be seen, the characteristics of the ship and the local wind pressures are needed to calculate the lateral forces. If this information is not available, most port authorities and the Naval Facilities Engineering Command[8] recommend using a design load of 1000 lb per linear foot of pier or wharf.

216. The force caused by currents will be negligible if the ship is moored parallel to the current. However, if the ship is not moored parallel to the current, this force may become significant depending upon the current profiles, depth of water, and the proximity of other structures.

217. The force exerted on the pier by the mooring line can be determined by the algebraic addition of the wind and current forces.

218. Vertical loads are those imposed by the weight of the supporting structure (dead load) and those imposed by wheel loads from trucks, railroad cars, and cranes, cargo, and equipment (live load). The uniform live load varies, but usually in the design of general cargo facilities, the load is assumed to be from 600 to 800 lb/sq ft. The

design for wheel loads follows the procedures outlined by the American Association of State Highway Officials (AASHO).[15] The uniform live load will control the design of the piles and pile caps, whereas the concentrated wheel loads, including impact, will control the design of the deck slab and beams.

219. In an attempt to evaluate the structural requirements of piers and wharves to handle large container equipment, a comparison was made using the analytical procedures outlined in section 4-7 of reference 16. The same vehicles employed in the evaluation of relative surfacing requirements (discussed in Part VI) were used in the analysis. The bridge class curves were generated for both shear (fig. 47) and bending moment (fig. 48) for each piece of container handling equipment.

220. The calculations were made with the vehicles loaded with 67,200 lb except for the Hyster, which has a maximum capacity of 62,000 lb and the P&H and GC-500 cranes, which were not loaded. The curve for the GC-500 crane is for one wheel assembly of the crane only. This was done because each wheel assembly is approximately 12 ft wide and because the assemblies are on 25-ft centers. Therefore, it was felt that for comparison with the other vehicles, a curve for only one wheel assembly would be appropriate. A hypothetical vehicle width of 160 in. was used to determine the width deviation correction factor for vehicles of classes 150 and larger.

221. To provide a meaningful comparison, these curves were plotted along with those for standard class hypothetical vehicles as defined in reference 16, the H20-S16 loading of the AASHO,[15] and 500- and 1000-lb/sq ft uniform live loads for 12-ft-wide lanes. The 500-lb/sq ft uniform load is the value used in current facilities of the Army Facilities Component System. The 1000-lb/sq ft load is the value employed by the Port of New York Authority for container facilities and is recommended by the Naval Facilities Engineering Command.[8]

222. As can be seen from the two sets of curves, the design must include a consideration of the effects of concentrated wheel loads. In this investigation, it was found that on short spans the mobile cranes developed moments and shear forces two to three times greater than those

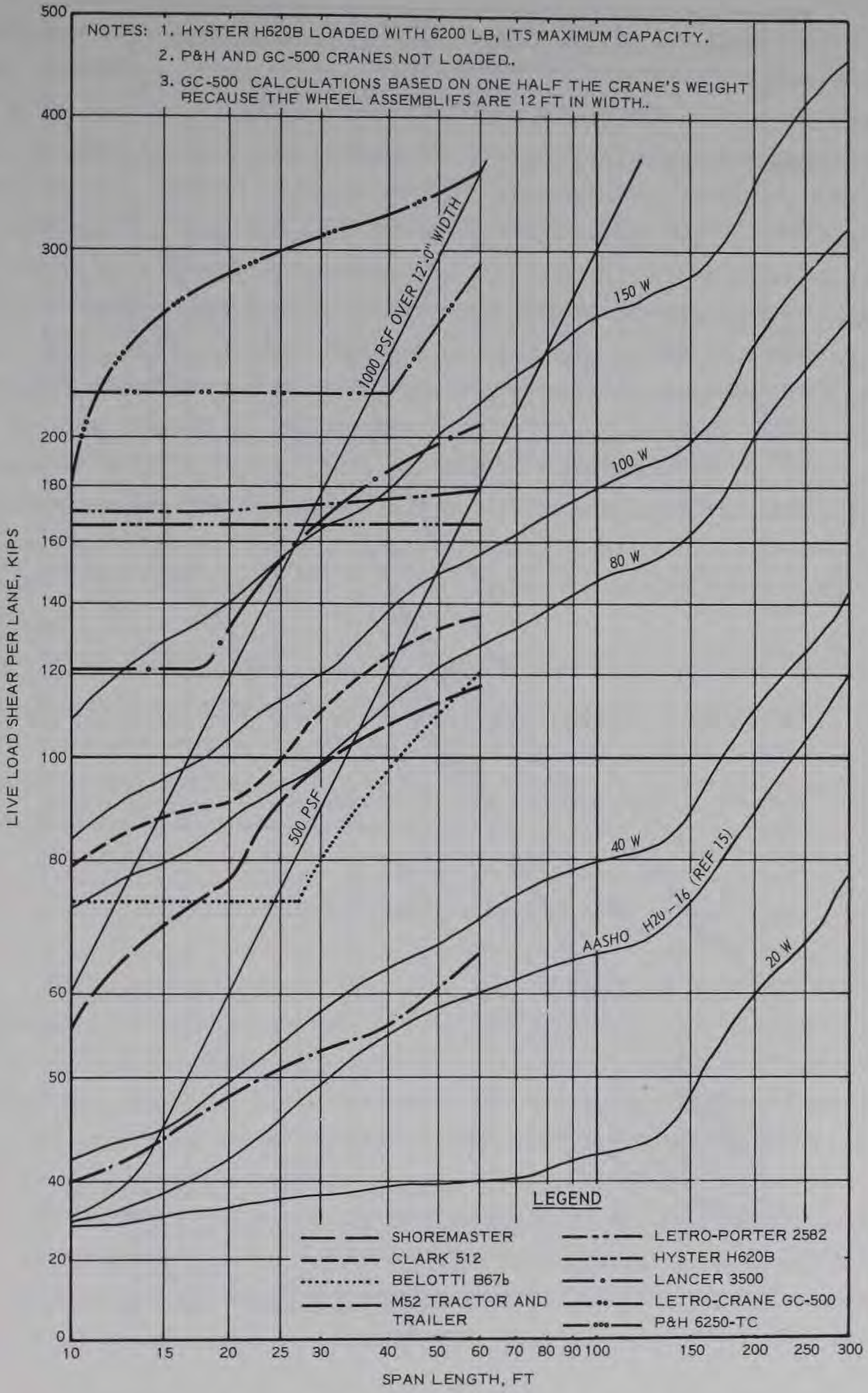


Fig. 47. Bridge class curves for shear

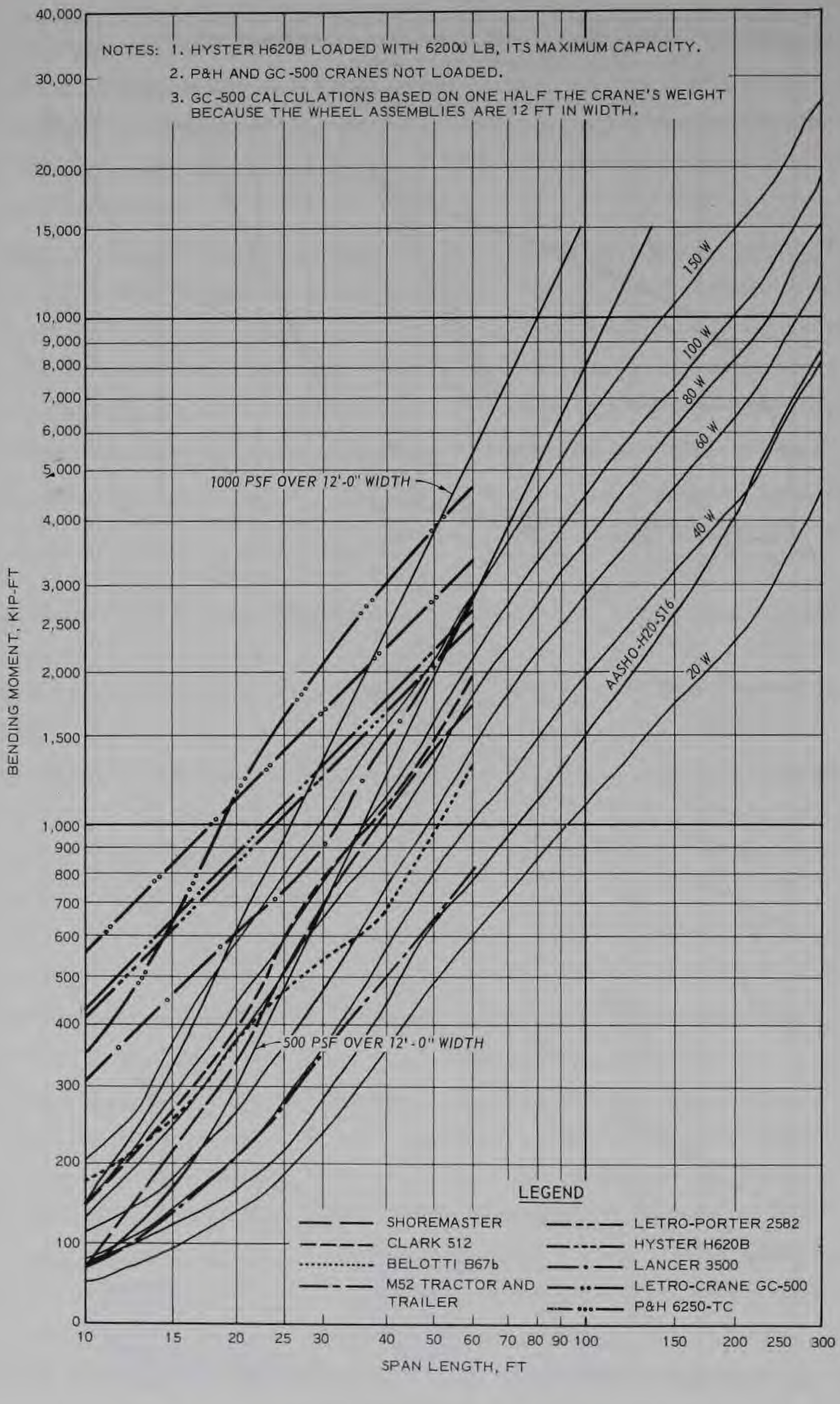


Fig. 48. Bridge class curves for bending moment

developed by a 1000-lb/sq ft uniform load. If a design incorporates span lengths in excess of approximately 15 ft, consideration must also be given to the possibility that more than one vehicle may be on a particular span at one time. Unlike the case of military fixed bridges, vehicles will operate on piers and wharves perpendicular to the axis of the stringers. Vehicles that are particularly short may be even more severe in this transverse orientation than when traveling parallel to the stringers. This loading condition should be thoroughly investigated.

223. When engineer resources are limited, it may be necessary to restrict use of a pier or wharf to certain types of equipment. If this is the case, access to the structure should be controlled, and supervisors of cargo handling operations should be informed of the structure's physical limitations. Signs should be posted at the approaches to the facility, and the port engineer should conduct periodic inspections of the facility to ensure that regulations are being properly enforced.

224. Concentrated loads exerted by cranes and railroad equipment must be carefully examined. The 17-ton gantry crane loading used in the past no longer appears to be applicable. Crawler, wheeled, and truck-mounted cranes exhibit an extremely wide variation in magnitude and distribution of concentrated loads.

Prefabricated Reinforced Concrete Pier Module

225. As expressed in the Joint Logistics Review Board document,[2] contingency operations should incorporate the use of preengineered, prefabricated facilities. As a result of recent developments in shipping, a need has arisen for a prefabricated pier component capable of handling live loads of 1000 lb/sq ft, high concentrated wheel loads, and a gantry-type container crane.

226. A preliminary study was conducted to determine the feasibility of designing a reinforced concrete pier component that would (a) fit on the Seabee barge ship, (b) weigh less than 1000 tons, (c) have a deck live load capacity of 1000 lb/sq ft and large concentrated wheel loads,

and (d) support a gantry-type container crane (wheel loads of 1000 kips on 5-ft centers).

Concept

227. The concept would be that this module could be loaded on the Seabee barge ship to be transported to the TO. Twenty-nine barges would permit the construction of a 1000-ft-long pier or wharf. The modules were designed for use with 6-ft-diameter caissons and the 500-ton-capacity DeLong jacks. The modules would be unloaded from the barge ship and floated into place. Through use of four caissons and DeLong jacks, the modules would be jacked to their required elevation, and then 24-in-diam piles would be driven through precast holes and epoxied to the girders. After the 24-in.-diam piles were in place, the four caissons and DeLong jacks would be withdrawn to be used on another module.

228. The module would be filled with a fine-grained material like sand with pavement placed over it, thus resulting in a relieving-type structure. This type of construction is used in commercial ports to allow high concentrated wheel loads and heavy loads to be dispersed over a number of pilings. The module could also be used as a causeway with a roadway width of 35 ft (see fig. 49).

Preliminary design

229. The module is 35 ft wide, 97.5 ft long, and 12.0 ft deep. The fabricated dead load is 970 to 980 short tons. This represents about 453 cu yd of concrete and 205,000 lb of reinforcing steel with a fabrication cost of $90,000 to $100,000 based on current bid prices plus 20 percent for contingencies (see figs. 50-53).

230. The module was designed according to the American Concrete Institute[17] (ACI) code using the working stress method. The floor system was analyzed as a two-way slab fixed on all edges. A total design load of 2400 lb/sq ft (dead load + live load of 1000 lb/sq ft) was used for all sections of the floor system. The entire floor system was provided with a uniform concrete depth and reinforcement ratio that satisfied the positive and negative moments of the larger members of the system.

231. All of the pilings were placed through the girders, thus

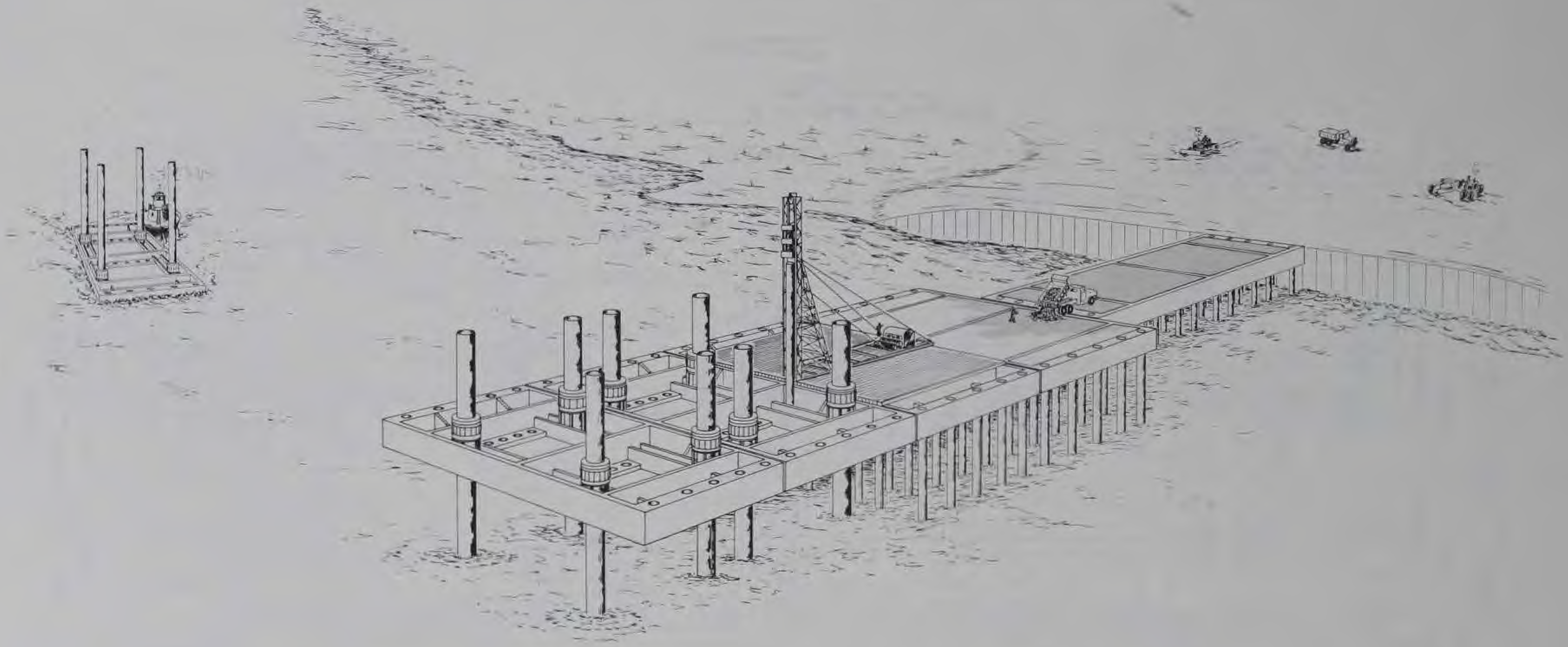


Fig. 49. Artist's concept of concrete pier module installation

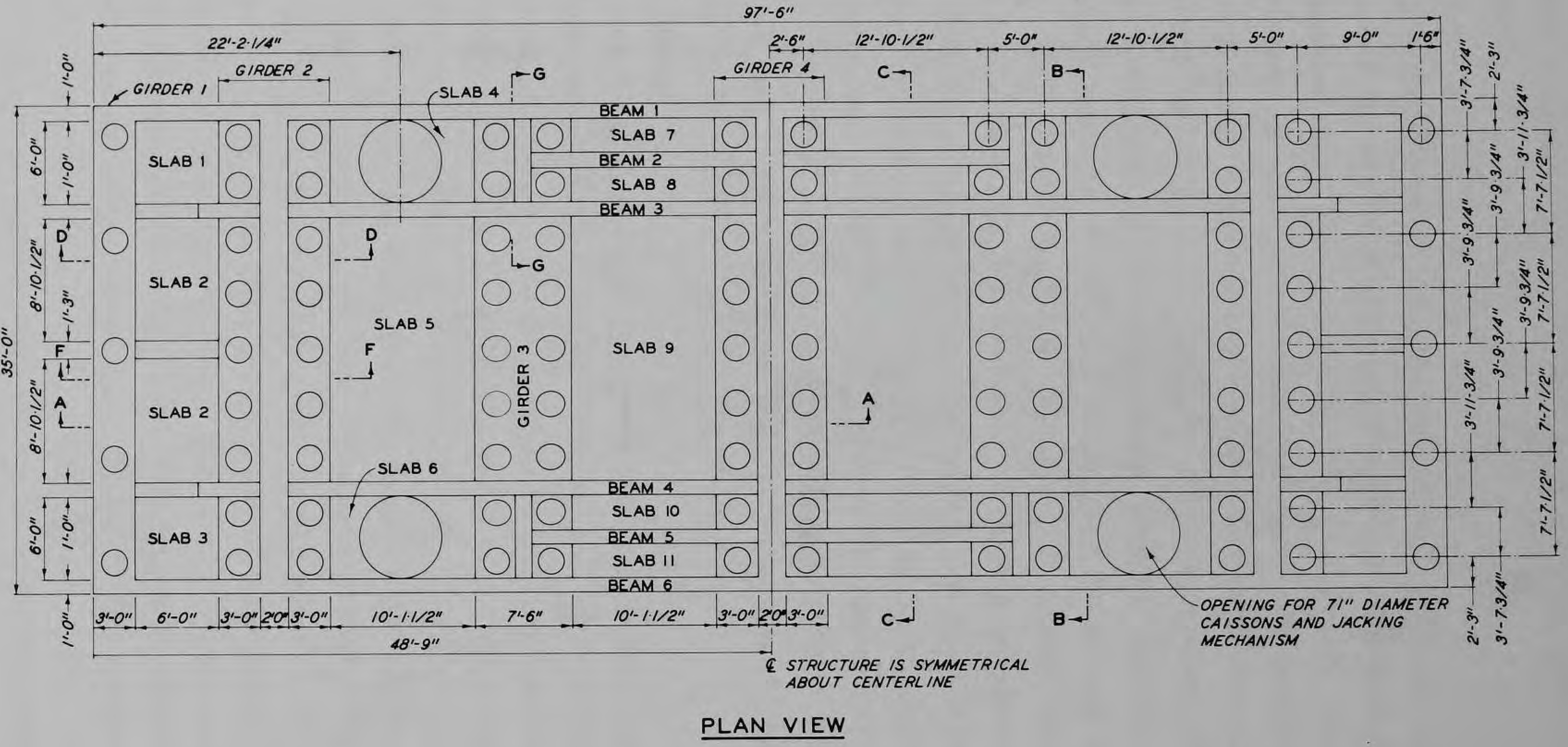


Fig. 50. Prefabricated reinforced concrete pier module, preliminary design

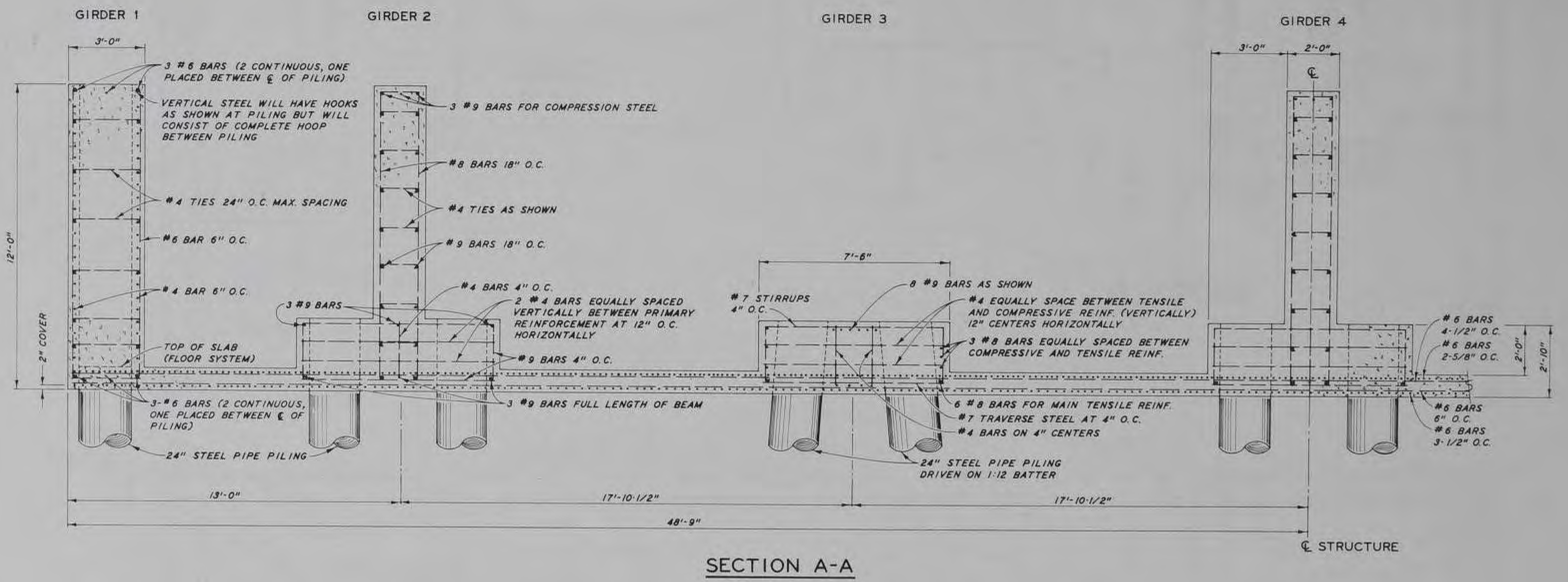
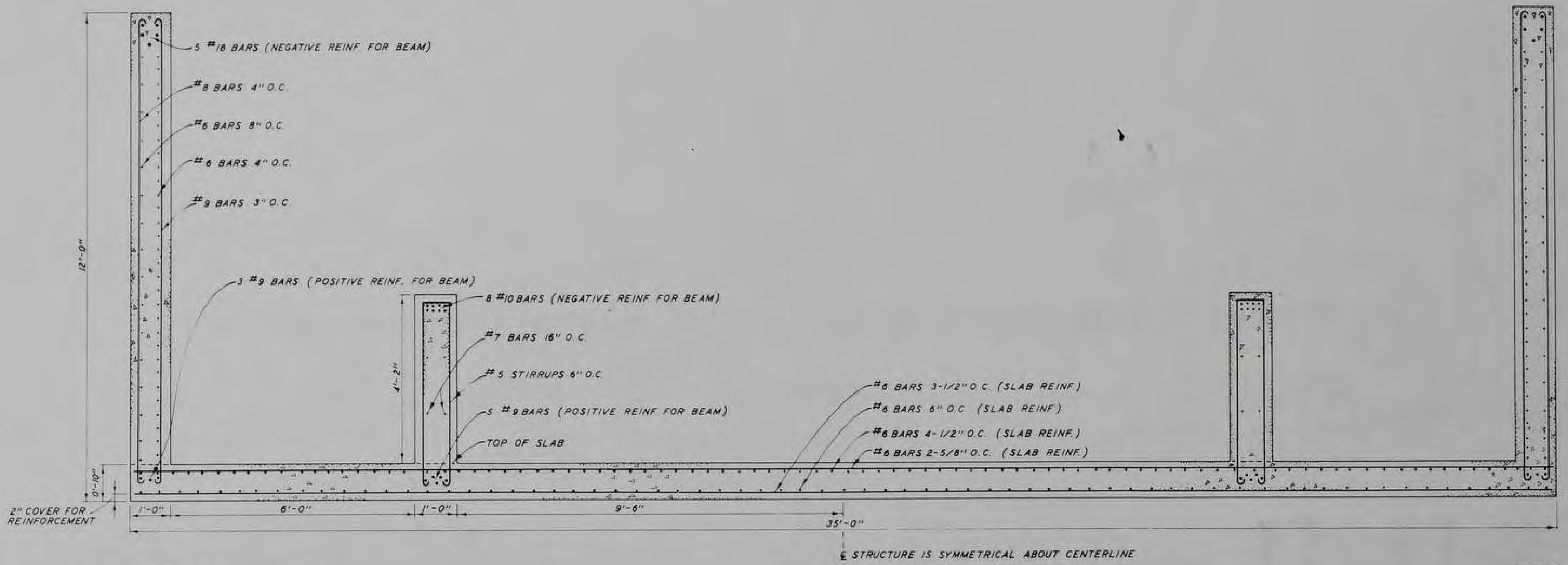
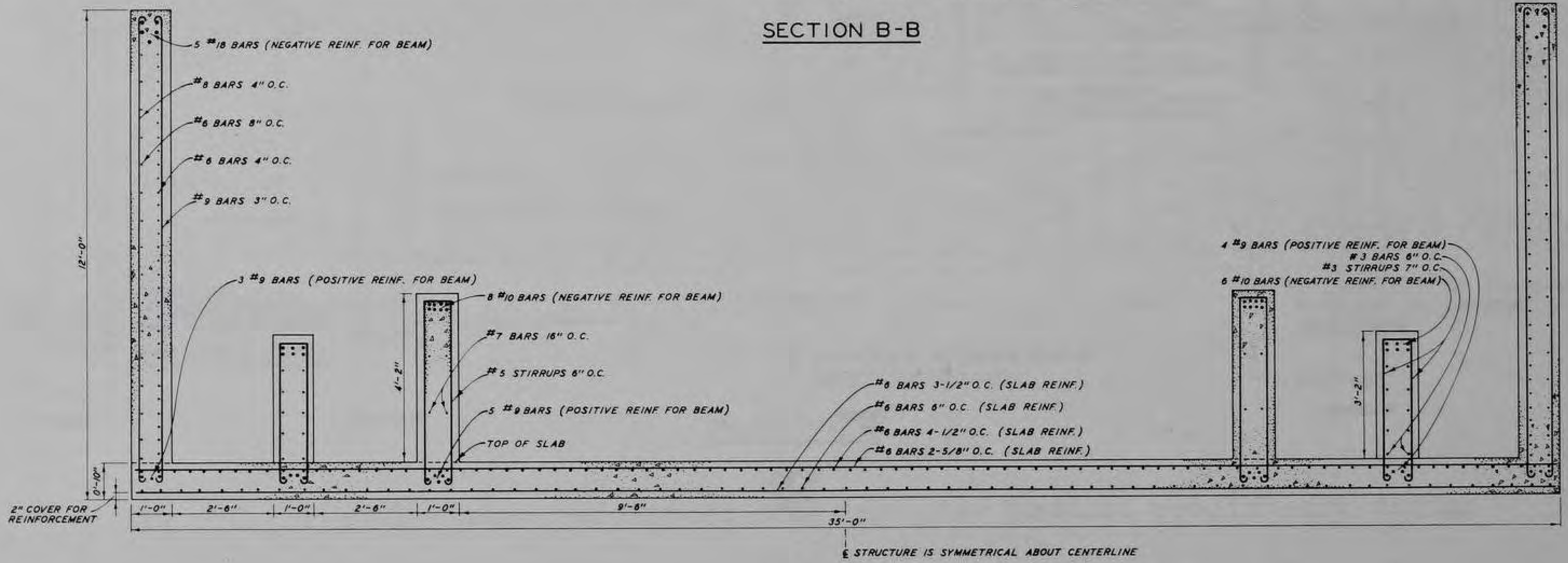


Fig. 51. Prefabricated reinforced concrete pier module, section A-A

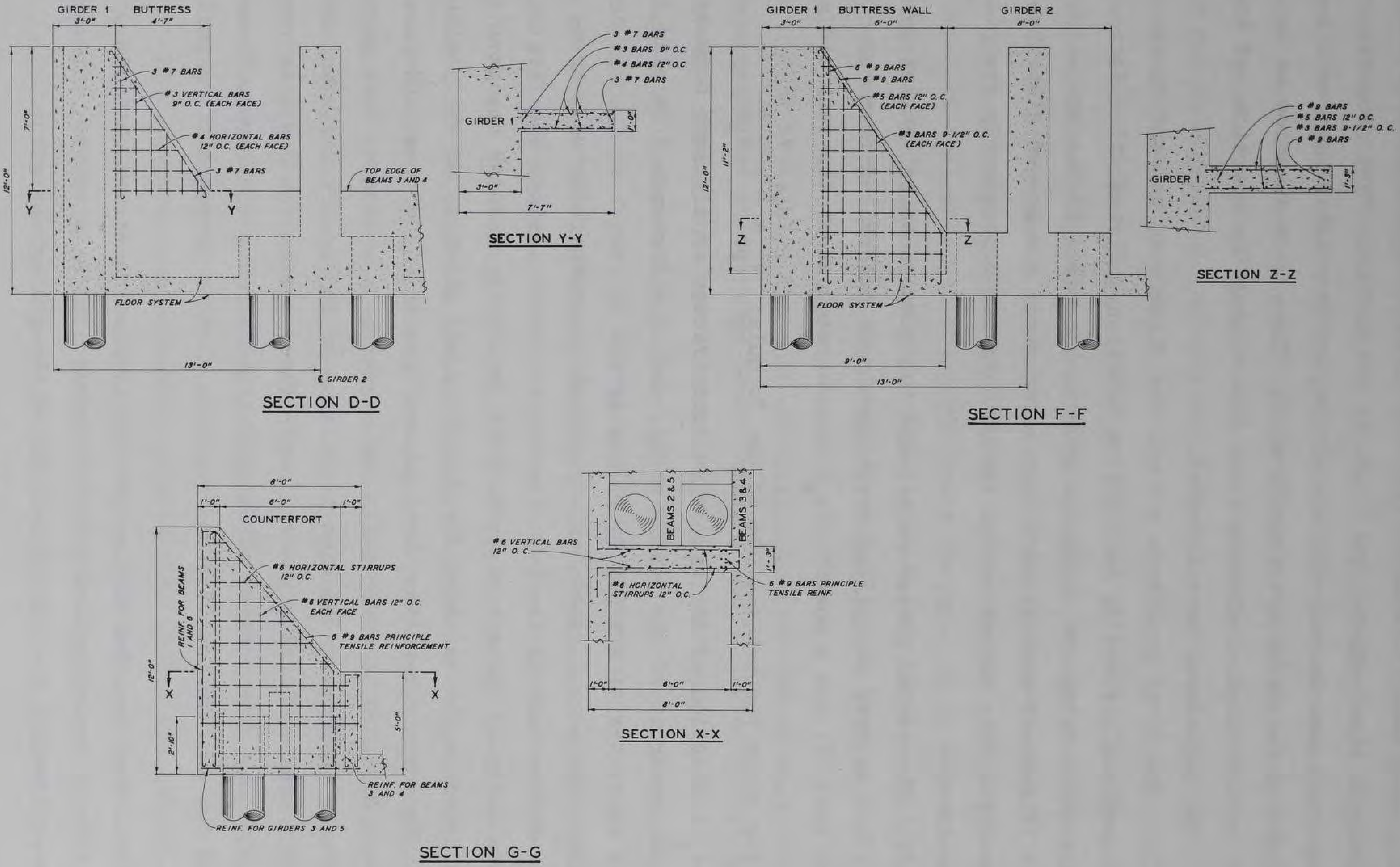


SECTION B-B



SECTION C-C

Fig. 52. Prefabricated reinforced concrete pier module, sections B-B and C-C



SECTION D-D

SECTION Y-Y

SECTION F-F

SECTION Z-Z

SECTION G-G

SECTION X-X

Fig. 53. Prefabricated reinforced concrete pier module, sections D-D, F-F, and G-G

permitting each beam to transfer its load directly to the girders and each girder to then transfer its loads to the piling. This procedure permitted the beams to have minimum widths, which reduced the overall dead weight of the structure considerably. There is a question as to the best or most logical procedure for determining the reactions of the piling. Two procedures were selected.

232. The first procedure assumed the girders to be continuous members completely fixed at each piling location. Distribution factors were calculated using the distances between the piles as the span lengths. Fixed-end moments were then calculated, and moment distribution was applied to determine the end moments and consequently the piling reactions.

233. The second procedure assumed the girders to be completely rigid. This allowed the piling reactions to be determined from the downward load (V) and a moment (Ve_x) concentrated about the centroid of the piling group through the use of the formula: $V_p = \frac{V}{n} + \frac{Ve_x X}{\Sigma_X 2}$ where V_p = reaction of piling, e_x = eccentricity or distance between V and the centroid of the piling group, and X = distance from pile in question to center of gravity of piling group.

234. The actual reactions are probably somewhere between those calculated from each of the two procedures; however, since the first procedure outlined (moment distribution) generally produced the more critical moments, it was used for designing all girders, as well as the beams. The maximum reaction obtained was less than 100 tons. Girders 2 and 4 were designed to carry rails for a gantry-type crane. Each girder was designed to support 880 kips total load or 25 kips/ft uniform load.

235. The inflection points in the floor system could not be predicted with any great degree of accuracy; therefore, reinforcement was provided for maximum positive and negative moments throughout the entire system.

236. Further, due to the specific type of construction (piling driven through precast holes and then epoxied to the girders), a shear problem could exist near the locations of the piling and girder

connections. Although this area was provided with shear reinforcement according to ACI Code, Section 318-71,[18] laboratory tests should be performed to ensure that the best placement of reinforcement is determined. These tests may indicate that it is possible to obtain maximum benefits from the shear reinforcement when it is placed at angles to the piling and not in horizontal and vertical directions as is recommended in reference 18 for all deep beams.

237. Lateral movement due to wind and ship loads should not be a problem, especially since battered pilings are recommended for girders 3 and 5 (checked for a horizontal load of 6 kips/linear foot of barge on the 35-ft faces). Lateral forces due to wave action have not been considered at this stage in the preliminary design. It is emphasized, however, that a final design should include a dynamic (vibratory) analysis to determine the natural frequency of the piling as well as the potential settlement of each pile.

238. Possibly, the most critical situation occurs when the loads are transferred to the edge beams (beams 1 and 6) during the jacking operation. During this operation, these beams must support their own weight, the end reactions of the girders, and the loads from the adjacent slabs. At first, it was attempted to place the jacks near the ends or corners of the structure; however, this resulted in an unreasonably high positive moment. Therefore, the jack locations were moved to a point midway between girders 2 and 3 or nearer midspan. This relocation resulted in the positive moment being reduced to a very reasonable level; however, as suspected, the negative moment was increased considerably. This indicates that a more conservative design would have resulted if the jacks had been initially placed near girder 2. However, this could not have been anticipated because an indeterminate structure cannot be designed without initially making assumptions, analyzing, and revising, if necessary.

239. Because the objective of this pier module was only to prove economic and practical feasibility, it was not believed necessary to completely redesign at this point in the investigation.

240. Counterforts were placed at both ends of girder 3 to provide

support to side beams 1 and 6 against lateral/torsional buckling during the jacking operation and to permit the beams to withstand the lateral pressures of the fill.

241. Foundation experts should determine if the proposed pile spacing will allow each pile to carry its anticipated load under normal site conditions. Conservative assumptions were made throughout the design of the module. Tests should be run to determine if this degree of conservatism is necessary.

242. It is possible that this approach has potential for providing expedient military ports. It would provide a low-cost maintenance structure with the load capability and transportability needed for container operations in the future.

Glued Laminated Wooden Deck

Background

243. Timber always has been one of the major construction materials used in a TO. Normally, it can be procured at or relatively close to the construction site. Timber construction techniques and the uses of timber can be readily taught to troops. The amount of construction equipment required for the installation of timber structures is kept to a minimum. Timber is relatively easy to work with and can be used in numerous situations.

244. The literature review for this project led to information on glued laminated deck research being conducted by personnel of the U. S. Forest Products Laboratory, Madison, Wisconsin,[19] who, in collaboration with the U. S. Department of Agriculture, Forest Service, Division of Engineering, are performing continuing research on timber bridges. The objectives of this research are to develop design procedures, to improve the preservative treatment of bridge members, and to improve deck systems.

245. The "Standard Specifications for Highway Bridges" by AASHO (reference 15) presents design criteria for nailed laminated deck systems and doweled wood deck systems. Reference 15 does not cover the

design of vertically glued laminated wood decking, which is thought to be superior to either of the other two systems. The Forest Products Laboratory is now in the process of publishing design criteria for glued laminated decking based on its research on experimental bridges.

Tests in progress

246. Results of deflection tests conducted by the Forest Products Laboratory on both glued and nailed laminated decks indicate that the glued decks are twice as stiff and superior in strength to the nailed decks.

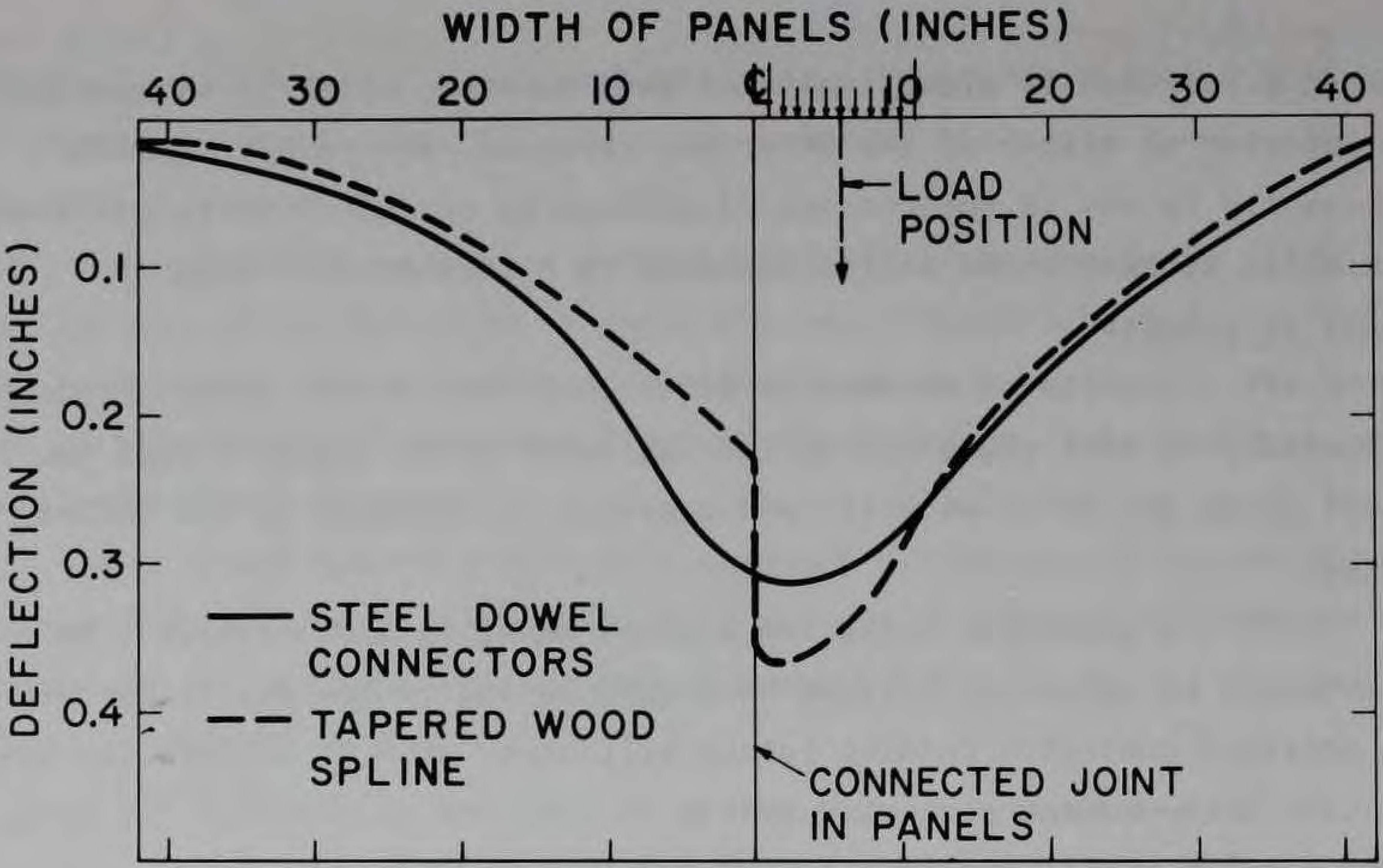
247. A practical width for a glued panel is 4 ft or less. This limitation is necessary because wood shrinks and swells due to changes in moisture content. Because joints will occur at 4 ft or less, an effective shear-moment connector system is required to minimize the movement between panels and provide for the transfer of load.

248. The Forest Products Laboratory has tested several different connector systems. Fig. 54 shows the two extreme deflection patterns obtained during the evaluation of connector systems. The steel dowel connectors (fig. 55) were the best of the connectors tested, and the Forest Products Laboratory is conducting research to define design criteria for the steel dowel.

249. The Forest Products Laboratory has also conducted field tests to determine if creosote treatment of deck panels will retard a rapid change in moisture content during periods of wetting and drying of the panels. The creosoted panels showed a maximum change in dimension of 0.4 percent over a year, which seems sufficiently stable that the panels will perform well in service.

250. The Forest Products Laboratory has also constructed test decks (fig. 56) to evaluate the performance of the glued laminated decking. These field and laboratory studies have shown that glued laminated decking is superior to nailed laminated bridge decking.

251. The field bridges have given some data for an economic comparison of nailed and glued laminated systems. Placing the nailed deck requires about ten to twelve times the man-hours required to place the glued deck. However, some additional equipment is required to handle

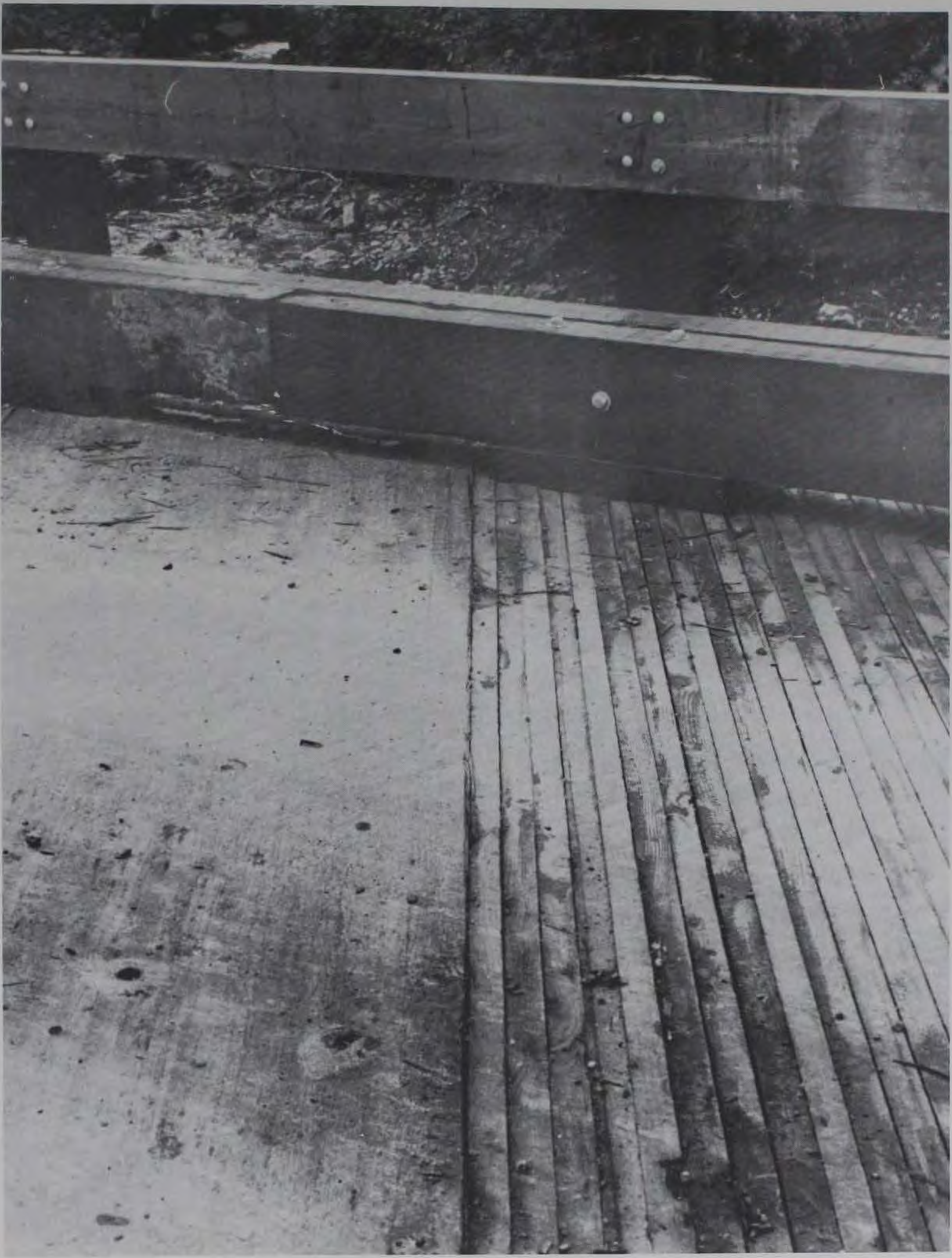


(Courtesy of U. S. Forest Products Laboratory, Madison, Wis.)

Fig. 54. Comparison of deflections of panel connector systems

(Courtesy of U. S. Forest Products Laboratory, Madison, Wis.)

Fig. 55. Steel dowel connector system



(Courtesy of U. S. Forest Products Laboratory, Madison, Wis.)

Fig. 56. Nailed and glued decks on field bridge

the heavy glued panels, so the ratio could be conservatively put at about eight times the number of man-hours.

Possible uses

252. A review of the literature obtained from the Forest Products Laboratory led to the conclusion that glued laminated panels have potential uses in military construction. The main interest lies in the use of these panels for pier and wharf facilities; however, a number of other uses for glued-laminated panels seems possible: (a) bridge decks, (b) gun platforms, (c) protective structures, (d) expedient surfaces for heavy equipment, (e) landing craft ramps, (f) camels and dock fenders, and (g) deck reinforcement for barges.

253. Initially, it was considered desirable that troops be capable of fabricating the deck panels in the TO. However, fabrication techniques require the surfaces of the individual pieces to be planed to a tolerance of 0.008 in. and the moisture content of the wood to be around 13 percent. This would require kilns to dry the wood to the correct moisture content, buildings with controlled humidity for storage and fabrication, a plane to surface the members, and construction jigs that would be able to exert a pressure of 150 psi. Also, approximately 4 hr are required for the glue on each panel to cure.

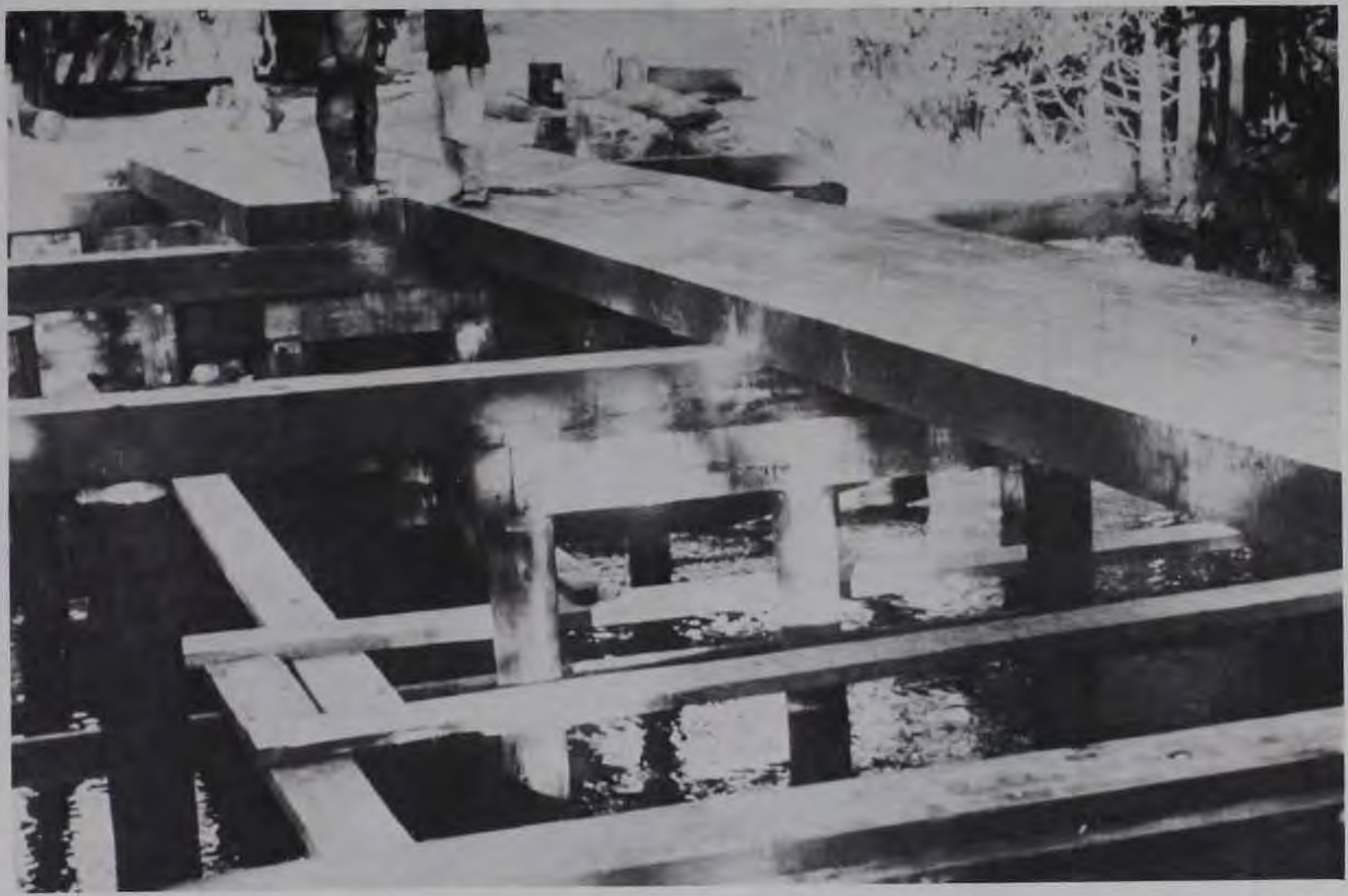
254. The large amount of quality control and the precise fabrication techniques make it impractical to fabricate panels in the TO. Therefore, the panels would be fabricated in commercial plants and then shipped to the TO for use. The prefabricated panels would replace a portion of the bulk timber normally shipped to the TO. The panels would greatly reduce the amount of time and manpower required to build facilities.

255. Presently in the Army Facilities Component System, the design live loads for piers and wharves are 500 lb/sq ft uniform load, Cooper E-50 railroad loading, and side pressure on the wharf of 1000 lb per linear ft.[1] The use of containerization will require dock facilities to be designed for heavier loads than presently in the system. A container pier or wharf will require live loads of 900 to 1000 lb/sq ft, concentrated wheel loads up to 50,000 lb, depending on the equipment,

and side pressure on the pier or wharf of 2000 lb per linear ft.

256. A vertically glued laminated deck was designed to support the same loads as a deck and stringer system of a pier described in reference 1. The glued laminated deck was designed using properties and design stresses from "Standard Specifications for Structural Glued Laminated Timber."[20] The deck was considered to be similar to that shown in fig. 57, in which no stringers were used. The vertically glued laminated system weighed 50 percent less than the normal nailed laminated deck and stringer superstructure. The Forest Service constructed the 58-ft-long wooden bridge (fig. 57) in Hiawatha National Forest at a cost of $5.25/sq ft for the vertically laminated wooden deck panels.

257. A composite design of vertically glued laminated wooden panels and concrete would fulfill the load requirements of a container wharf or pier. A composite section consisting of vertically glued



(Courtesy of U. S. Forest Products Laboratory, Madison, Wis.)

Fig. 57. Glued laminated bridge

panels, made up of alternating 2x10's and 2x12's and 5 in. of concrete was investigated. The section was designed to meet the specifications of the AITC Timber Construction Manual[21] on vertically nailed laminated timber plank and concrete composite deck, because design procedures for vertically glued laminated bridge decks (fig. 58) were not available at the time of the investigation.

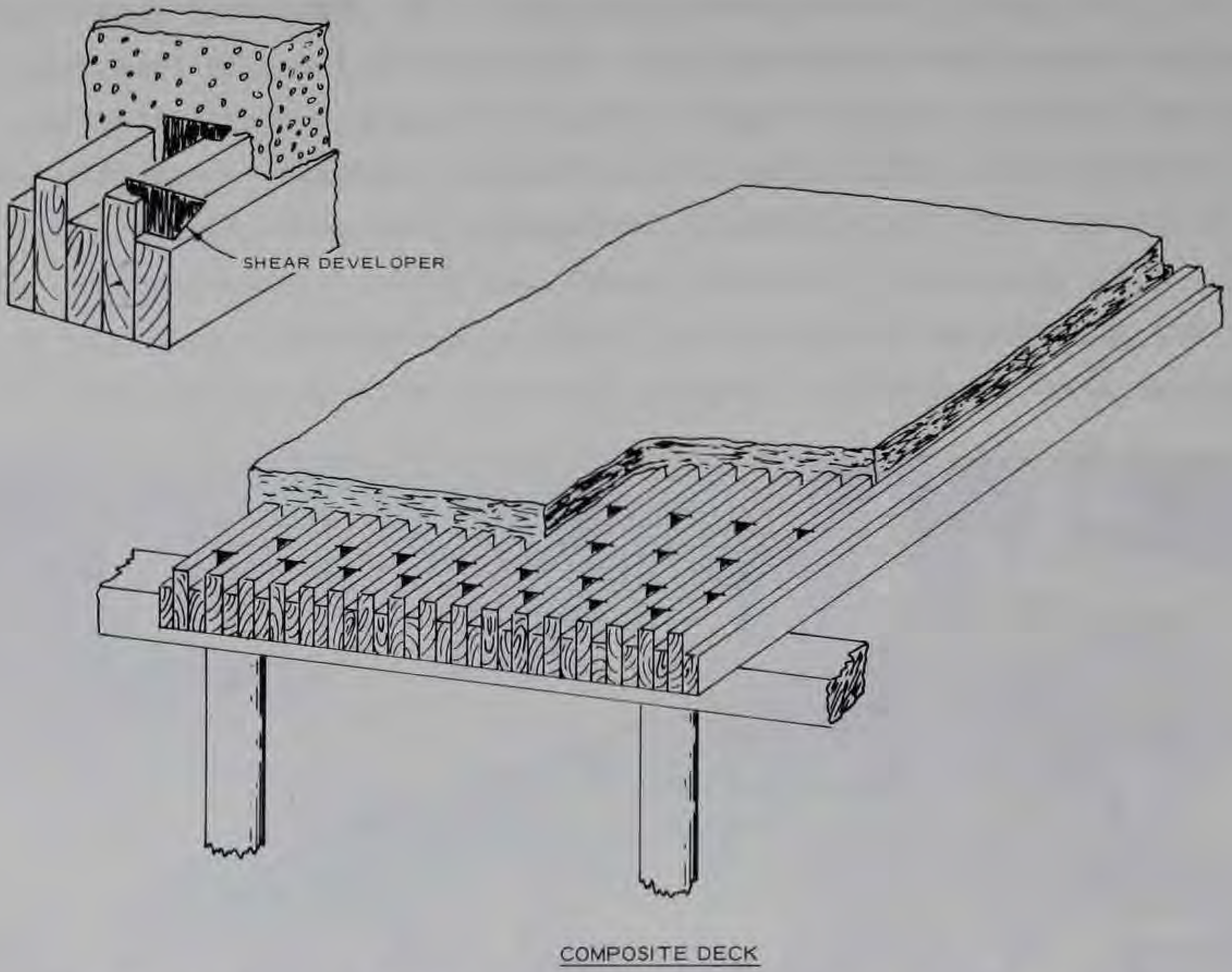
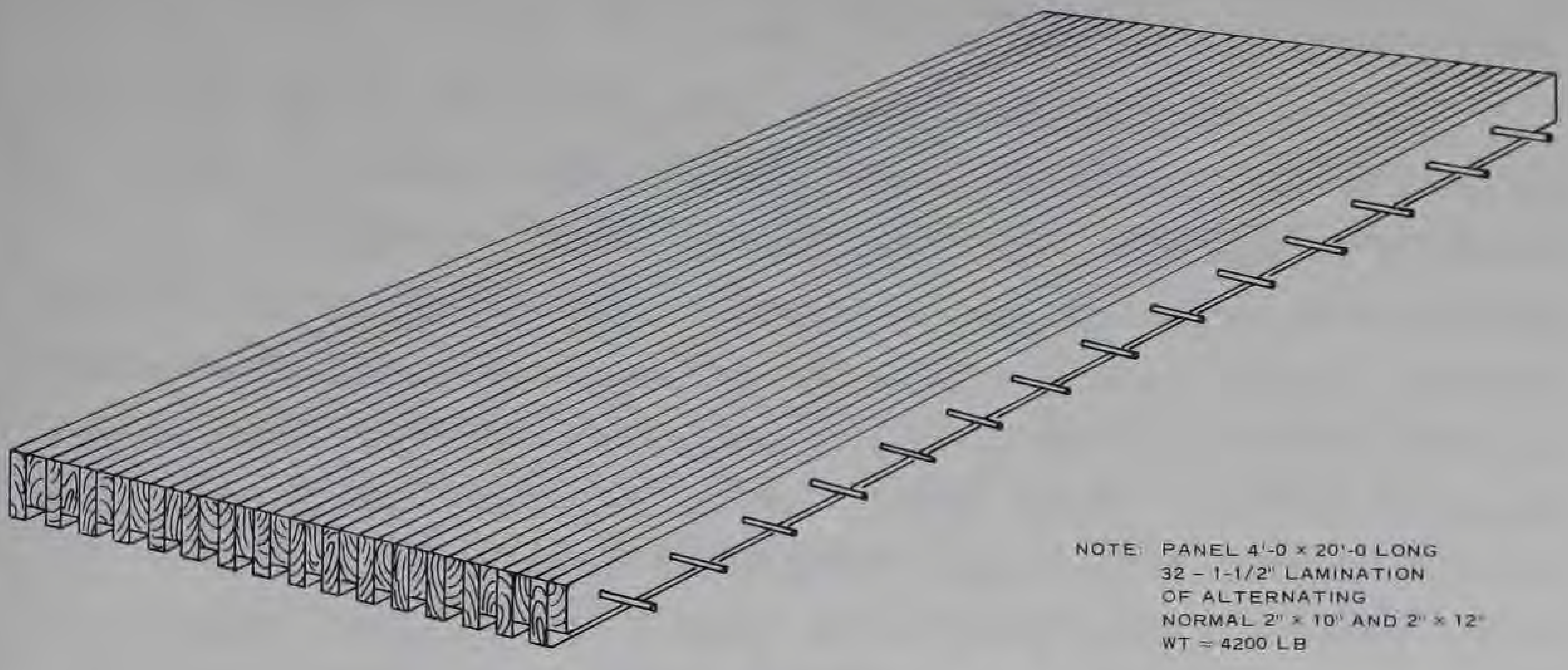


Fig. 58. Composite deck of glued laminated wood and concrete

258. The glued laminated panels are also intended for use by themselves. If the panels are inverted so that the even surfaces are up, they can be used as class 80 bridge decking in span lengths up to 20 ft. These panels (fig. 59) weigh approximately 4200 lb and are thus transportable by CH47 helicopters.

Paneled bridge system

259. During the investigation of glued laminated decking, it was found that Weyerhauser Company of Tacoma, Washington, is currently



NOTE: PANEL 4'-0 × 20'-0 LONG
32 – 1-1/2" LAMINATION
OF ALTERNATING
NORMAL 2" × 10" AND 2" × 12"
WT = 4200 LB

Fig. 59. Glued laminated deck panel

marketing a panelized bridge system (fig. 60). These bridges are being used on secondary roads in Washington State and on private roads of logging companies. The bridges' superstructures consist of all glued laminated members, stringers, diaphragms, deck panels, and wheel guards. The system is designed in accordance with AASHO standards.[15] The live load (from reference 15) is H20-S16 with no impact or overload. The dead load is 65 lb per square foot of roadway. A bridge system of this type appears to be suitable for use in the TO.

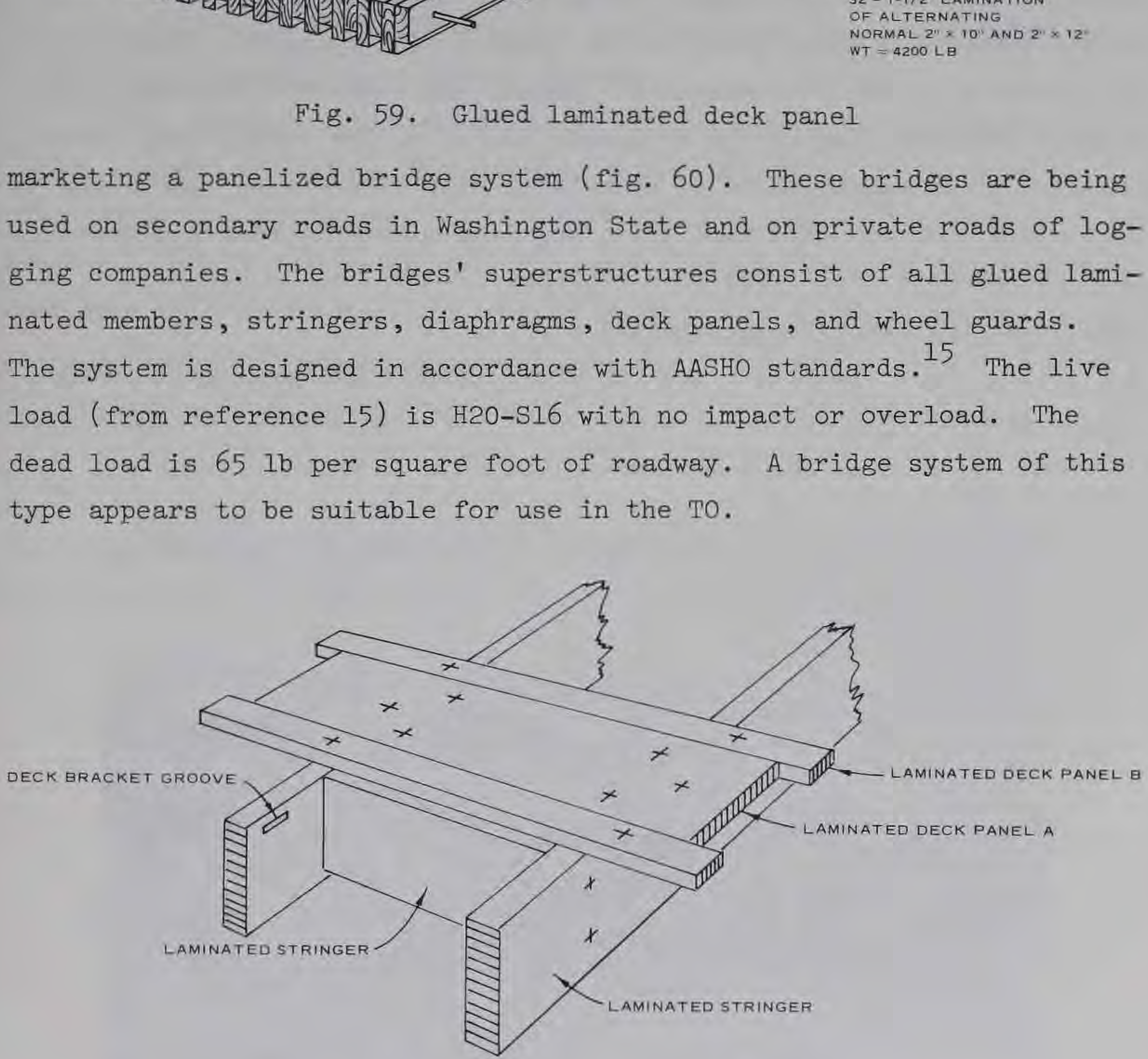


Fig. 60. Weyerhauser panelized bridge system

Roll-on/roll-off Facilities

260. The United States Army is the world's largest user of roll-on/roll-off vessels, mostly in the form of landing craft. In early stages of an amphibious operation, landing craft, lighters, and Navy landing ships can be expected to provide a major portion of the resupply tonnage. Landing beaches will be in continuous use. After a port site has been secured, lighter operations employing landing craft and barges may still continue. These vessels may be employed to handle ammunition, carrying it from the roadstead to the inner harbor where mooring fully loaded ammunition ships would be too great a safety hazard. Experience in Vietnam with the maintenance of landing craft beaches indicated some lack of understanding of the equipment utilizing the facilities. The result was the construction of structures that were not as functional as they could have been and that often required more maintenance effort than the austere facilities they replaced.

Commercial roll-on/roll-off vessels

261. Unlike military landing craft, most commercial roll-on/roll-off vessels are equipped with stern ramps and side doors. At commercial harbors, one or more ramps similar to the ones shown in fig. 61 are

Fig. 61. Roll-on/roll-off ramp

usually constructed at intervals along a container wharf for use by those ships equipped with stern ramps. At military harbors where DeLong barges are used for container facilities, the top deck may be 20 ft or more above water level, even at high tide. This makes it extremely difficult to construct pile-supported ramps that will match up with both the ship's ramp and the pier deck.

Landing craft facilities

262. There are several very important factors that should be taken into consideration in the design of landing craft beaches or "ramps." One of the most important aspects is to fully understand the environmental conditions for which a landing craft was designed and the normal beaching and extraction procedures.

263. Landing craft presently in the inventory were designed for use on beaches with gradients greater than 3 percent. With normal beaching loads, these craft draw 3 to 4 ft of water at the bow. If a landing craft is not to dry out with an outgoing tide, the shore landing ramp must extend out from the shoreline to within 20 ft of where 3 ft of water exists at low tide, assuming that the beach gradient is sufficient to preclude grounding at the stern of the vessel (see fig. 62).

264. If it is assumed that the point of grounding at the bow is 20 ft from the end of the lowered bow ramp, the gradient of the face of the beach ramp must be about 3:20, or about 15 percent. The ramp must be constructed out of material with the following characteristics:

- a. It must be able to withstand the trafficking of heavy-material-handling equipment while in a completely saturated condition.
- b. It must provide adequate traction to vehicles entering or exiting the craft.
- c. It must be flexible enough to prevent serious damage to the landing craft using the facility.
- d. It must be able to resist the scour action caused by the prop wash of landing craft exiting the facility and from currents flowing parallel with the shoreline.

The most practical materials that will satisfy these necessary qualities are crushed rock, gravel, or small cobbles. These materials are heavy

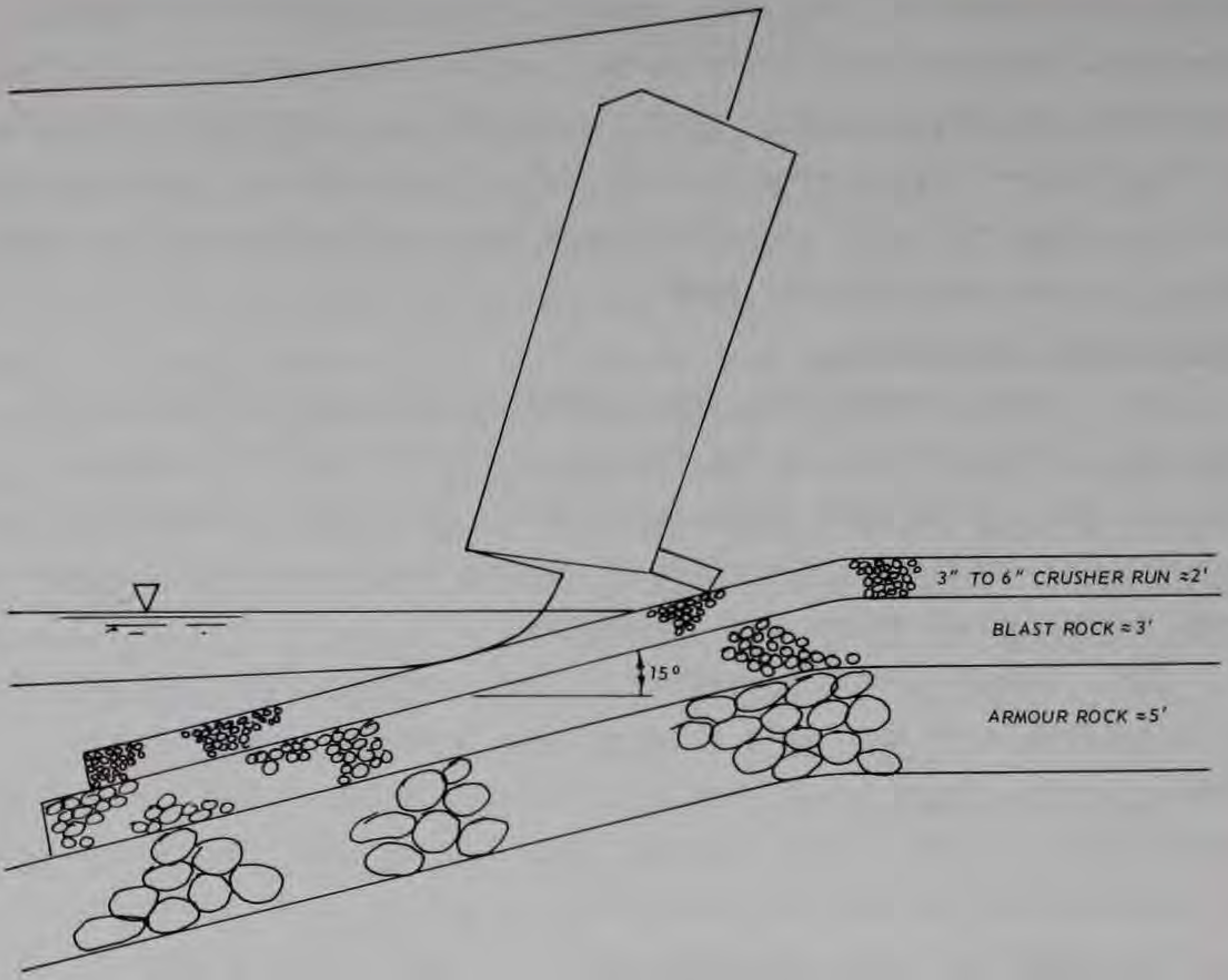


Fig. 62. Landing craft ramp

enough to resist scour, do not lose their shear strength when saturated, and, if properly placed, are flexible enough to prevent highly concentrated loading of the hull of the craft.

265. If the littoral or tidal currents parallel to shore cause a continuous depletion of shore ramp material, it may be possible to slow this action by constructing a permeable timber pile groin adjacent to the facility. If this is done, the piles should be left extending well above high water level so that they do not become a navigation hazard. The groin should be extended slightly beyond the end of the ramp. The permeability of the groin should be decreased in stages by installing additional piling until scour has been reduced to tolerable levels. To install an impermeable groin would cause accretion to occur behind it and a steep drop-off at the end, which is usually undesirable.

266. Pilings at a landing craft facility can also be driven

onshore to the side of each ramp to act as mooring bits. Mooring lines can be connected from the stern of the landing craft to these piles so that the engines can be shut off while loading and unloading the craft. This will reduce the wear on both the cooling system and the propellors and also reduce the number of operating hours on the engines. Another benefit is the reduction in the amount of scour caused by the flow of water beneath the hull.

267. In some locations, particularly near the mouth of a river, rock may not be readily available. Under such conditions, it may be necessary to construct a rigid landing ramp out of either concrete or timber. Under such circumstances, it is usually desirable to design the facility much in the same manner as those required for servicing ships with stern roll-on/roll-off ramps or for ferry boats. Mooring facilities should be provided along the side of the craft so that the bow does not have to bear against the rigid structure. The end of the ramp should not be more than 16 ft wide so that the shore ramp will not interfere with the bow doors on the old model LST's (1153 and 1156 classes). If mooring dolphins are employed to secure the landing craft, it is highly desirable that they be connected by catwalks so that lines can be handled easily. The spacing of the dolphins should be compatible with the different size craft using the facility. The dolphins should be as permeable as possible so that the slips do not silt up. It may be considered beneficial to extend a pier between two landing craft ramps to provide both mooring and a platform from which a crane can deck-load LST's. This type of facility is also ideal for loading and unloading barges. The pier can be constructed from small self-elevating barges such as the Ammi barge (fig. 63).

Roll-on/roll-off ramps

268. No general solution was found to the problem of providing facilities for discharging commercial roll-on/roll-off ships. There appears to be no standard height above water level of either side doors or stern ramps. Because the difference between loaded and light draft of a ship may be as much as 20 ft and the tidal variation within many harbors is 10 ft or more, provisions may be necessary to accommodate a

Fig. 63. Ammi barge

change in elevation of stern and side doors of as much as 30 ft. If the gradient on a ramp is limited to 30 percent to ensure rapid discharge and loading of vehicles, a total ramp length of 60 to 70 ft may be required, depending on the elevation at the shore end.

269. If a stage is employed, it is usually best to use a flat deck barge with as much freeboard as possible. The decks of Ammi and Navy cube pontoons are usually too low unless cribbing is placed between the deck and the ramp. A barge with 10 ft of freeboard would be more appropriate. The shore connecting ramp may be constructed out of tactical bridging or available fixed bridge materials. TM 5-312, "Military Fixed Bridges,"[16] and TM 5-277, "Bailey Bridge,"[22] may be used for design, but, because the ramp may be on a significant slope, a live load impact of 25 percent or more should be employed in the design calculations. Chapter 22 of reference 22 describes the use of panel bridging on barges.

Tanker Discharge Facilities

270. The increasing need for petroleum in the TO makes it

essential to develop tanker discharge facilities as soon as possible. During the investigation of these facilities, some equipment and methods were studied that may allow rapid construction of petroleum facilities.

271. In the initial stages of port development, either tankers or barges can be employed as POL storage facilities. Fig. 64 shows a 122,000-bbl-capacity barge constructed from a T-2 tanker hull. Its four cargo pumps can discharge 17,140 bbl per hour against a 300 ft head. Smaller liquid cargo barges could be transported overseas aboard barge ships and either moored within a port or moved ashore on a compressed air cushion.

272. The primary disadvantage of floating storage is its vulnerability and the threat that a major spill would have on the rest of the port. Oil booms and recovery equipment as well as fire fighting equipment must be on hand.

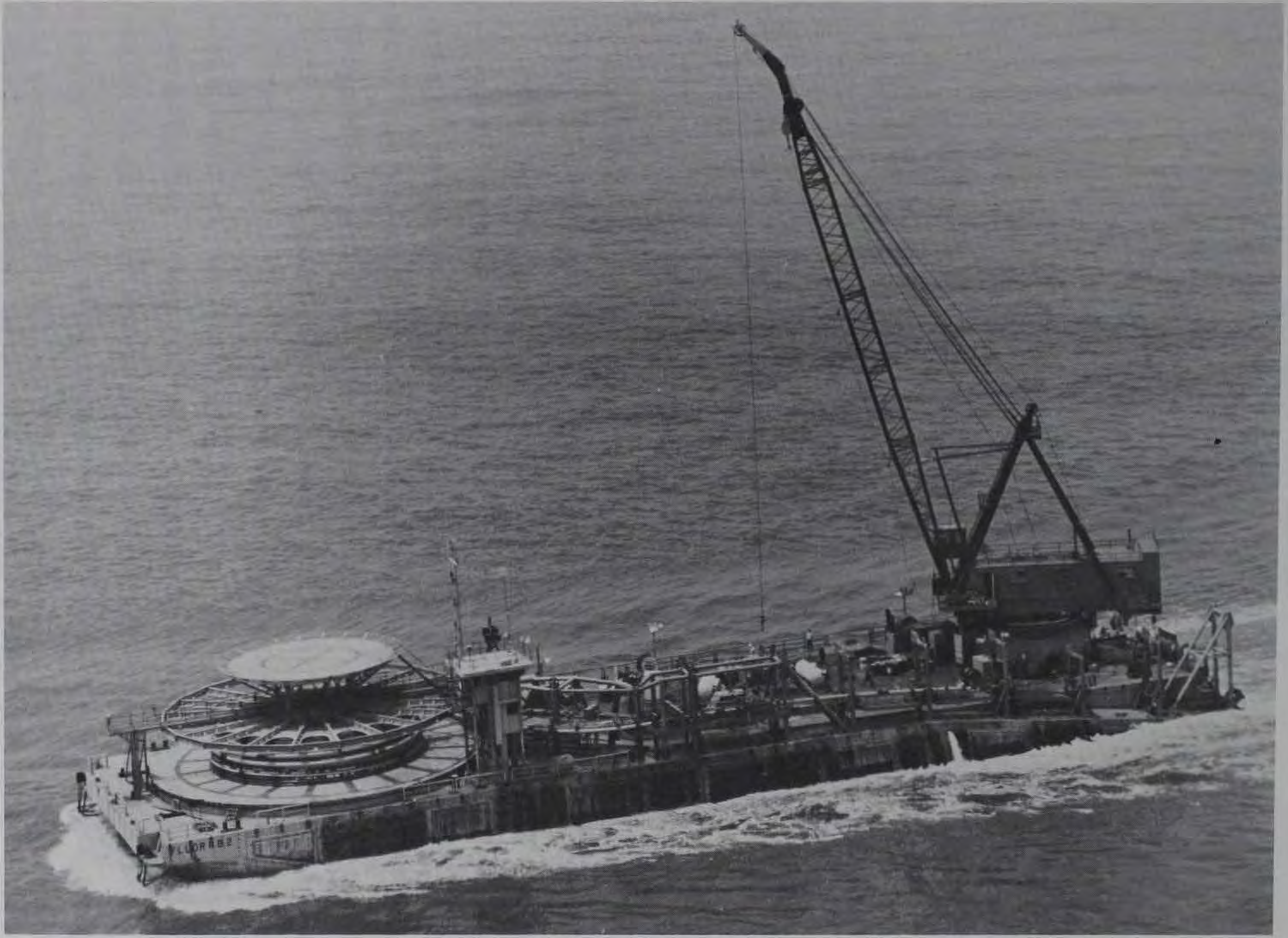
273. The discharge of tankers directly ashore has been a problem that has received a great deal of attention for a number of years. Several developments have been made toward solving this problem such as the retrievable hoseline, collapsible tanks, single-point mooring buoys, and explosive anchors.

274. By the time a port is secured, however, more reliable systems will be required to transfer large quantities of petroleum ashore. The most practical means of laying a pipeline very rapidly appears to be the reel-type pipe laying barge. The Flour RB-2 (fig. 65) is capable of carrying 18,000 ft of 12-in.-diam American Petroleum Institute pipe and laying it at a rate of 2 miles per hour. With this piece of equipment, a normal submarine pipeline could be laid in one work day.

275. Presently, the only proven method of mooring a tanker at an exposed site that is compatible with Army requirements is a single-point mooring buoy, as shown in fig. 66. This mooring method consists of a buoy normally 25 to 40 ft in diameter, a set of four to eight anchors and chains to hold the buoy in place, and hoselines to connect the buoy to both the tanker and submarine pipeline. The Army currently owns three International Marine and Oil Development Corporation single-point moorings of this type.

(Courtesy of Tidewater Marine, New Orleans, La.)

Fig. 64. Tide Mar 19 petroleum barge



(Courtesy of Flour-Ocean Services, Houston, Tex.)

Fig. 65. Flour reel-type laying barge

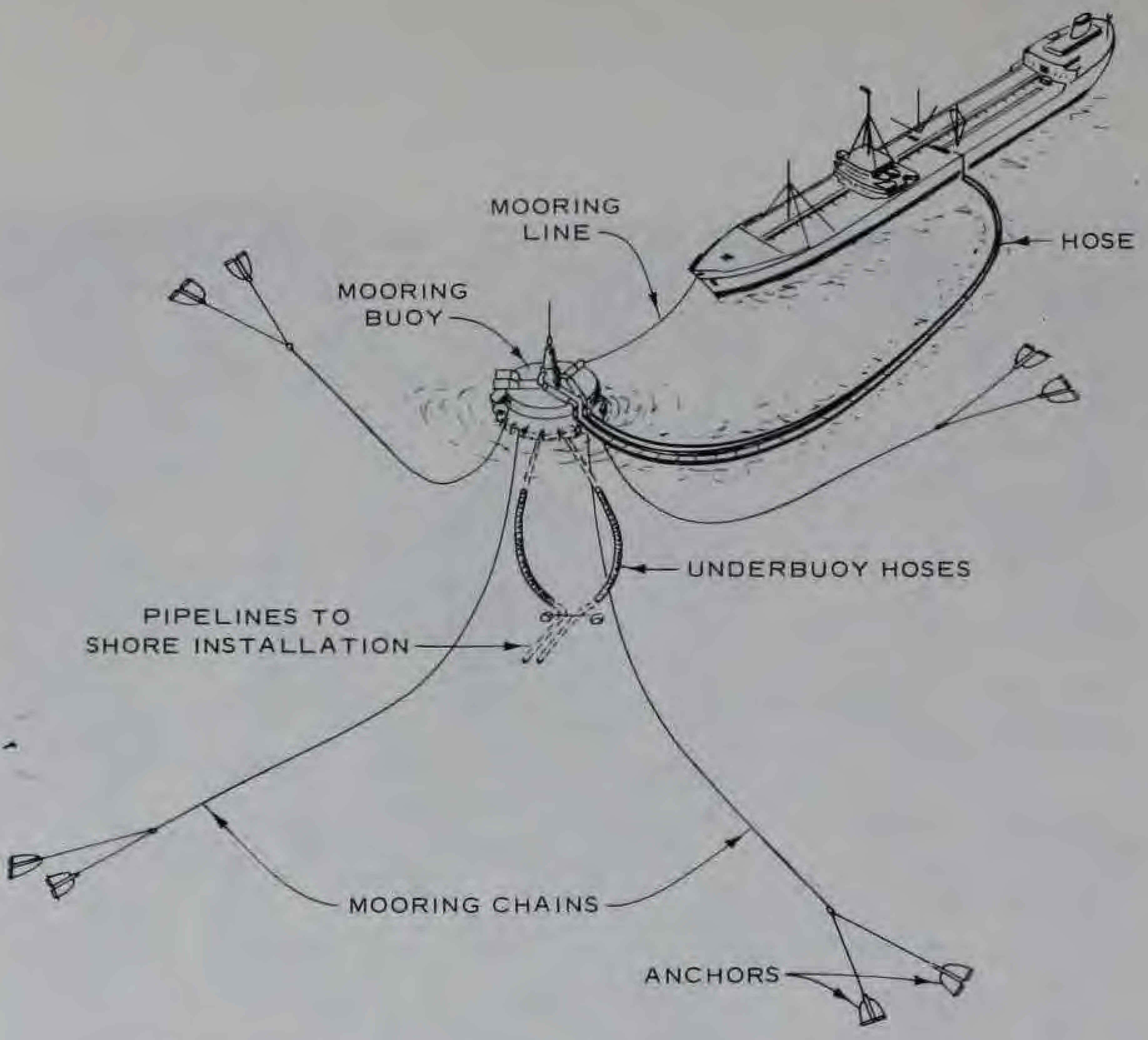


Fig. 66. Single-point mooring system

276. Any buoy moored with heavy chain is a problem to install. Three-in.-diam chain weighs 83.3 lb per linear ft in the air and 72.5 lb per linear ft in water. If a buoy is equipped with eight legs each 500 ft long, the total weight of chain required will be about 166.6 short tons. Eight 15,000-lb anchors would account for another 60 tons. Handling weights of this magnitude in open water requires special equipment and trained personnel. The connection of a hoseline from the buoy to the submarine pipeline is a problem requiring skilled divers. This hoseline also requires considerable maintenance.

277. Because of its complexity of installation, the conventional single-buoy mooring system is not ideally suited to military applications. Alternatives were investigated, and a system believed to be most suitable was the rigid-arm mooring system patented by Equipment Mecaniquer & Hydrauliques (EMH) of Paris, France (fig. 67). This mooring system is unique in that it relies on a spreading foundation rather than either anchors or piling. Its rigid arm also eliminates the problem

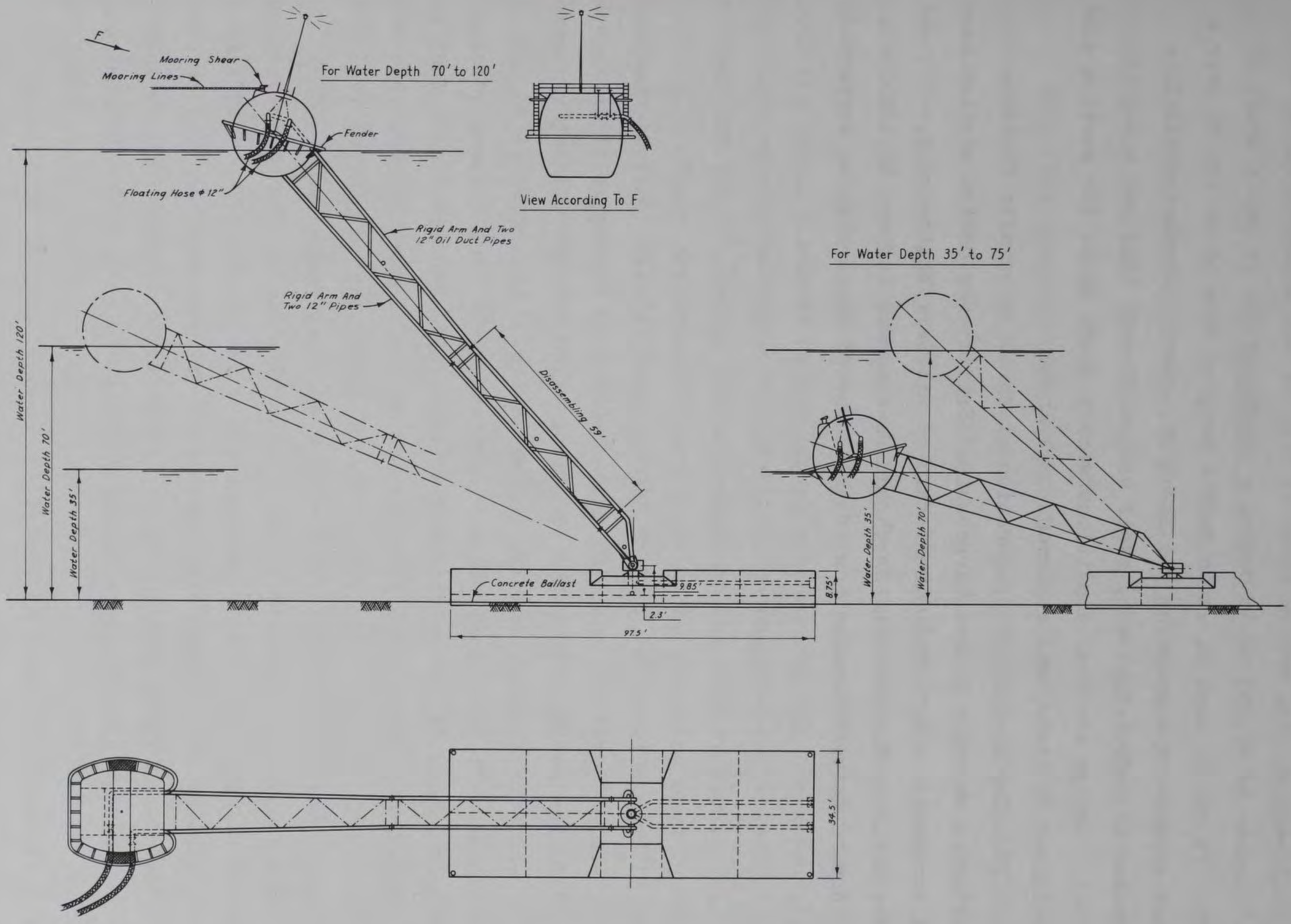


Fig. 67. Rigid-arm mooring system for a 63,000-dwt tanker

associated with the hoseline from the buoy to the submarine pipeline. The rigid-arm mooring system shown in fig. 67 was designed for a "hand size" tanker of 63,000 dwt's having a length of 760 ft and a draft of 42 ft. It can be used in water depths ranging from 35 to 120 ft over a bottom capable of supporting 400 lb/sq ft. Design mooring conditions comprised an 8-ft (eight sec) swell with a 30-knot wind and a 4-knot current. Design survival conditions were a 20-ft swell (14 sec), a wind velocity of 75 knots, and a current of 7 knots.

278. The shipping configuration of the buoy permits it to be transported aboard a Seabee barge ship. Preliminary design studies have been furnished to both the Directorate of Military Engineering, OCE, and to the Mobility Equipment Research and Development Center, Fort Belvoir, Va. A more detailed evaluation of this concept appears to be warranted.

PART IV: DELONG BARGE

Description and Past Uses

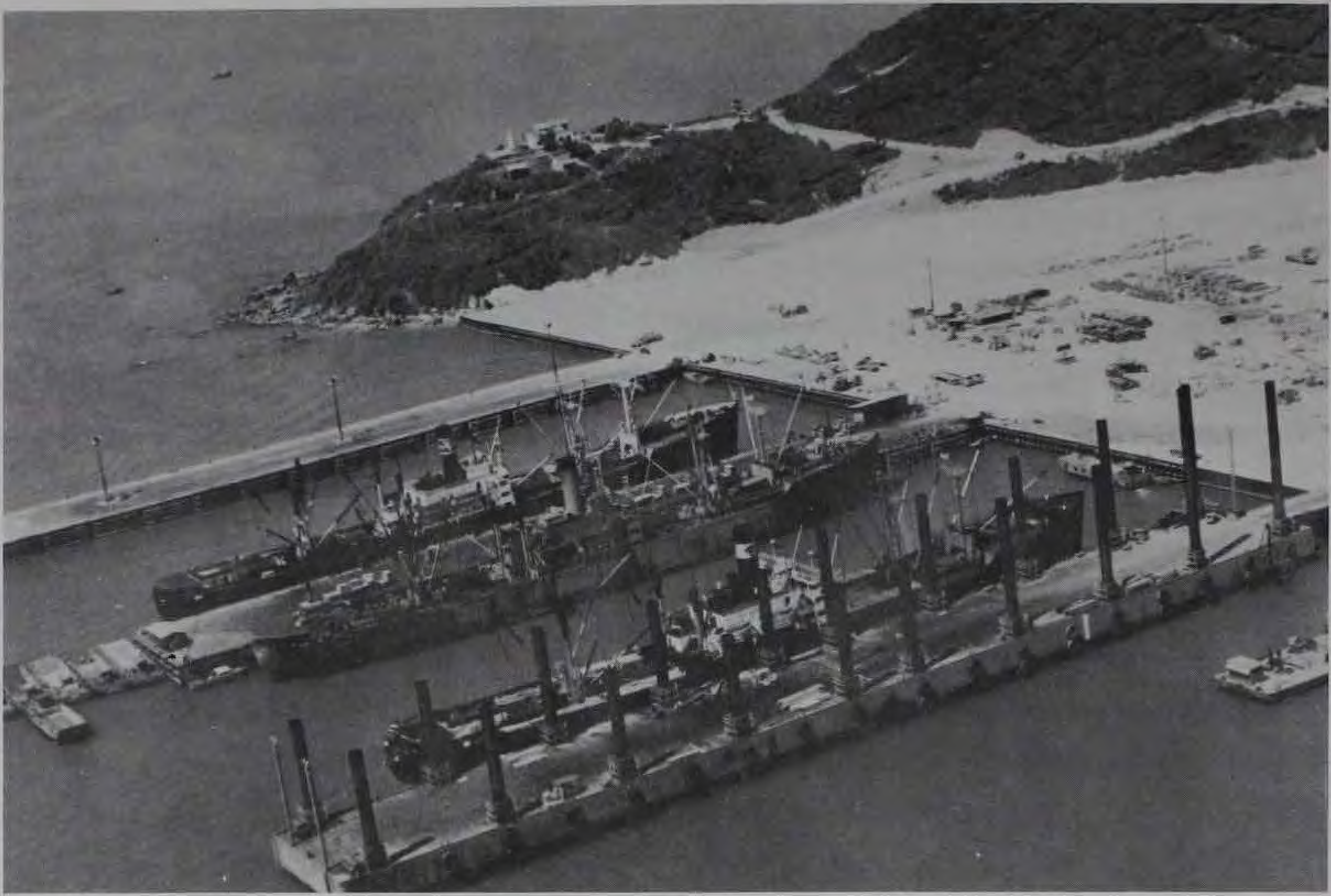
279. The self-elevating spud barge pier, commonly known as the DeLong pier, consists of barge units and a number of spuds or caissons that support the barge above the water.

280. The design of the barge allows it to be towed from a preparation site to its point of erection. Once at its erection site, the caissons are laced, and the jacking operation can be started. The air jacks are approximately 10-1/2 ft in height and 10 ft in diameter. Each is capable of raising 500 tons at a nominal rate of 12 ft per hour with individual strokes of 12 in. The barge is supported from each jack by four tie bars. A master control panel synchronizes the operation of the air jacks on all caissons. The jacks can be operated individually through the use of control panels mounted on the side of each.

281. There are presently two sizes of barges being used in the military system. The "A" barge is 300 ft long, 80 ft wide, and 13 ft deep. It is supported by ten 6-ft-diam caissons and ten 500-ton-capacity jacks. The "B" barge is 150 ft long, 60 ft wide, and 10 ft deep. It is supported by six 6-ft-diam caissons and six 500-ton-capacity jacks. Two "A" barges were used to form a 600-ft-long pier at Da Nang, South Vietnam (fig. 68). A combination of "A" barges to form the pier and "B" barges to form the causeway was used as a temporary facility at Vung Ro Bay, South Vietnam (fig. 69).

282. The DeLong barge is a welded steel honeycomb-like structure consisting of plates and stiffeners. It is designed to support a uniform live load of 600 lb and a medium-sized tank. The barge is divided into watertight compartments to maintain safe subdivision in case of accident during towing. Normally, 4- by 12-in. wood planking is laid over and secured to the steel deck plate to provide a nonskid working surface.

283. Each caisson is essentially welded steel pipe that is 6 ft in diameter and 140 ft long and weighs approximately 80 tons. The wall



(Courtesy of DeLong Corporation, New York, N. Y.)

Fig. 68. "A" barge pier at Da Nang, South Vietnam

(Courtesy of DeLong Corporation, New York, N. Y.)

Fig. 69. Combination "A" and "B" barge pier and causeway at Vung Ro Bay, South Vietnam

is normally 1-1/2 in. of ASTM A-131 steel. A steel diaphragm is positioned 19 ft from the bottom end of each caisson to develop end bearing after sufficient penetration has been obtained to ensure lateral stability. Another diaphragm is fitted 40 in. from the top end, thus enabling the caisson to float. The load-carrying capacity of the pier and the depth of penetration of the caissons depend upon both the foundation soils and the unbraced length of the caissons. Generally, the erection site will be suitable if the foundation soils consist of consolidated clays and nonplastic materials. If the soils are impenetrable, organic, or highly plastic, they are generally considered to be unsuitable.

284. For a temporary installation, the barge is jacked to the desired elevation, the grippers within the jacks are inflated to 350 psi, and the shutoff cocks and isolation valves are closed. This supports the barge on the caissons as long as the pressure is maintained. If a semipermanent installation is required, the caissons are driven or jacked to sound footing or refusal. Then the barge is welded to the caissons, the jacks removed, the caissons cut off flush with the barge deck, and cover plates installed over the caisson wells. Before the caissons are welded off, however, a thorough foundation settlement analysis should be performed.

Utilization as Container Facilities

285. One approach to providing container facilities at military ports would be to utilize existing "A" and "B" DeLong barges in the Army's inventory to support container gantry cranes. Installations of this type are being used at Cam Rahn Bay, South Vietnam (fig. 70), and in a civilian operation at Pier 13, Staten Island, New York (fig. 71).

286. The barges at both of these facilities have been modified to accept the wheel loads of the container gantry cranes. Gantry cranes of this type weigh approximately 1,000,000 lb and have design wheel loads of 100,000 lb with wheels on 5-ft centers. The gantry cranes at the Cam Rahn Bay installation have a lift capacity of 27.5 tons and will not lift a commercial 40-ft container loaded to its maximum capacity of 67,200 lb.

(Courtesy of Paceco, Alameda, Calif.)

Fig. 70. DeLong barges supporting gantry cranes at Cam Rahn Bay

(Courtesy of Raymond International, New York, N. Y.)

Fig. 71. DeLong barges supporting gantry cranes at Pier 13, Staten Island, New York

To load and off-load the larger container ships, the gantry cranes require a lifting reach of approximately 115 ft. This varies with the crane's location with respect to the face of the pier, with the width of the fendering system, and with the beam of the ship.

287. The minimum desirable lifting capacity of a military gantry crane is 30 long tons at a waterside reach of approximately 105 ft. The gage of the support rails normally varies from 30 to 50 ft. Most commercial facilities are now using gages up to 100 ft. The longitudinal clear spread between legs should permit the handling of hatch covers up to 50 ft wide. Container gantry cranes can average about 20 container lifts per hour and represent the most efficient means of off-loading container ships.

288. The erection time for a gantry crane is from 2 to 5 months, depending on the availability of the parts, construction equipment, and skilled technicians to erect it. At least one (preferably two) 100- to 150-ton-capacity mobile crane is required for erection.

289. The initial cost of the gantry-type container crane varies according to its specifications, but normally it is approximately $1,000,000. The lead time for manufacturing these cranes is about a year. In a military operation, a crane of this size would present enormous security problems, and repair would be extremely difficult. Also, there is some question as to whether existing DeLong "A" barges can be economically modified to support these cranes.

290. Another approach to off-loading container ships is through the use of large mobile truck- and crawler-mounted cranes operating from the deck of a DeLong barge (see fig. 72). Table 2 and fig. 73 show the manufacturer's rated capacities for a number of commercially available cranes. The capacities shown do not reflect any reduction for lift block or spreader bar. These two pieces of equipment may weigh up to 15,000 lb. Fig. 73 shows that the large mobile cranes are not capable of lifting 40-ft containers weighing 67,200 lb beyond a 90-ft radius. This means that the heavy containers must be loaded into the inboard cells of ships with large beams. This does not appear to be a great problem because most 40-ft containers will probably not exceed 50,000 lb.

(Courtesy of Manitowoc, Manitowoc, Wis.)

Fig. 72. Container off-loading through the use of crawler-mounted cranes

Table 2

Characteristics of Various Commercially Available Cranes

Manufacturer	Model	Type of Lower Works	Length of Boom, ft	Hoist Speed with 50^k Rig fpm	Approximate Gross Weight kips	Maximum Capacity at Minimum Radius, kips	Minimum Radius ft
P&H	6250 TC 80 tons	Truck	150 Container tip	140	384.0	160.0	35
American	9520	Truck	150 92" tubular	80	301.0	218.0	27
Lima	7700	Truck	150	150	398.0	279.6	35
Manitowoc	4600	Crawler	150	112	494.6	227.7	29
American	11250	Crawler	150	163	494.0	271.0	29
LeTourneau	GC500	Gantry Rubber tires	120	170	708.5	150.0	29
Butters	50 tons	Stiffleg	150	38		112.0	36
American	S-40	Stiffleg	180	90 (380 hoist) 180 (550 hoist)		179.0	40
American	S-50	Stiffleg	200	90 (380 hoist) 180 (550 hoist)		368.0	50
Floating Crane	264 B	Pedestal (barge)	123.5	56		200.0	55

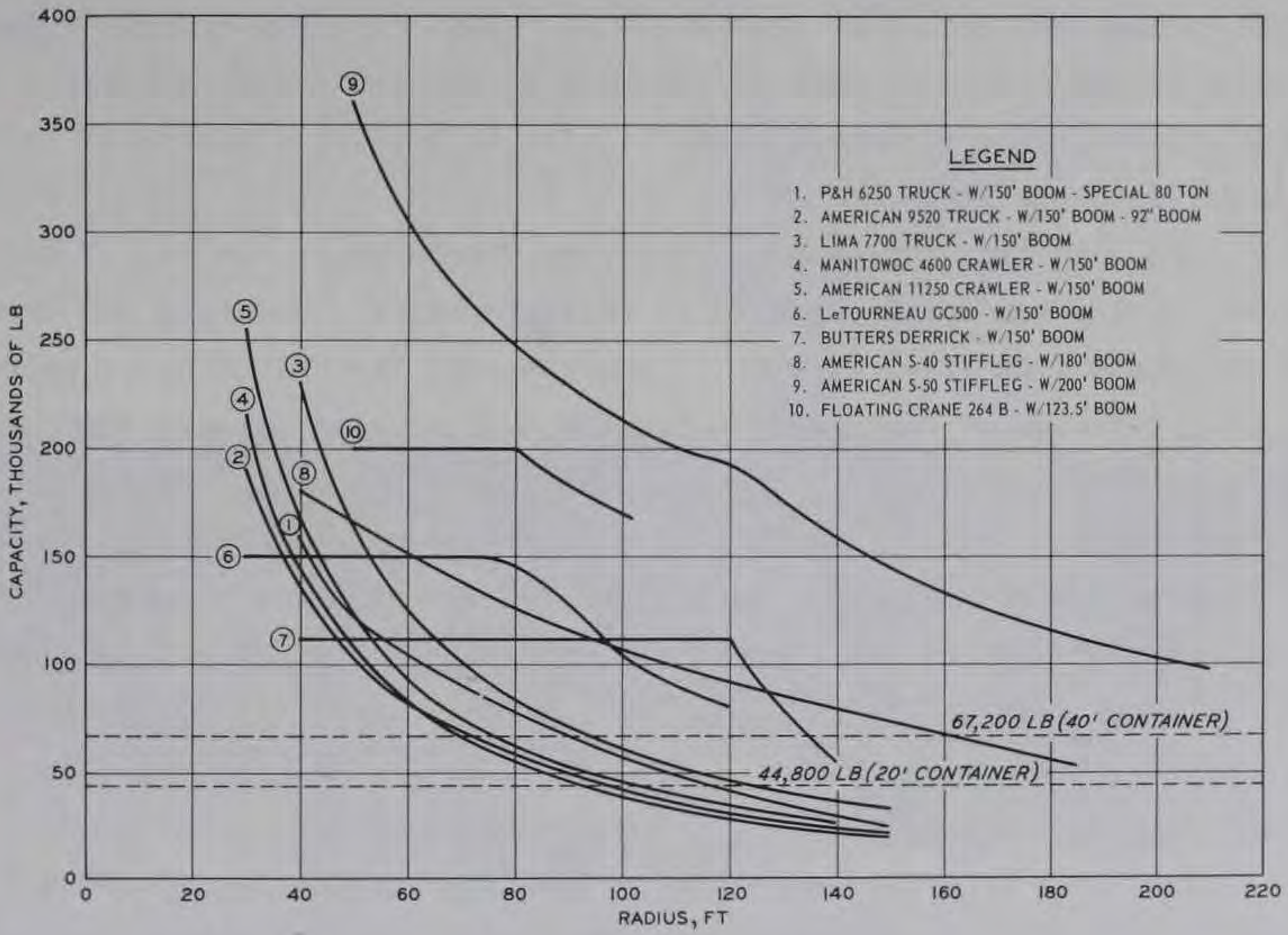


Fig. 73. Crane capacities

However, it will require that personnel responsible for the placement of containers on the ship know the unloading capabilities at the ship's destination so that the containers will be placed in cells that are within the lifting capabilities of the cranes at the destination.

291. The large truck- and crawler-mounted cranes (figs. 74 and 75, respectively) may weigh from 350,000 to 500,000 lb, depending on the model and counterweight required. A problem may arise if the DeLong barge is not structurally able to support these heavy loads. A simplified analysis of the DeLong deck indicates that the deck may require strengthening before a large mobile crane can operate on it.

292. If the DeLong barges have been installed as a temporary installation, caissons extending above the deck will possibly interfere with the swing of the crane's boom (see fig. 68). The operator may be required to boom up and down to avoid the caissons in loading and unloading containers. This could have a dramatic effect on the rate of containers being discharged or loaded. Ideally, a large mobile crane will average about 15 container lifts per hour. The cost of these large mobile cranes is about one-half the cost of the container gantry cranes. They also have the advantage of being able to perform a number of other heavy-lift operations.

293. A third approach to container discharge is the use of a series of fixed mounted stiffleg or whirley cranes. Mounting the cranes on platforms (see figs. 76 and 77) would permit the unloading of ships from either side of the pier and provide a clear area beneath the crane for the movement of cargo. The stiffleg system has a low initial cost, is easy to store and maintain, and is quickly erected. The platform could be added to the DeLong barges before towing to the TO and the crane assembled after the barges have been jacked into place. The cyclic times would be very close to those of a large mobile or crawler crane. The stiffleg crane also could be mounted on a barge and used for construction purposes.

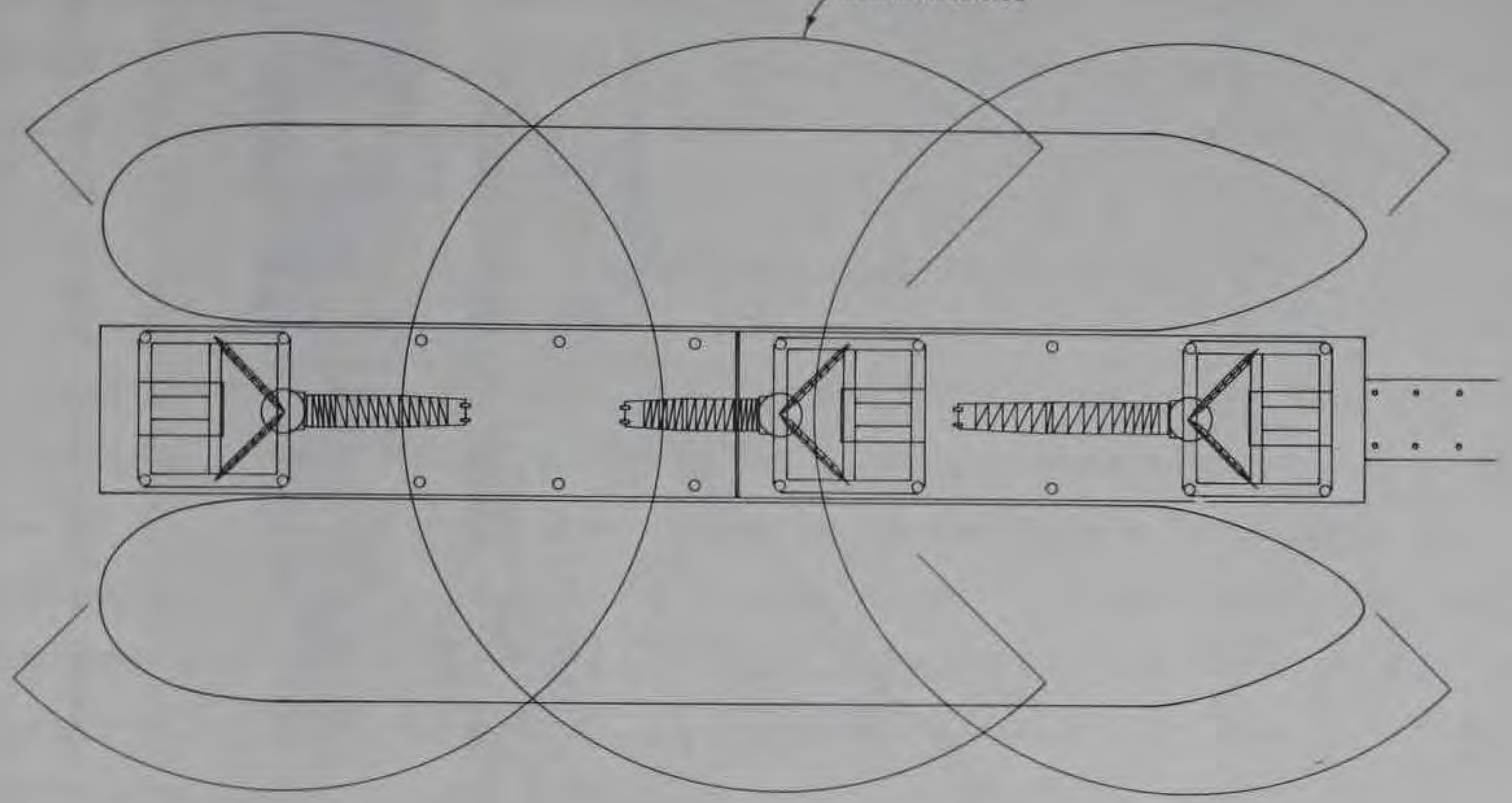
294. The DeLong barges were designed to support a uniform load of 600 psi on the deck. For container operations, new port facilities are being designed to support a uniform live load of 1,000 lb/sq ft.

(Courtesy of Clark Equipment, Lima, Ohio)

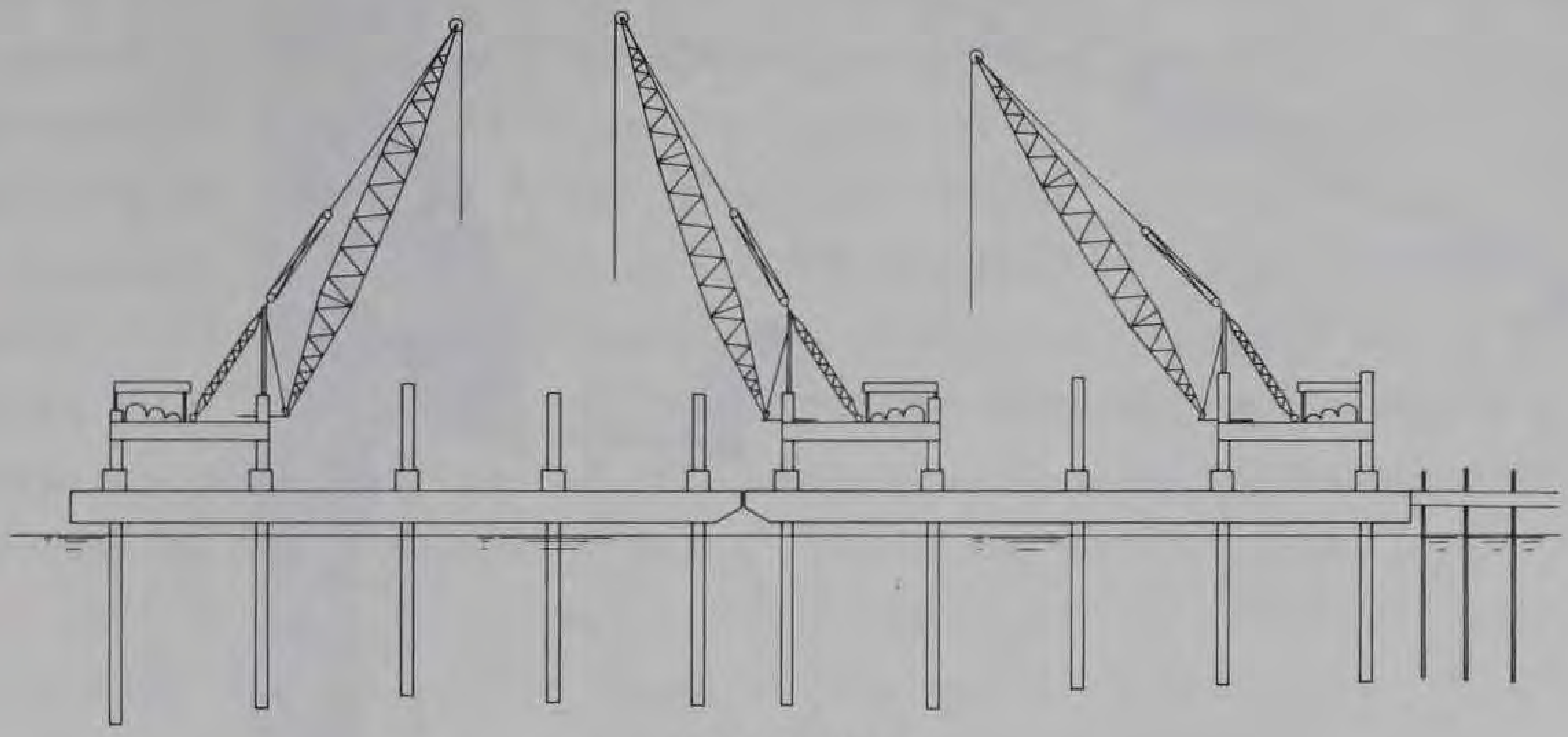
Fig. 74. Lima 7700 truck-mounted crane

(Courtesy of American Hoist and Derrick, Saint Paul, Minn.)

Fig. 75. American 11250 crawler-mounted crane



PLAN



SIDE ELEVATION

Fig. 76. American S-40 stiffleg cranes mounted on 300-ft DeLong "A" barges

(Courtesy of Nueces County Navigation District, Corpus Christi, Tex.)

Fig. 77. Stiffleg crane

For deck design, the concentrated wheel loads will usually be the governing factor. Concentrated wheel loads run as high as 80 kips for container handling equipment that is now commercially available. The deck system of the DeLong barge should be checked before permitting container equipment having high wheel loads to operate on it.

Shore Connections

295. The connection of the "A" and "B" DeLong barges with the shore is a construction task that has virtually been ignored. Although 79- by 30-ft girder spans are currently in the Army's inventory, the problem of installing a substructure for support is not addressed in Army publications. Installations in Vietnam employing these spans utilize 48-in. piling, which must be driven by a large pile hammer. These spans are also not capable of supporting large mobile cranes and container handling equipment. Panel bridging may be used to construct the girder spans but must be configured in a "deck" span arrangement rather than as the normal "through" span. The horizontal clearance limitation presented by the through span limits the efficient use of forklifts. Unreinforced Bailey decking is also not capable of supporting high concentrated wheel loads. Floating causeways would be appropriate only as an expedient measure because of the difference in elevation of the DeLong and the causeway pontoons. Earth and rock causeways may be employed but only after a study of the effects that they would have on the hydraulic regimen of the harbor. Also, stabilization of the sides of the causeway to protect it from the effects of wave and tidal action as well as from scour at the end of the causeway must be considered.

296. Because of the length of time and the effort required to construct the shore connections mentioned above, an investigation was made of the Navy's Ammi pontoon system as an alternative to employing DeLong "B" barges, as was done at a temporary installation at Vung Ro Bay, Vietnam (fig. 69). The Ammi pontoon (fig. 63), like the DeLong barge, is a spud-type barge that can be hoisted above the water. The Ammi, however, is designed primarily to supplement and replace the P or

T series pontoon causeway sections for the discharge of LST's and landing craft. The Ammi is designed for water depths of approximately 20 ft rather than the 40 to 50 ft of water in which a DeLong barge might be installed. It was concluded that standard Ammi causeway pontoons do not have sufficient structural strength to be employed as a causeway for the DeLong barges.

297. There appears to be a definite need for a self-elevating pontoon that is between the DeLong "B" barge and the standard Ammi pontoon in both size and strength. This barge should be compatible with either the LASH or Seabee system to permit it to be easily transported to an overseas TO. Its weight should not exceed the lift capability of Army floating cranes (100 short tons). It should be capable of functioning either as a flat-deck cargo barge or as a construction barge. The barge should be capable of performing as an elevated causeway module in water depths of 50 ft. Piling would, therefore, have unbraced lengths of approximately 75 ft. Each barge should be able to support the largest equipment that could be operated on the DeLong barge while in its elevated position. It should provide a roadway width of at least 22 ft (preferably 35 ft). It is desirable that it be equipped to handle liquid cargo after minor modifications, and its hull should be suitable for ocean touring at moderate speeds.

Analysis of the DeLong "A" Barge

Reasons for analysis

298. The DeLong "A" barge was analyzed because it was questionable whether it had the horizontal stability to resist the berthing forces that large new container ships could impose on it. In Vietnam, large earth moving tires were used for fendering the DeLong piers. This system was apparently satisfactory. Most of the ships used in Vietnam were break-bulk vessels of a C-4 class or less. The new container ships have dwt's that are two or three times greater than that of C-4 class vessels.

299. As will be discussed in Part V, the horizontal load and the

energy-absorption capacities of the fendered structure are two of the many factors that must be taken into account when designing fenders. The DeLong barge was investigated in this study due to a lack of information concerning the horizontal load and energy-absorption capacities of the barge.

300. The DeLong is essentially a box girder consisting of plates and stiffeners, and a thorough analysis would require the use of plate and membrane theory. An analysis of this type was not within the time limit or funding capability of this study. Therefore, a simplified approach was used to determine the horizontal load and energy-absorption capacities of the barge with different lengths of caissons.

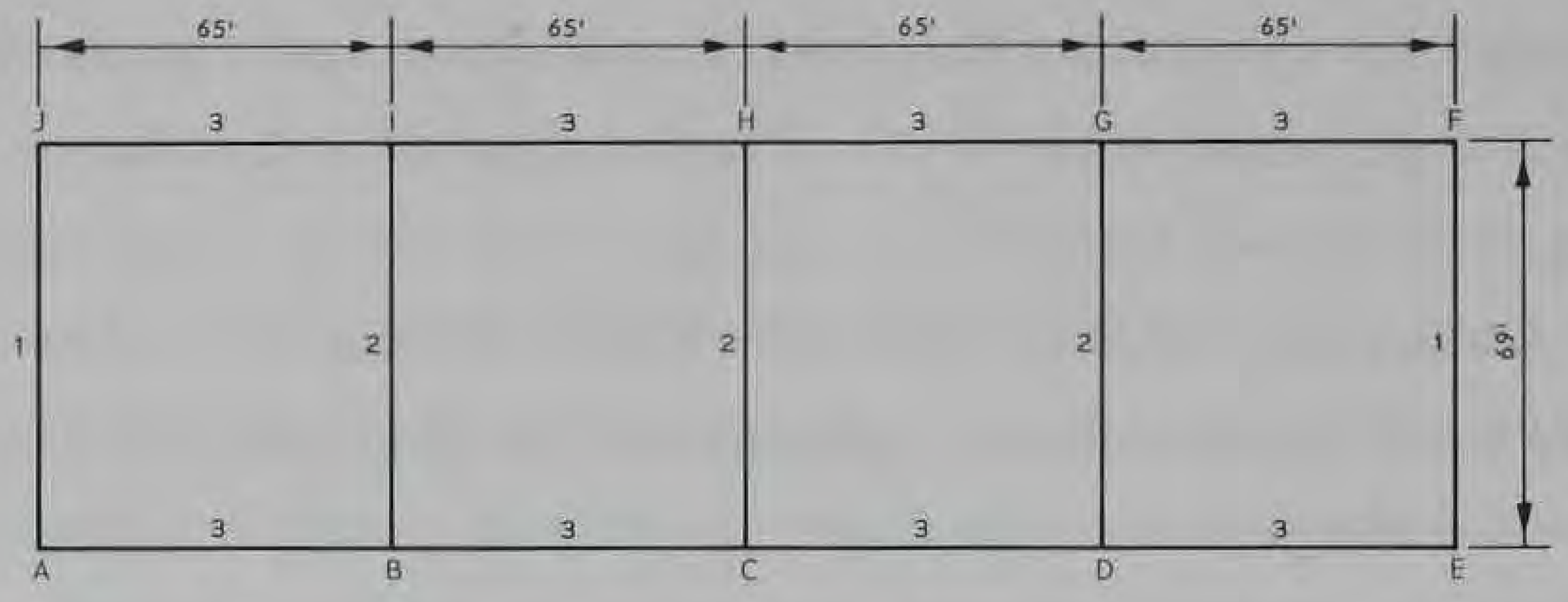
Calculations

301. Hand calculations were performed using two caissons and a section of the barge as a beam connecting the tops of the caissons. The bottoms of the caissons were assumed to have a point of fixity 10 ft below the bottom. A rigid frame analysis was performed for four different lengths of caissons (40, 50, 60, and 70 ft). The allowable horizontal load was determined when the design stress was reached in a caisson. The resulting allowable horizontal loads seemed to be conservative, due to the fact that the barge is a large and very stiff structure and that more than just two caissons would be resisting the berthing forces.

302. A second analysis was performed in which the barge was considered a one-story rigid frame with each caisson being a column and sections of the barge being beams between the columns (fig. 78). The moment of inertia, section modulus, radius of gyration, and weights were calculated for the caissons and assumed beams using the geometric and material properties shown in figs. 79 and 80.

303. After the geometric properties of the members had been calculated, the moments, forces, and displacements in the frame were determined using the three-dimensional beam element of the General Structural Analysis Program (SAP) presented in reference 23. Computations were made for caissons with unbraced lengths of 40, 50, 60, and 70 ft. The unbraced lengths were chosen by assuming one point of fixity at the bottom of the barge and the other point 10 ft below the ground level.

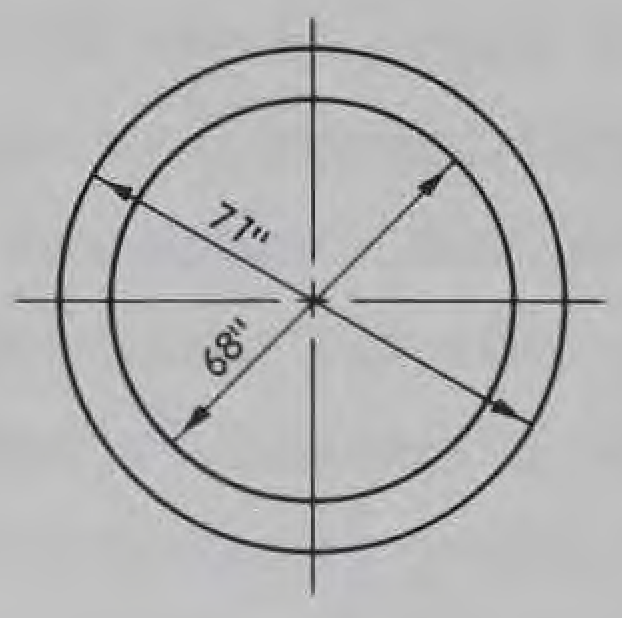
Isometric view



Top view

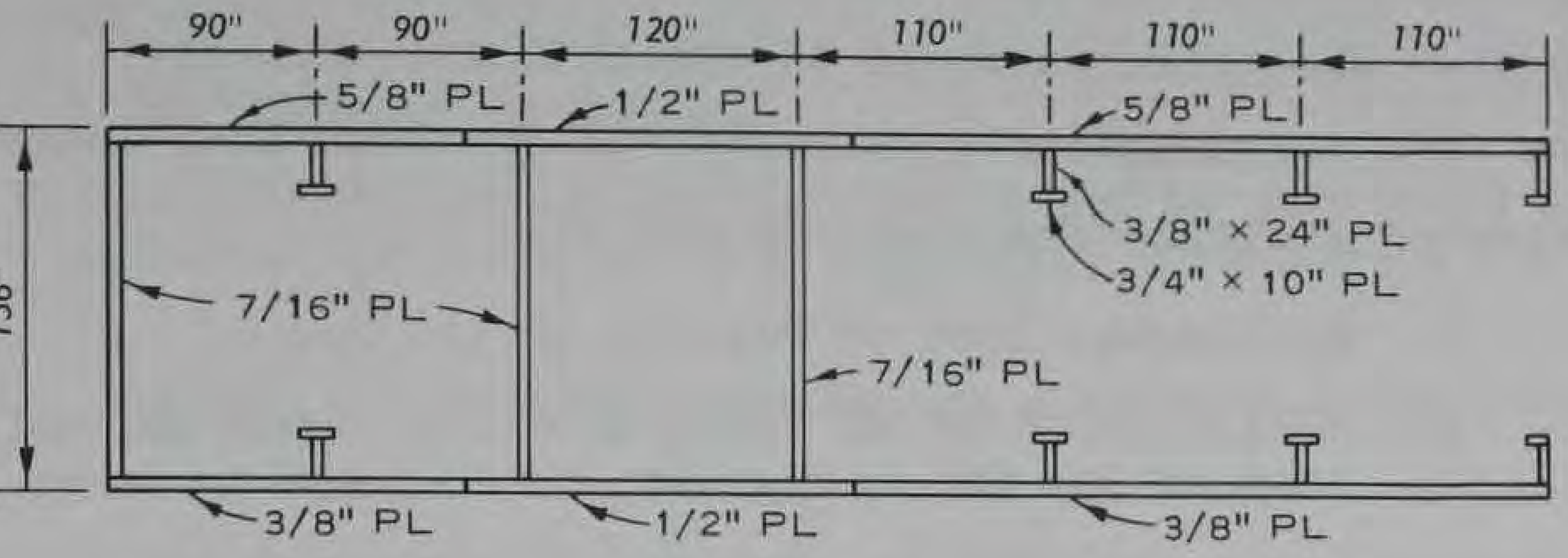
Fig. 78. Simplified frame used in barge analysis

	MATERIAL PROPERTIES			
MATERIAL	BEAM 1 ASTM A-131 STEEL	BEAM 2 ASTM A-131 STEEL	BEAM 3 ASTM A-131 STEEL	COLUMNS ASTM A-131 STEEL
TENSILE STRENGTH	58,000 PSI	58,000 PSI	58,000 PSI	58,000 PSI
YIELD POINT	32,000 PSI	32,000 PSI	32,000 PSI	32,000 PSI
YOUNG'S MODULUS	29×10^6 PSI	29×10^6 PSI	29×10^6 PSI	29×10^6 PSI
POISSON'S RATIO	0.25	0.25	0.25	0.25
WEIGHT DENSITY	0.283 LB/IN.^{3}	0.283 LB/IN.^{3}	0.264 LB/IN.^{3}	0.283 LB/IN.^{3}

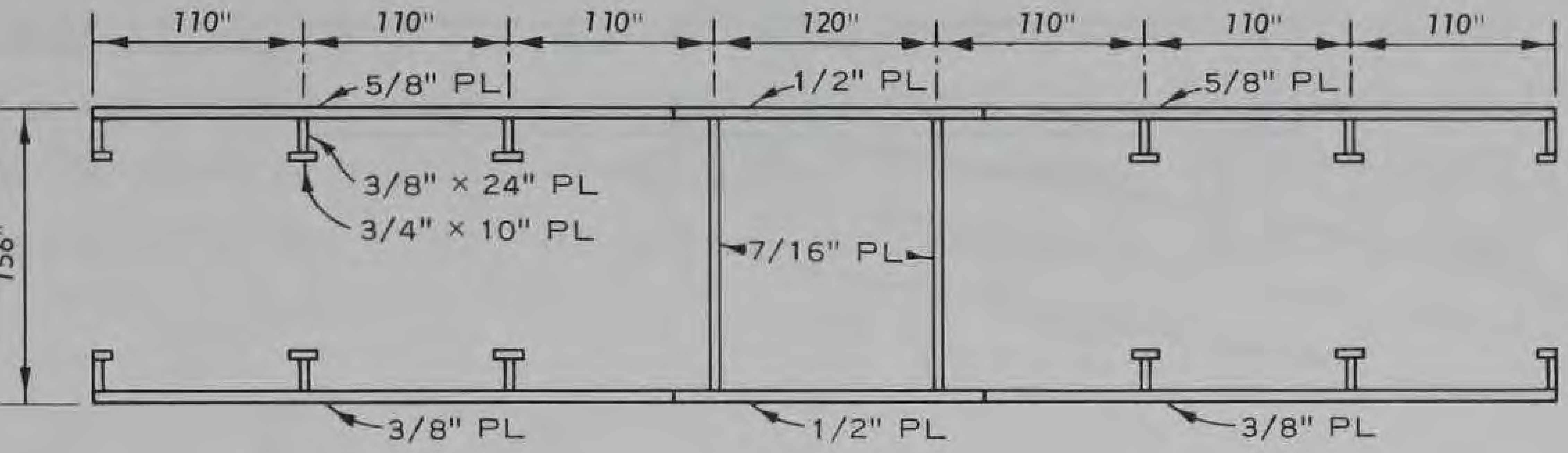


Cross section

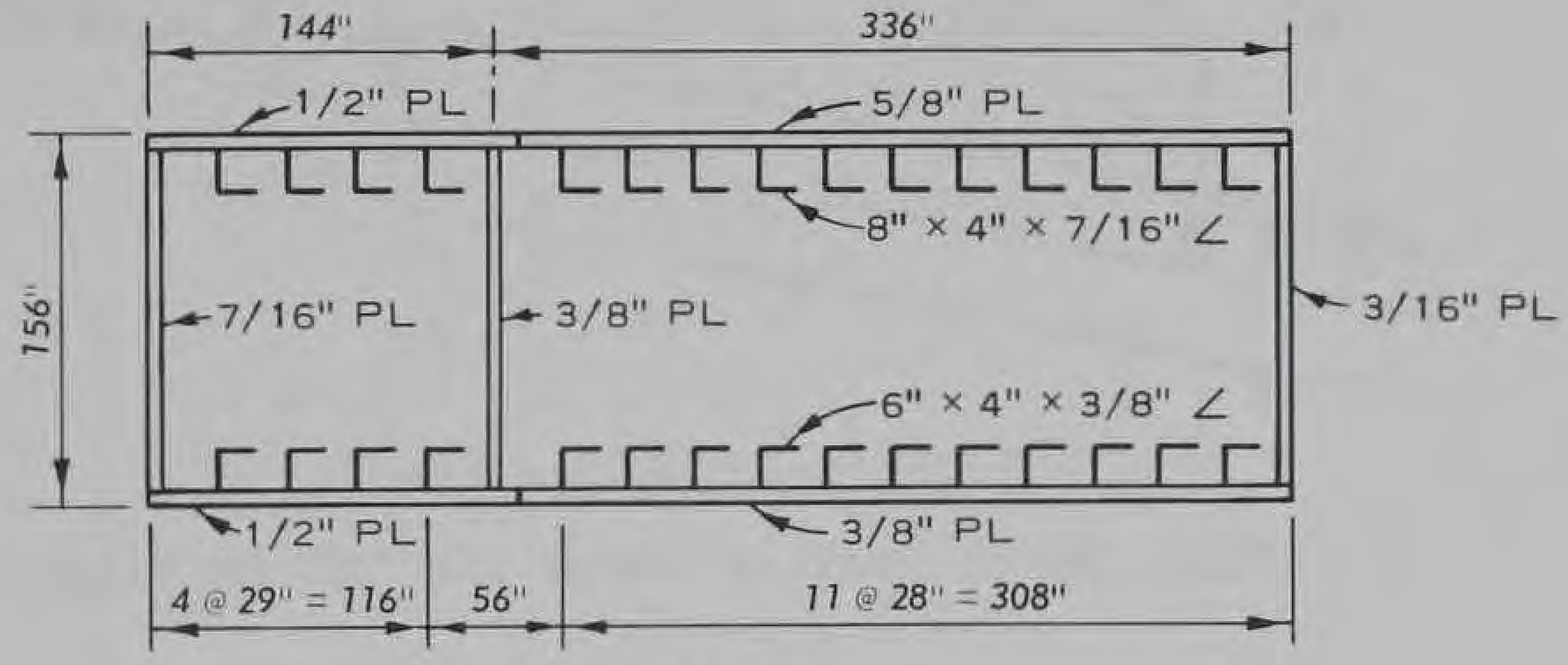
Fig. 79. Material properties and cross section used for geometric properties of columns



BEAM 1



BEAM 2



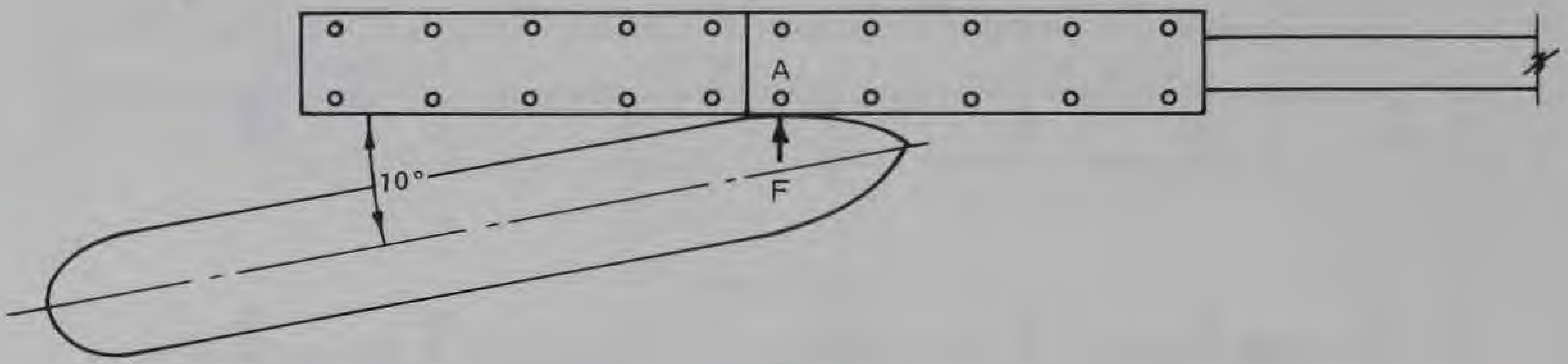
BEAM 3

Fig. 80. Cross sections used for geometric properties of beams

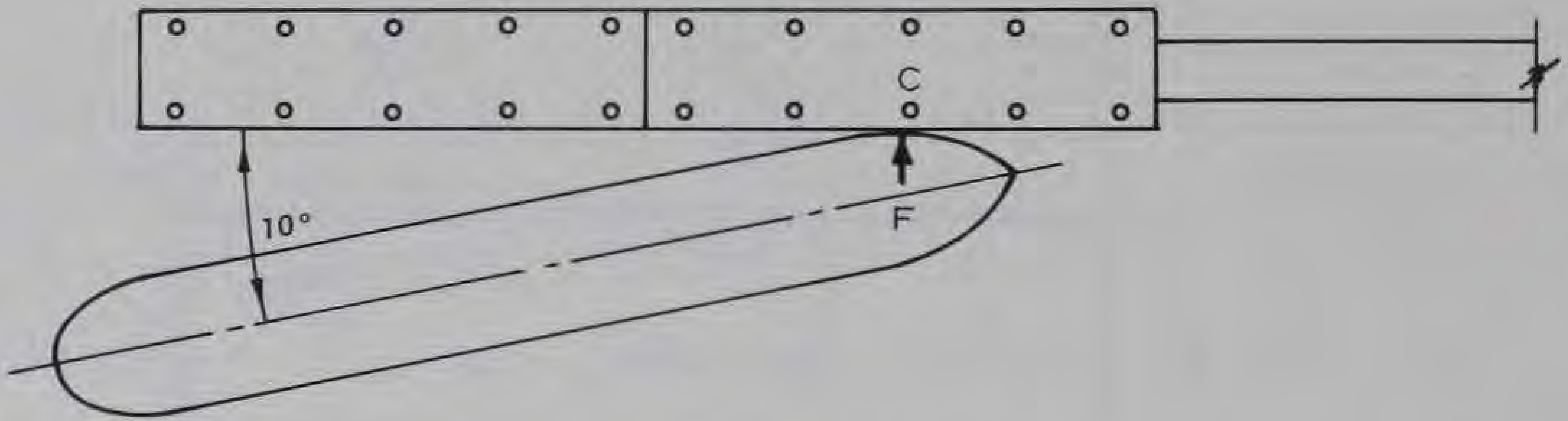
Therefore, 20-, 30-, 40-, and 50-ft water depths were represented. The forces, moments, and stresses were calculated based on the assumption that there would be no localized failure in the plate structure of the barge and that the caissons would be the critical members.

304. The calculations were performed for four load cases at each of the unbraced lengths (see figs. 78 and 81):

- a. Horizontal load at Point A of the frame.
- b. Horizontal load at Point A of the frame and uniform deck load of 250 lb/sq ft.
- c. Horizontal load at Point C of the frame.
- d. Horizontal load at Point C of the frames and uniform deck load of 250 lb/sq ft.



a. End-of-barge loading



b. Center-of-barge loading

Fig. 81. Barge loading cases for SAP calculations

The allowable horizontal load was determined for each load case when the stresses in the critical caisson satisfied the following requirements:

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \approx 1.0$$

where

f_a = computed axial stress

F_a = axial stress that would be permitted if axial face alone existed.

f_b = computed bending stress

F_b = compressive bending stress that would be permitted if bending moment alone existed (0.6×32.0 ksi = 19.2 ksi)

305. The results of the calculations performed using the SAP program are shown in fig. 82 for the horizontal load placed at point A of the barge and in fig. 83 for the horizontal load placed at point C of the barge.

306. The energy-absorption capacity of the barge was calculated by multiplying the calculated allowable horizontal force by one-half of the displacement at the point where the force was assumed to be applied. Fig. 84 shows deflection versus allowable horizontal load for the load at point A of the barge, and fig. 85 for the load at point C of the

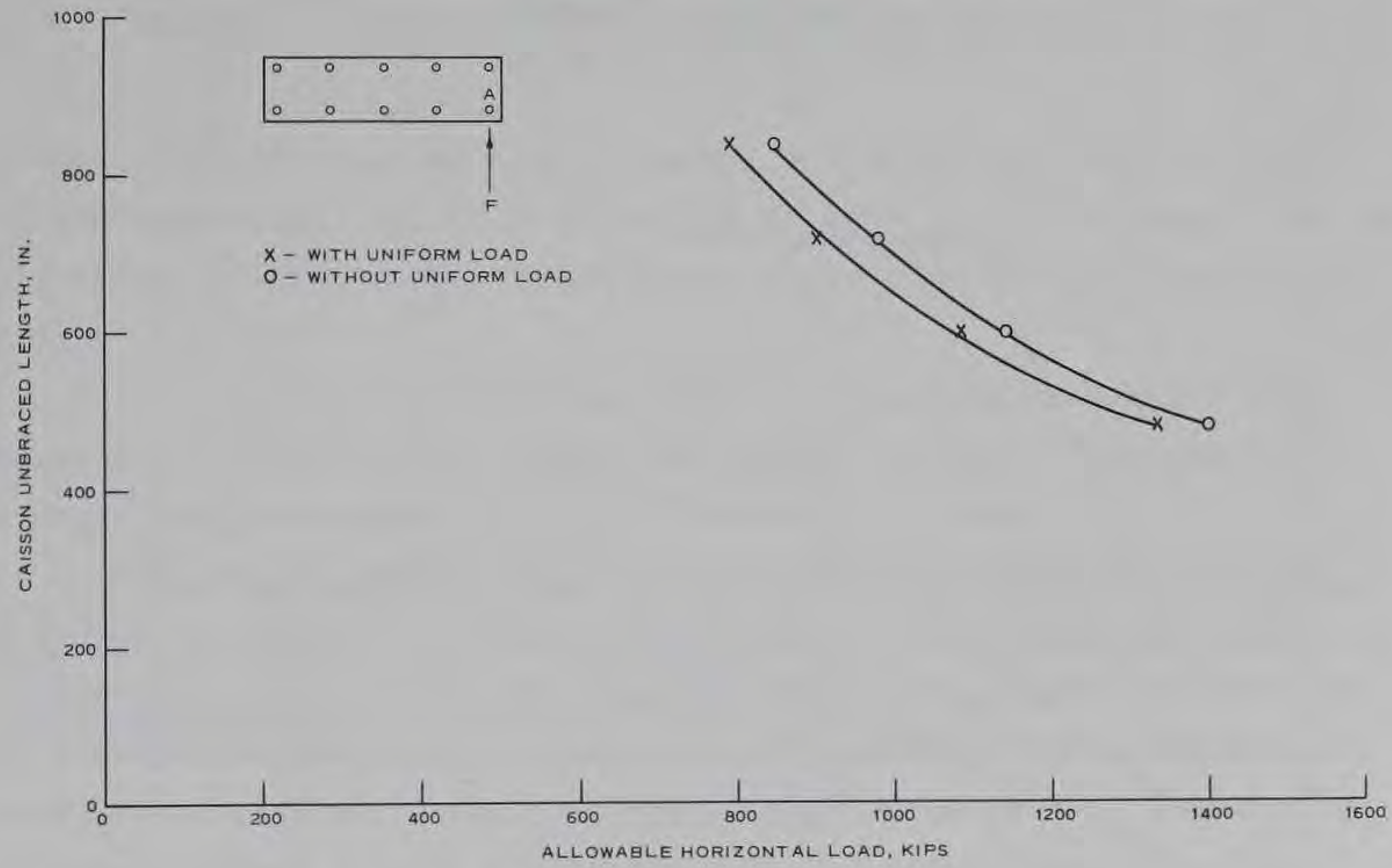


Fig. 82. Results of SAP calculations for horizontal load at point A of barge

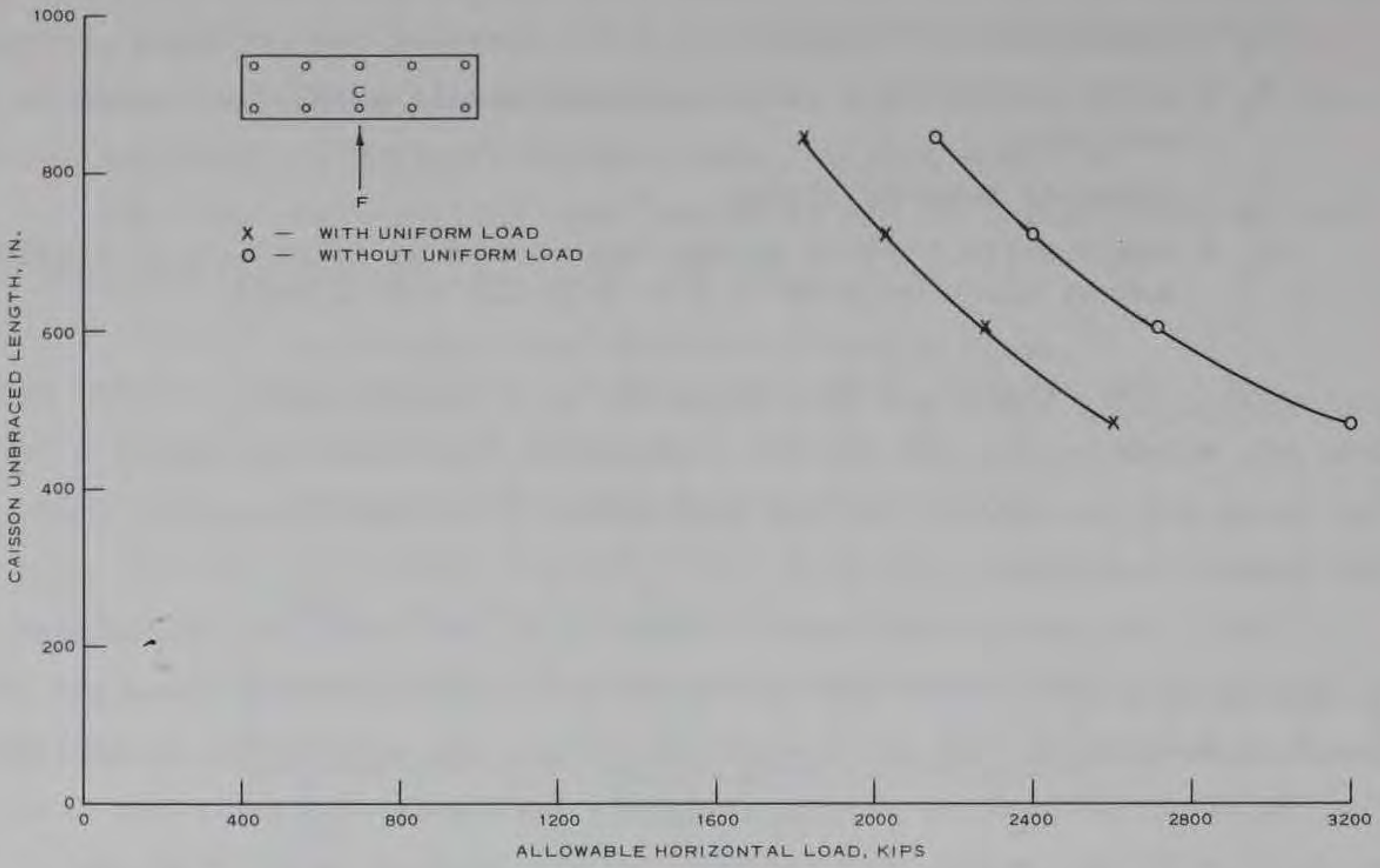


Fig. 83. Results of SAP calculations for horizontal load at point C of barge

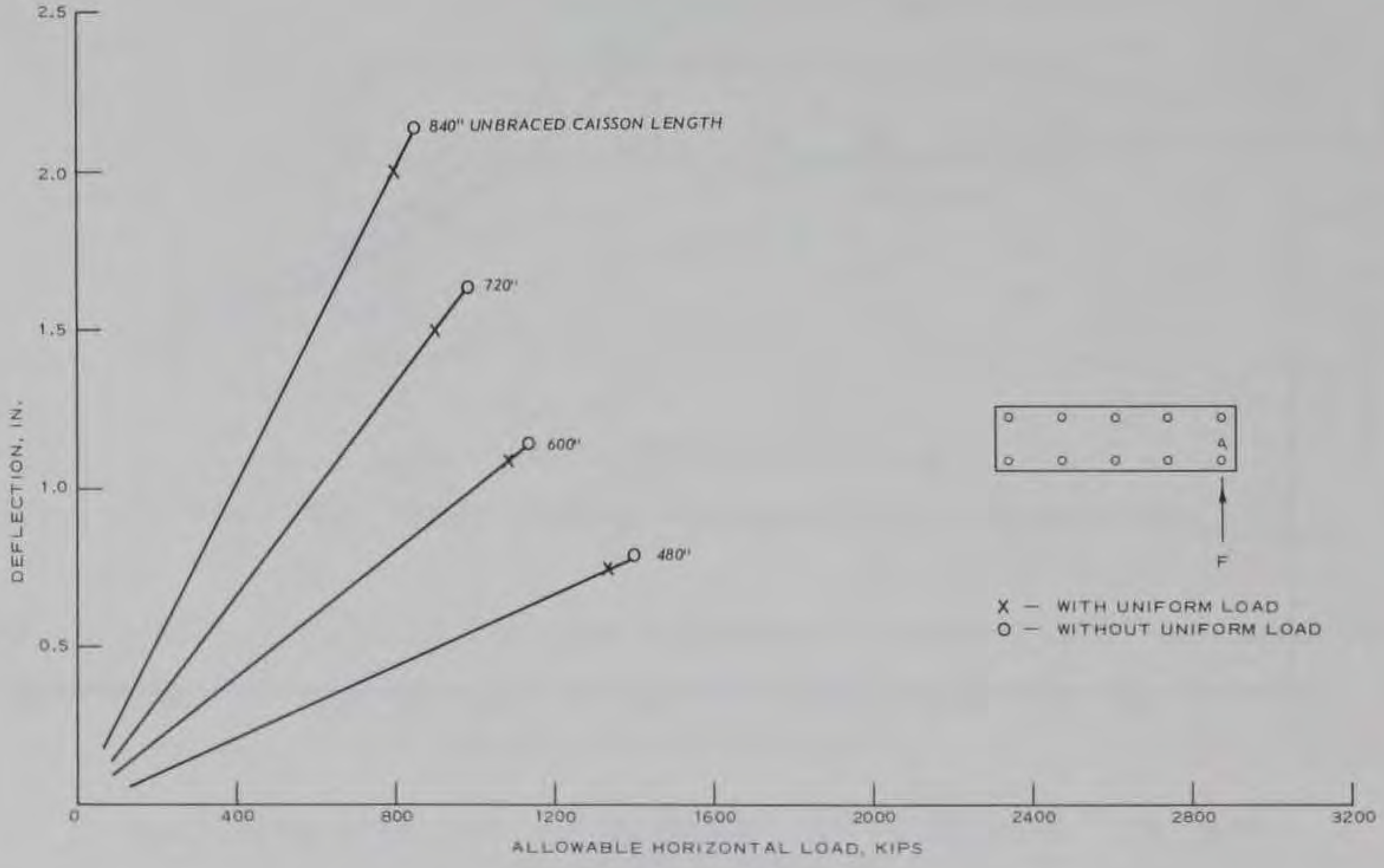


Fig. 84. Deflection versus allowable horizontal load for load at point A of barge

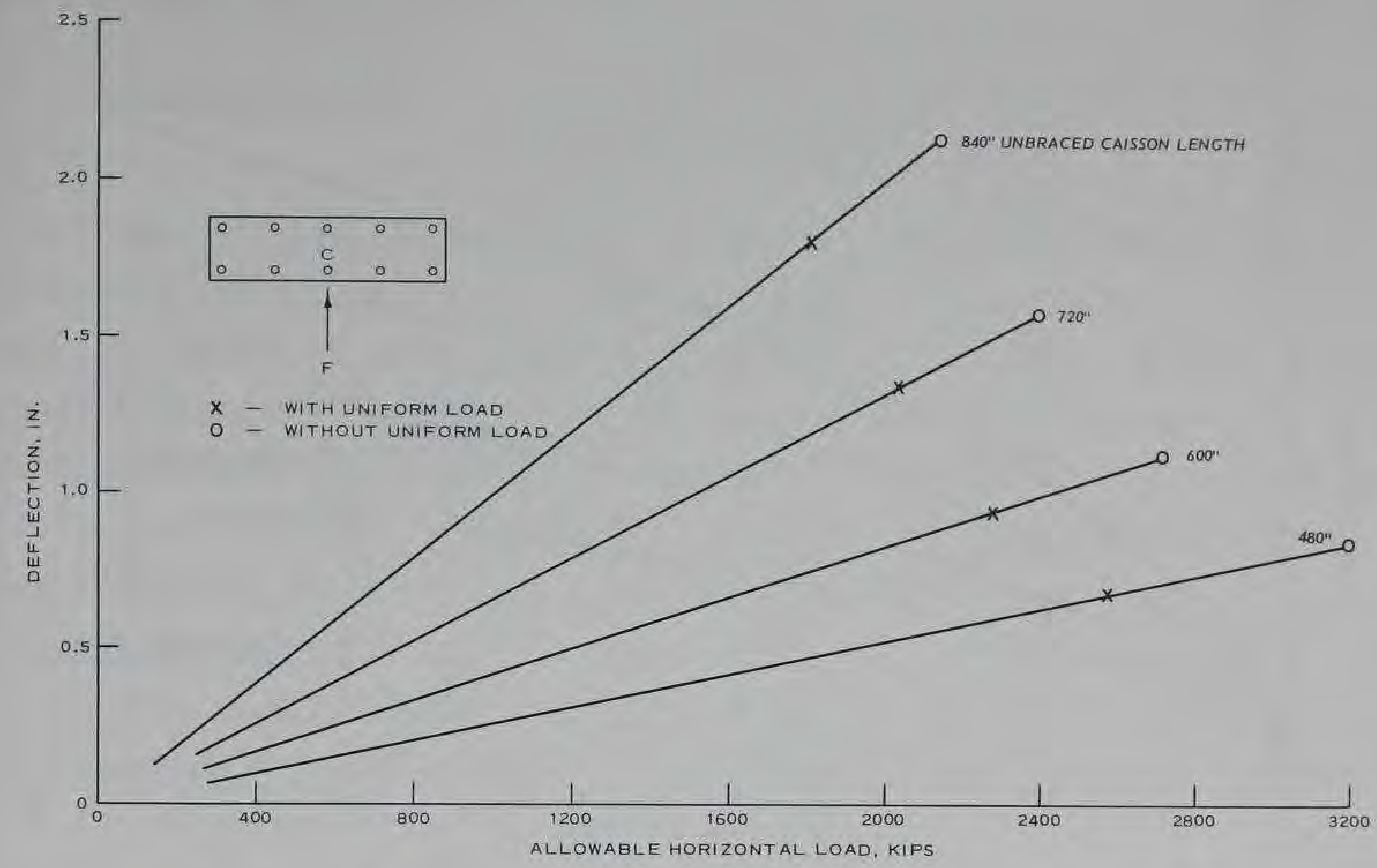


Fig. 85. Deflection versus allowable horizontal load for load at point C of barge

barge. Fig. 86 shows deflection versus energy for the load at point A of the barge, and fig. 87 for the load at point C of the barge. The application of these curves in designing fenders for DeLong barges is explained in Part V.

307. The calculations show that as the unbraced length of a caisson increases, the allowable horizontal force decreases and the energy-absorption capacity of the structure increases.

308. It is emphasized that the loads and curves that were developed for the DeLong barge were calculated on a crude and simplified representation of the structural elements of the barge. The DeLong barge is a complicated structure consisting of plates and structural shapes. Localized damage would probably occur to the side and deck plating of the barge before failure occurred in the caissons. The curves in figs. 84-87 should be used with good engineering judgment until a more

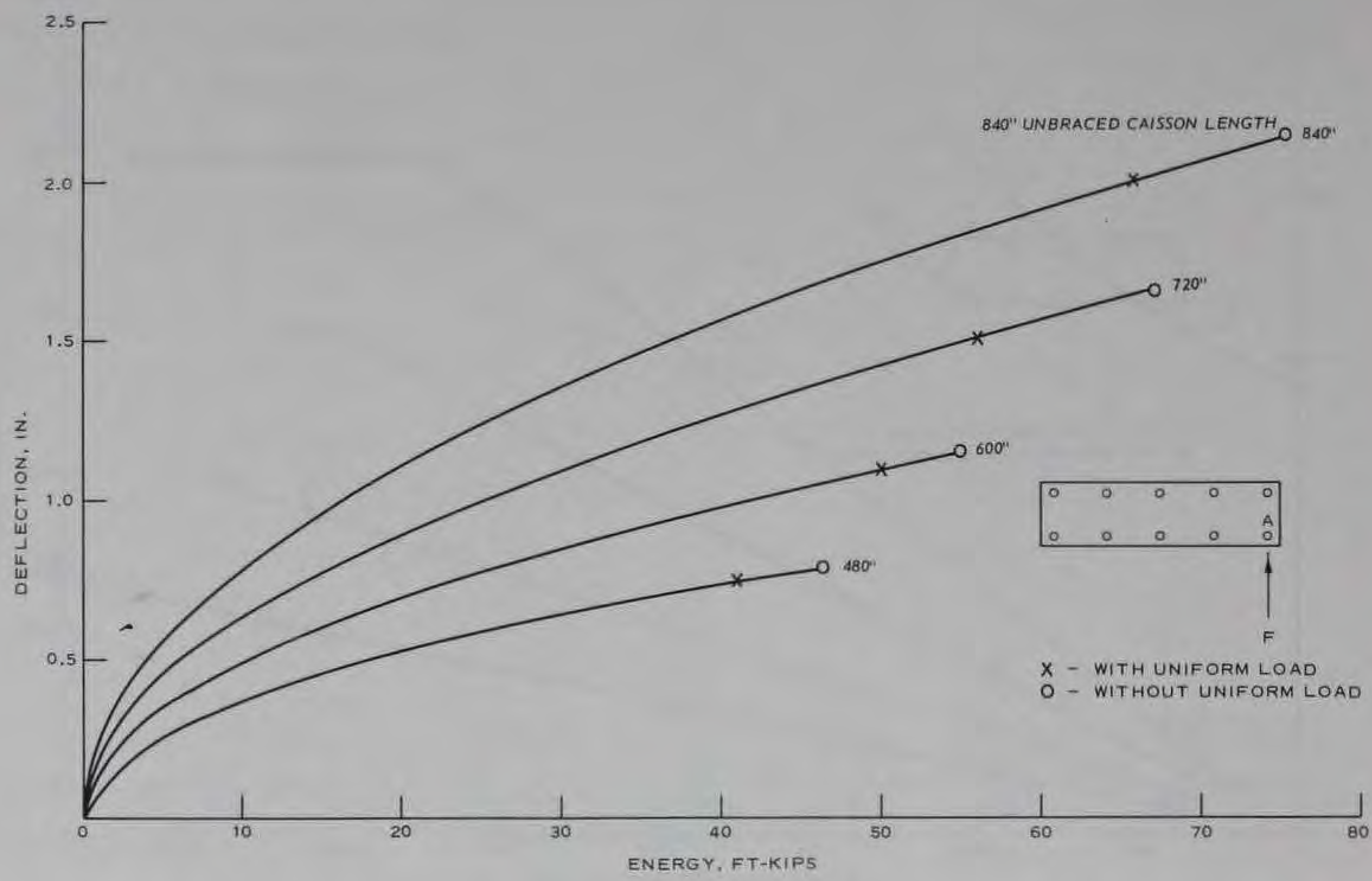


Fig. 86. Deflection versus energy for load at point A of barge

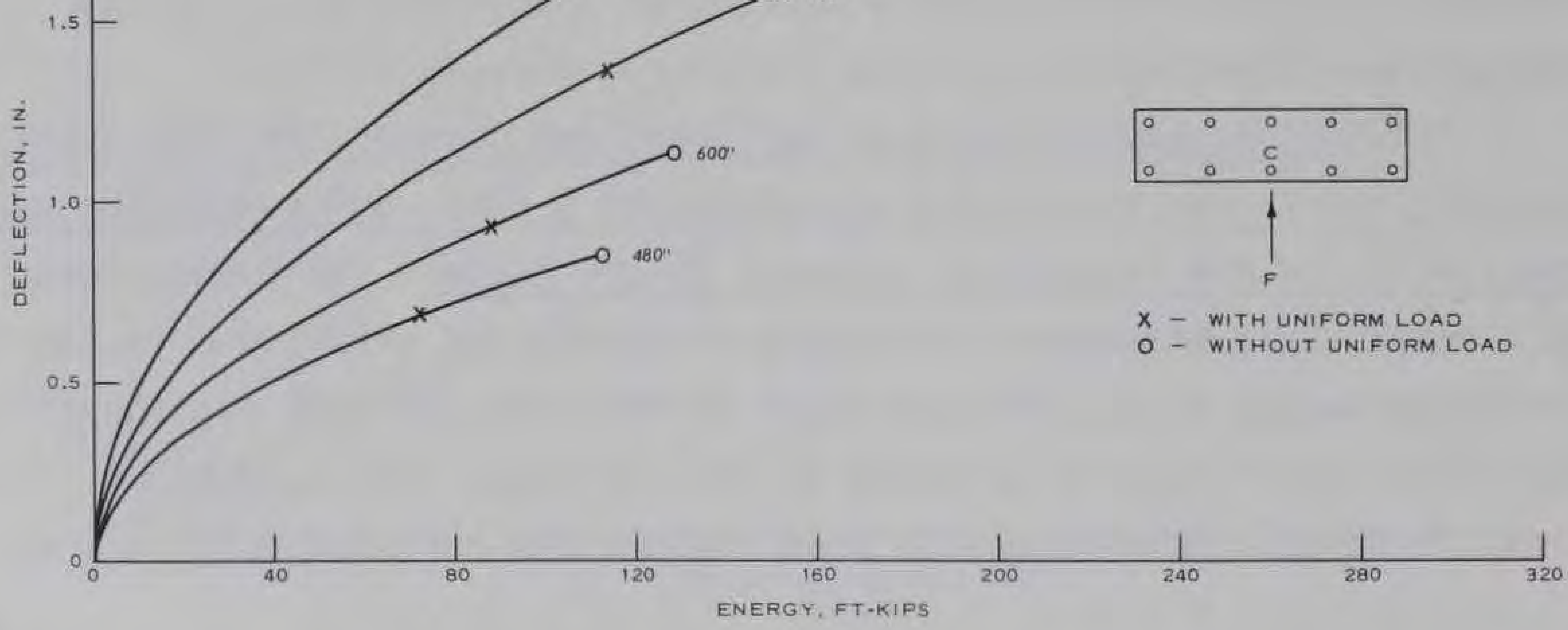


Fig. 87. Deflection versus energy for load at point C of barge

exact analysis can be performed and the structural capabilities of the DeLong barge determined.

Caisson Installation

309. An investigation was performed of the design and installation techniques for the caissons of the DeLong barges owned by the Army. Through the use of a one-dimensional stress wave computer program developed at Texas A&M University,[24] it was possible to analyze stresses in a piling during simulated driving. Because of funding limitations, it was decided to limit the objective of the study to either verifying existing procedures or defining any problems that may warrant further investigation.

310. A pile hammer was chosen which met the specifications listed in paragraph 9.c of TB 5-360-1.[25] The hammer had a 40,000-lb ram weight and a 3-ft stroke. The caisson had the standard 1-1/2-in. wall thickness and a diaphragm (plug) 19 ft from the bottom.

311. The general findings of the study were that the caissons in their present configuration are not suited for driving. The soil plug increases the mass at the bottom of the caisson to such a magnitude that driving stresses immediately above the plug exceed the allowable strength of the steel walls. Resistance resulting from inertia limits the driving capacity to approximately the same that can be obtained from jacking. Damage to the caisson in the form of bulging and buckling at or immediately above the bottom plug prevents the caisson from being completely withdrawn from the deck well without first cutting off the bottom 20 to 25 ft.

312. There are a number of steps that can be taken to reduce the stresses developed in a caisson during driving. For instance, the walls can be increased in thickness. Although this would increase the allowable bending moment in the caissons, the greater allowable bending moment would improve the barge's ability to withstand horizontal loads. Another remedial step would be to reduce the size of the soil plug or eliminate it altogether. The problem with this is that the location

of the bottom diaphragm determines the amount of penetration that can be obtained before end bearing is developed. If the diaphragm is installed at the tip and the foundation soil happens to be dense sand, it is extremely likely that the 500-ton maximum jacking force will be reached before fixity against rotation is achieved. A penetration of 25 to 30 ft is normally required to achieve fixity. If fixity is not developed, the allowable bending moments in the caissons are greatly reduced; consequently, the allowable horizontal loading of the barge is greatly reduced. If the diaphragm is not installed and foundation soils are highly plastic, full end bearing will probably not develop and, without it, neither will the required 500 tons capacity.

313. One suggested solution to this problem is to install two diaphragms, one at or near the tip and the other approximately 30 ft from the tip. If the soil would not permit sufficient penetration to achieve fixity, the bottom diaphragm could then be cut out with a torch or the pile could be driven with a hammer.

PART V: FENDERS AND DOLPHINS

Factors in Designing Fenders

314. The design of fender systems for marine structures requires working knowledge of the factors influencing the design. Some of these factors are:

- a. Size and berthing velocities of ships.
- b. Magnitudes of surge and wave action.
- c. Hull configurations of ships and other vessels using the facility.
- d. Allowable force and deflection of pier or wharf structure.
- e. Soil conditions.
- f. Velocity and direction of winds.
- g. Tidal variation.
- h. Velocity and direction of currents.
- i. Availability and cost of materials, skilled labor, and equipment.
- j. Skill and experience of pilots.
- k. Difficulty of approach.
- l. Availability of tugboats.
- m. Amount of list that will occur in vessels, especially in floating cranes and derricks.
- n. Willingness of operating personnel to maintain mooring lines.
- o. Presence and activity of marine borers and other causes of gradual deterioration.
- p. Design life of the facility.

Due to this large number of factors, it can be easily understood why a single standard design for all sites would not be appropriate.

315. The purpose of a fender system is to protect both the vessel and the docking facility from damage resulting from relative motions between the two. The berthing forces are usually the most critical because loading is concentrated over a fairly small portion of the facility. There are situations, however, when a ship will be retained at a

pier under environmental conditions that would normally be considered too dangerous to risk berthing, and these situations should be examined. A ship approaching from an angle of 10 deg may come in contact with as little as 10 to 30 linear ft of the fender. After securing, the same ship will normally have about one-half its length breasting against the fender.

316. Table 3 (from reference 26) shows some of the forces from winds and currents acting on various types of ships. Inspection of this table readily reveals the importance of mooring a ship parallel to strong currents. Although both the wind and current forces can be considered as static, when they are combined with surge forces, they can impose large roll and surge movements on a vessel. Under this situation, a highly resilient fender system may tend to amplify movement of the vessel. If a natural frequency with large movements is established, major damage can be inflicted to the pier, the ship, and the fender within a very short period of time.

317. The danger of sustaining major damage to a discharge facility by keeping a surging vessel at berth during adverse conditions can seldom be justified. Past operations have apparently relied upon the ship's master to determine the conditions that would warrant having a ship removed from the pier. This practice of relying on the judgment of the master is apparently based more on responsibility for the ship's safety rather than on knowledge of the structural properties of the pier. Maximum deflections that the pier and fender can tolerate under loading can normally be determined from an analysis of the structure. This information can then be used to rationally analyze the possibility of the structure being damaged. The most direct approach would be to monitor the amount of deflection occurring in the fender system. If it approaches the maximum design level, then the ship should be moved.

318. There are also steps that can be taken to discourage the development of large movements of vessels caused by wave and surge action. The principle involved is one of changing the natural frequency of the ship and its mooring system so that it is out of phase with the

Table 3

Ship Data for Mooring Operations
(from Reference 26)

Vessel	Length (ft)	Beam (ft)	Draft (ft)		Loaded Displacement (long tons × 1,000)	Area (ft^2 × 1,000)								Force (kips)							
						Above Waterline				Below Waterline				30-Knot Wind				4-Knot Current			
						Bow		Beam		Bow		Beam		Bow		Beam		Bow		Beam	
			Light	Deep		Light	Deep	Light	Deep	Light	Deep	Light	Deep	Light	Deep	Light	Deep	Light	Deep	Light	Deep
Assault Ships																					
LHA	820	106	--	26	39.3	5.6	--	--	--	--	2.8	--	21.3	20.2	--	--	--	--	33.8	--	1,055
LPD 4	570	84	17	22	16.9	3.5	3.1	30	27.2	1.4	1.9	9.7	12.5	12.7	11.2	108	98	12.7	21.7	472	614
LPA 249	564	76	22	27	18.0	2.9	2.5	22.8	19.9	1.7	2.1	12.4	15.2	10.4	9.0	82	72	11.1	23.5	610	751
LKA 113	575	82	15.1	25.5	12.2	3.4	2.5	22.2	16.5	1.3	2.1	8.9	14.6	12.2	9.2	80	59	11.5	24.1	435	722
LSD 36	555	84	15	19	13.7	3.5	3.2	28.1	25	1.2	1.6	8.2	10.5	12.7	11.9	100	60	10.7	19	402	520
LST 1179	518	68	11.5	15	8.3	2.3	2.1	26.8	25	1.6	1.0	6.0	7.8	8.3	7.5	97	90	13.9	12.7	294	386
Roll-on/Roll-off																					
Comet	500	78	25	29	18.3	3.0	2.7	26.6	24.1	1.1	2.3	7.0	14.5	10.9	9.7	96	87	17.3	25	615	717
Sealift	540	83	19.5	29	21.5	3.5	2.7	25	18.5	1.6	2.4	10.6	15.7	12.4	9.6	90	67	14.3	26.9	520	776
Admiral Callaghan	694	92	19.5	27	23.7	4.2	3.5	29.9	24.7	1.8	2.5	13.5	18.7	15.2	12.7	108	88.9	15.9	29.8	665	925
General Cargo																					
C-2	455	63	15	27	13.9	2.0	1.2	19.5	14	1.0	1.7	6.8	12.3	7.1	4.4	70	50	8.5	19	336	608
C-3	492	70	16	29	18.2	2.5	1.5	21.4	15	1.1	2.0	7.9	14.3	8.8	5.5	77	54	10	22.6	388	706
C-4	564	72	20	33	22.1	2.6	1.7	23.3	16	1.4	2.4	11.4	18.7	9.3	5.9	84	58	12.8	26.7	555	923
Tankers																					
T-2	524	68	14	30	21.9	2.3	1.2	23.9	15.5	1.0	2.0	7.3	15.7	8.3	4.4	86	56	8.5	23	359	775
T-5	656	86	16.5	35	35.1	3.7	2.1	31.1	19	1.4	3.0	10.9	23	13.3	7.6	112	68	12.6	34.2	535	1,136
MSTS	595	84	14.5	32.5	31.3	3.5	2.0	29.2	17.5	1.2	2.7	7.7	19.4	12.7	7.3	105	63	10.9	30.7	378	959
AOR 2	659	96	21	35	32.0	4.6	3.3	34.1	25	1.3	3.2	9.0	22	16.6	11.8	122	90	11.9	36.2	443	1,087
Universe Ireland	1,135	175	26	79	375.8	15.3	6.0	92.2	32	4.6	14	30	89	55	21.8	342	115	40.5	150	1,450	4,429
Barge Transports																					
LASH	860	107	20	37	61.0	5.7	3.9	49.6	35	2.1	4.0	17.2	31.8	23	14	178	126	19	46.5	850	1,572
Seabee	875	106	17.5	32	44.7	5.6	3.7	45	33	1.9	3.4	15.3	28	21.2	13.3	162	118	17	40.9	755	1,385
Breakbulk Freighter																					
VC-2	455	62	15.5	29	15.2	1.9	1.1	19.9	14	0.9	1.8	7.1	13	6.9	4.0	72	50	8.5	19.7	346	640
Mariner	563	76	18	30	21.2	2.9	2.0	22.8	16	1.4	2.3	10.2	17	10.4	7.1	82	58	12.2	25.8	500	835
Gulf Banker	495	69	18.5	30	17.2	2.4	1.6	19.1	13.4	1.3	2.1	9.2	14.9	8.6	5.7	69	48	11.4	23.1	450	734
Freighter/Container																					
Seamaster	572	82	21	30.5	21.4	3.4	2.6	23.9	18.4	1.7	2.5	12	17.5	12.1	9.3	86	67	14.5	28.6	595	865
Santa Lucia	560	81	20	30	21.7	3.3	2.5	23	17.5	1.6	2.4	11.2	16.8	11.8	8.9	83	63	14.5	27.1	553	830
Wolverine Mariner	564	76	21.5	32	22.8	2.9	2.1	25	17	1.6	2.4	12.1	18	10.4	7.5	90	61	14.4	27.3	595	889
Challenger	560	75	20	31.5	21.1	2.8	2.0	24	16.5	1.5	2.4	11.2	17.6	10.1	7.0	87	59	13.3	26.6	550	870
Container with Crane																					
Pacific Trader	544	70	21	32	22.9	2.5	1.7	21	15.5	1.5	2.2	11.4	17.4	8.8	6.0	76	56	13.1	25.8	560	861
American Liberty	700	90	21	32	32.6	4.1	3.1	29	21.5	1.9	2.9	14.7	22.4	14.6	11.0	105	77	16.8	34.3	725	1,108
Container Without Crane																					
Portland	523	72	22	31	20.2	2.6	2.0	20.5	15.5	1.6	2.2	11.5	16.2	9.3	7.0	74	56	14	24.9	565	801
Oakland	685	78	19	30	32.1	3.0	2.2	24.1	16.3	1.5	2.3	13.1	20.6	11.0	7.8	87	59	13.2	27.6	640	1,112
Jacksonville	524	68	19.5	31	22.9	2.3	1.5	22.0	16.0	1.3	2.1	10.2	16.2	8.3	5.5	79	58	11.8	24.3	505	871

combined movements of the waves and surge. Some remedial steps that may be tried are:

- a. Hold the ship against the pier with a tugboat or constant-tension winch.
- b. Relocate or reorient the facility.
- c. Install mooring bouys or dolphins outboard of the pier face.
- d. Kedge bower and stern anchors to outboard sides of ship during berthing maneuvers.
- e. Change to more or less elastic bow, stern, and breasting lines or install elastic snubbers or dampeners in the mooring lines.
- f. Add or remove fendering units.
- g. Install mooring dolphins inboard of the pier face if the movement of the pier is significant.

Design

319. The actual design of a fendering system is based on the law of conservation of energy. To the port construction engineer, this means that the amount of energy being introduced into the system must be determined and then a means devised to absorb the energy within the force and stress limitations of the ship's hull, the fender, and the pier.

Steps in Designing Fenders

320. The steps listed below represent one method of designing fenders:

- a. Determine the energy that will be delivered to the pier upon initial impact (see table 4). The selection of a design vessel should be based on recommendations from the Military Traffic Management and Terminal Service and the Military Sealift Command.
- b. Determine the energy that can be absorbed by the pier or wharf (distribution of loading must be considered). For

Table 4
Energy To Be Absorbed By Fenders

Vessel	Length (ft)	Beam (ft)	Draft (ft)		DWT (long tons × 1,000)	Velocity* ft/sec Sheltered	Energy* ft-kips Sheltered	Velocity* ft/sec Moderate	Energy* ft-kips Moderate	Velocity* ft/sec Exposed	Energy* ft-kips Exposed
			Light	Deep							
Assault Ships											
LHA	820	106	--	26	--	0.3	91.7	0.4	163.0	0.6	366.7
LPD 4	570	84	17	22	7	0.3	40.3	0.5	111.96	0.7	219.5
LPA 249	564	76	22	27	6.1	0.3	48.2	0.5	133.86	0.7	262.4
LKA 113	575	82	15.1	25.5	14	0.3	31.0	0.55	104.10	0.8	220.3
LSD 36	555	84	15	19	5.5	0.3	31.1	0.55	110.12	0.7	169.6
LST 1179	518	68	11.5	15	3.5	0.35	25.5	0.6	74.88	0.9	168.5
Roll-on/Roll-off											
Comet	500	78	25	29	6.5	0.3	49.9	0.5	138.73	0.7	271.9
Sealift	540	83	19.5	29	12.1	0.3	57.2	0.5	158.80	0.7	311.2
Admiral Callaghan	694	92	19.5	27	13.5	0.3	60.5	0.5	168.00	0.7	329.3
General Cargo											
C-2	455	63	15	27	9.7	0.3	40.4	0.55	135.80	0.8	287.4
C-3	492	70	16	29	12.7	0.3	52.1	0.5	144.69	0.7	283.6
C-4	564	72	20	33	14	0.3	66.3	0.5	184.16	0.7	361.0
Tankers											
T-2	524	68	14	30	16.5	0.3	64.5	0.5	179.23	0.7	351.3
T-5	656	86	16.5	35	23.6	0.3	99.7	0.45	224.22	0.6	398.6
MSTS	595	84	14.5	32.5	25.5	0.3	86.9	0.45	195.52	0.6	347.6
AOR 2	659	96	21	35	25	0.3	86.6	0.45	194.87	0.6	346.4
Universe Ireland	1,135	175	26	79	326.5	0.2	497.5	0.3	1,119.66	0.4	2,984.7
Barge Transports											
LASH	860	107	20	37	44	0.3	161.5	0.35	219.83	0.5	448.6
Seabee	875	106	17.5	32	27.0	0.3	112.2	0.4	199.48	0.55	374.0
Breakbulk Freighter											
VC-2	455	62	15.5	29	10.6	0.3	46.1	0.5	127.91	0.8	327.4
Mariner	563	76	18	30	12.9	0.3	59.4	0.5	164.94	0.7	323.3
Gulf Banker	495	69	18.5	30	11	0.3	50.3	0.5	139.81	0.7	274.0
Freighter/Container											
Seamaster	572	82	21	30.5	12.8	0.3	62.5	0.5	173.60	0.7	340.3
Santa Lucia	560	81	20	30	12.7	0.3	59.1	0.5	164.23	0.7	321.9
Wolverine Mariner	564	76	21.5	32	12.7	0.3	65.7	0.5	182.61	0.7	357.9
Challenger	560	75	20	31.5	13.5	0.3	60.8	0.5	168.80	0.7	330.8
Container with Crane											
Pacific Trader	544	70	21	32	12.2	0.3	68.1	0.5	190.59	0.7	373.6
American Liberty	700	90	21	32	19	0.3	87.3	0.45	196.45	0.65	409.87
Container Without Crane											
Portland	523	72	22	31	9.7	0.3	58.6	0.5	162.64	0.7	318.8
Oakland	685	78	19	30	17	0.3	89.9	0.45	200.0	0.65	414.8
Jacksonville	524	68	19.5	31	11.6	0.3	68.5	0.5	190.34	0.7	373.1

* Velocities shown were determined from fig. 2-22 of reference 8; energies shown were calculated using procedures outlined in Chapter 2 of reference 8.

structures that are linearly elastic, the energy is one-half of the maximum static load level times the amount of deflection. Allowance must also be made in cases where other vessels may be moored at the pier. If the structure is exceptionally rigid, it can be assumed to absorb no energy.

c. Subtract the energy that the pier will absorb from the effective impact energy of the ship to determine the amount of energy that must be absorbed by the fender.

d. Select a fender design capable of absorbing the amount of energy determined using step 3 without exceeding the maximum allowable force in the pier. Consideration must be given to the effect that the thickness of the fender will have on the lifting capacity of the ship's gear and dock cranes.

Design Example

321. A LASH ship must be berthed at a pier consisting of two DeLong "A" barges. The draft of the ship, the tidal variation, and the gradient of the bottom indicate that the caissons in the center of the pier will have an unbraced length of 840 in. The pier is located in a moderately sheltered area. What type of fender should be installed?

a. In table 4, the berthing energy of a LASH ship at a moderately sheltered site is given as 220 ft-kips.

b. If it is assumed that the ship will initially impact near the center of the pier, it is likely to strike the end of one of the two barges. In figs. 82 and 84, the maximum horizontal force absorbed by a barge with caissons having 840 in. of unbraced length is given as 790 kips. Fig. 86 shows that the maximum energy absorbed by the same barge is 66 ft-kips.

c. Subtracting 66 ft-kips from 220 ft-kips leaves 154 ft-kips that must be absorbed by some type of fender.

d. If the impact is assumed to occur over 20 linear ft of fender, each linear foot of fender must absorb 7.7 ft-kips (154 ft-kips/20) of energy without exceeding a force of 39.5 kips per linear ft (790 kips/20 ft).

322. References 7 and 8 indicate that an 18-in.-O.D., 9-in.-I.D.

(18 × 9) cylindrical rubber fender will absorb 8 ft-kips of energy per linear ft at a load of 40 kips per ft. The cylindrical-type fender offers the advantage of being suitable for a number of different fender configurations. Some of the different configurations are shown in figs. 88-91. The availability of this type of fender unit in the TO would allow engineer units considerable flexibility in fender design. The curves in figs. 82 and 84 are based on the assumption that maximum stresses occur in the caissons. Therefore, a check must be made to determine if the load distribution in the barge is adequate.

323. The DeLong "A" barge's side shell plating is stiffened every 2.29 ft by a 7- by 4- by 7/16-in. angle, as shown in fig. 92. If a width of shell plate equal to 30 times the plate thickness is considered to act with the angle as the flange of a beam, its cross section has a section modulus of 18.08 in.^{3} If the allowable bending stress under impact loading is taken as 25 ksi, the maximum allowable bending moment will be 452.0 in.-kips. The allowable concentrated load can then be plotted as a function of its location along the beam, as shown in fig. 92. The values shown are somewhat conservative in that the ends of the beams are assumed to be simply supported and the behavior of the plate as a membrane is not considered. It is felt that the allowable loads could be increased by 50 percent and still be safe, but should not exceed 24 kips per linear ft, which is the maximum allowable compressive load in the deck or bottom plating. In the case of the 18 × 9 cylindrical fender draped as shown in illustration 2 of fig. 93, the individual units would be limited to 10 kips per linear ft if they extended to 3 ft below the deck plate. At this loading, the fender would absorb only about 2 ft-kips per linear ft. To make matters worse, the total reaction in the barge would reach a magnitude of only 200 kips per linear ft (10 kips per linear ft × 20). At this load, the barge will absorb only approximately 4.5 ft-kips of energy. It can, therefore, be concluded that the 18 × 9 cylindrical fender will protect the caissons from being overloaded but that there is a good possibility that the side shell plating will sustain localized damage. This fender would be adequate for sheltered locations where a ship's effective

(Courtesy of Goodyear, Akron, Ohio)

Fig. 88. Fendering example (draped cylindrical rubber fender)

Fig. 89. Fendering example (side-loaded cylindrical rubber fender)

(Courtesy of Uniroyal, Mishawaka, Indiana)

Fig. 90. Fendering example (cylindrical rubber fender in end compression)

(Courtesy of Uniroyal, Mishawaka, Indiana)

(Courtesy of Uniroyal Mishawaka, Indiana)

Fig. 91. Fendering example (two side-loaded cylindrical rubber fenders)

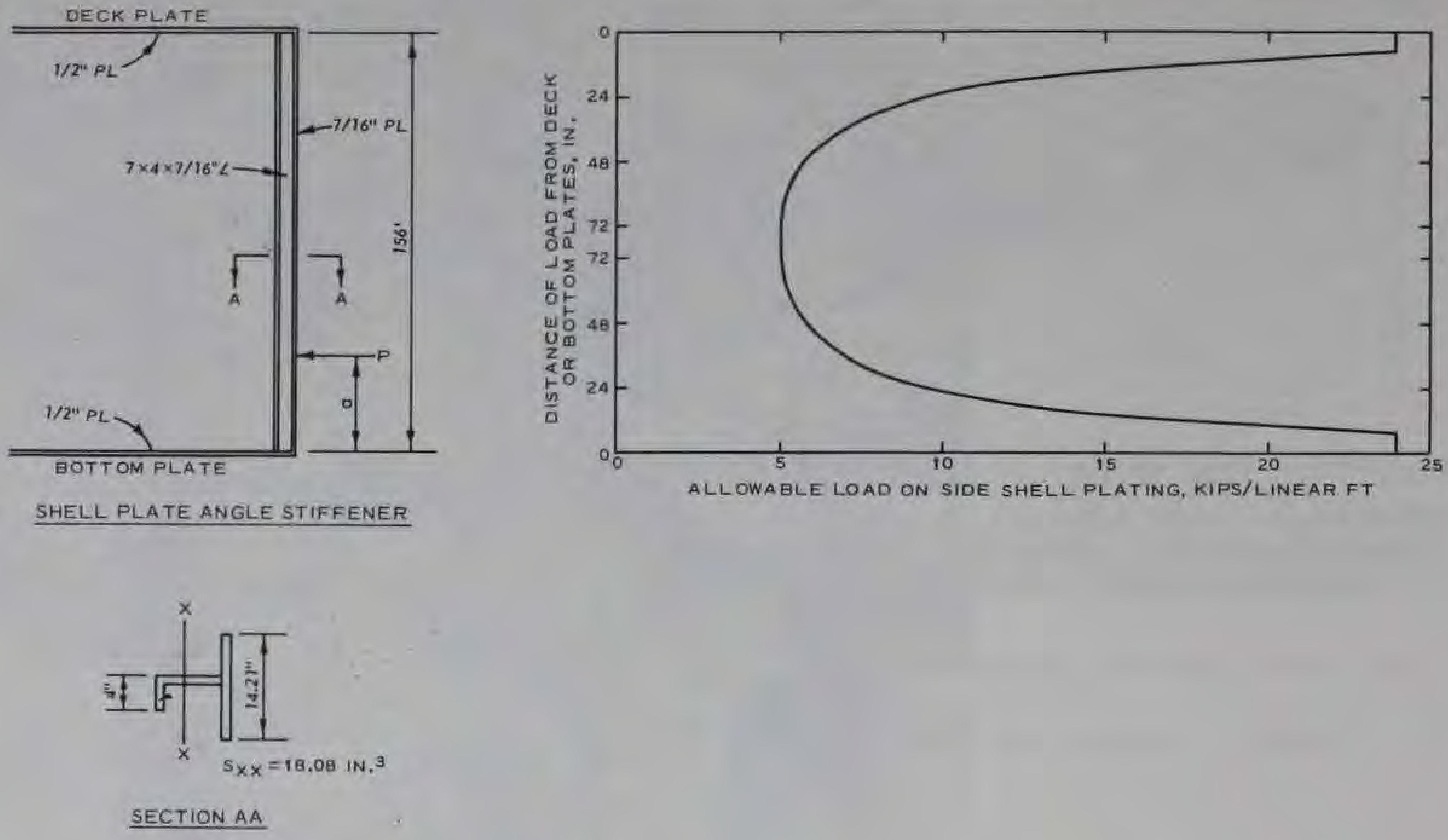


Fig. 92. Side shell plating of DeLong "A" barge

berthing energy does not exceed 68 ft-kips, which is approximately equal to the energy of a C-4 general cargo vessel.

324. Because of the limitations of the side shell plating, a draped cylindrical fender cannot reach an efficient working load. A wing-type fender that is a variation of a cylindrical fender can be attached to the hull immediately below the deck level (see illustration 1, fig. 93). In this manner, the fender unit can be loaded to 24 kips per linear ft rather than be limited to 10 kips per linear ft, which would be the case if its center were located 2 ft below deck level.

325. A Uniroyal 12-in.-O.D. by 5-in.-I.D. (12 × 5) wing-type marine fender can absorb 3.3 ft-kips of energy per linear ft at a load of 24 kips per linear ft. If the impact is considered to occur over a span of 20 linear ft, the total energy absorption would be 66 ft-kips, and the load on the barge would be 480 kips. At this loading, the barge would absorb approximately 25 ft-kips of energy. The total energy absorption for the system would therefore, be about 90 ft-kips. Examination of table 4 shows that this system would be appropriate only for sheltered locations.

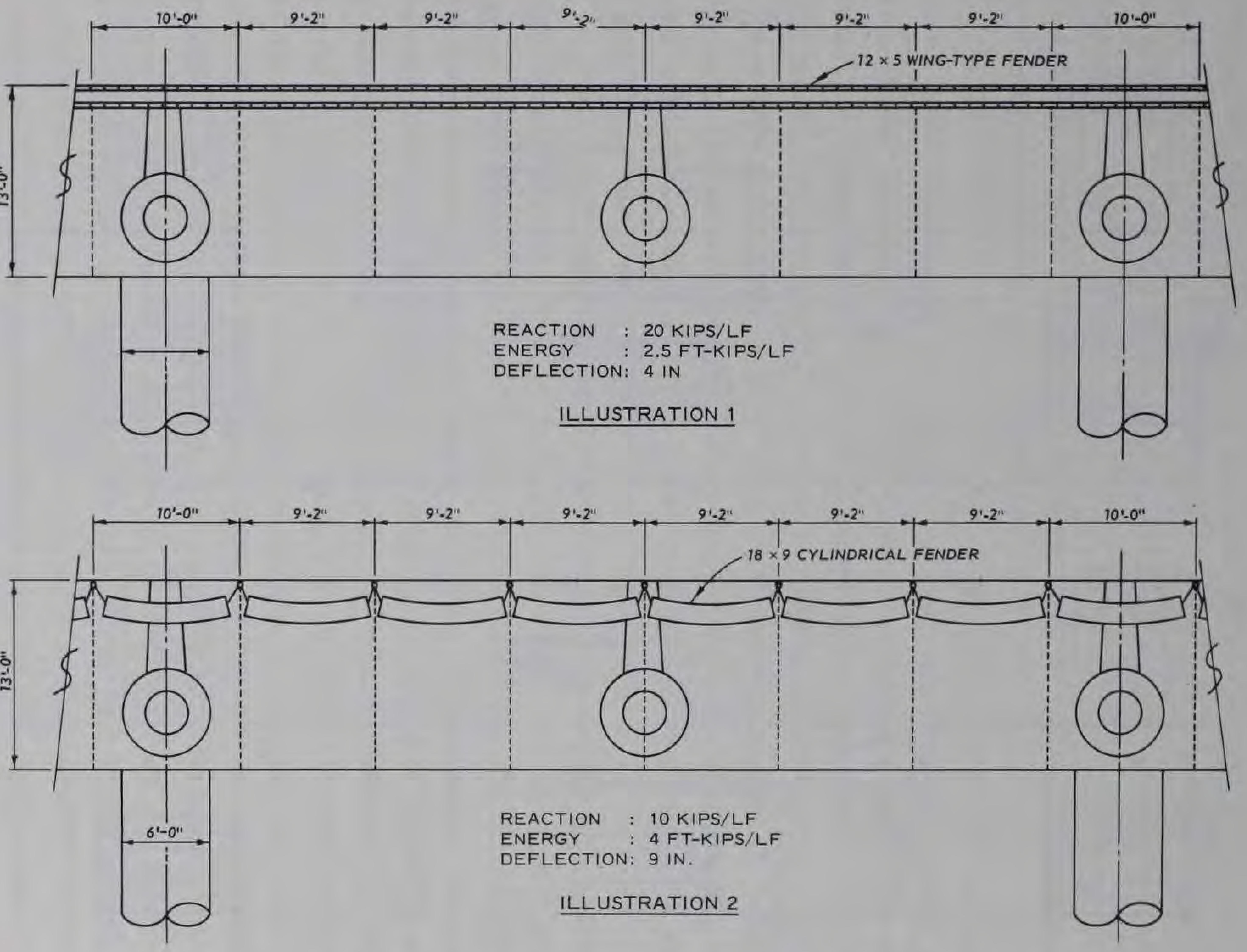
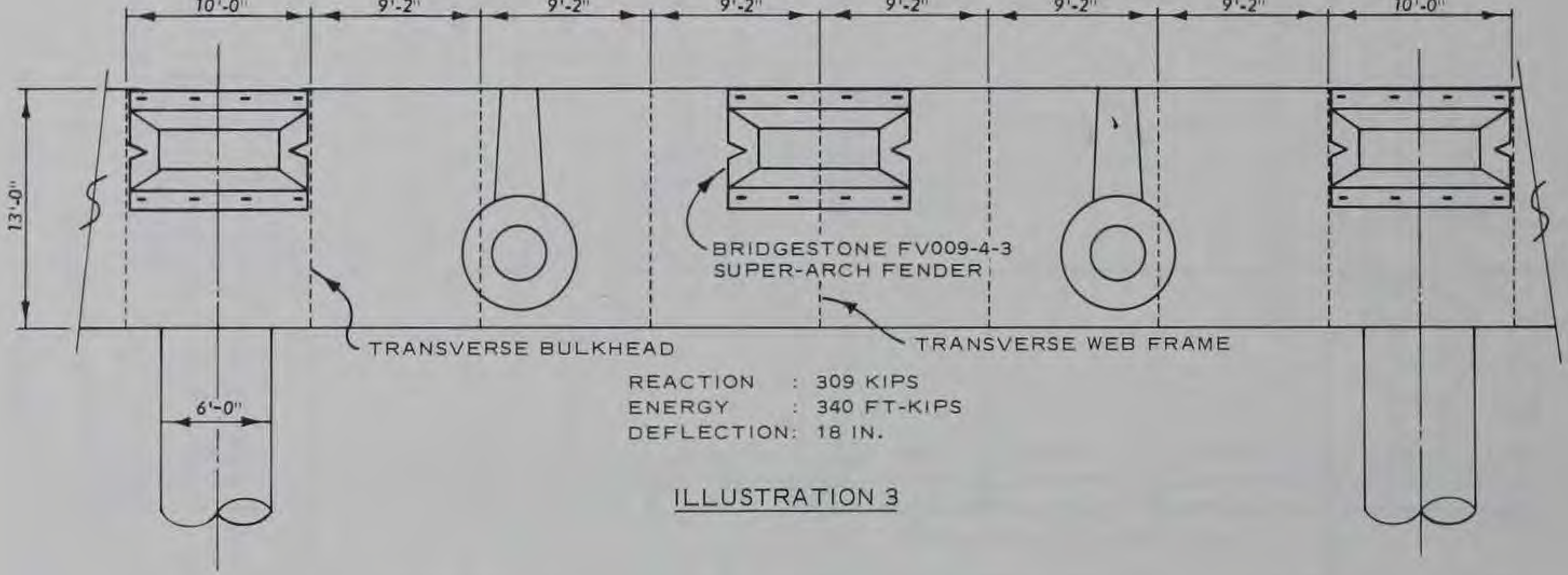
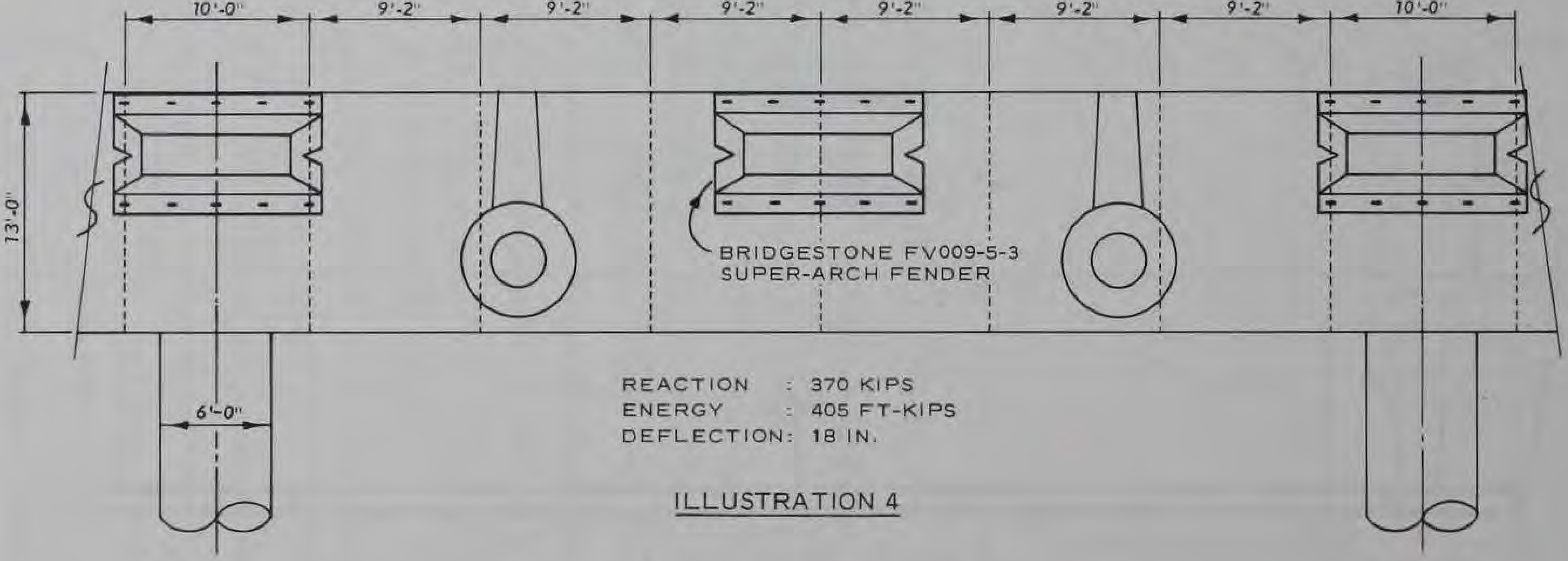


Fig. 93. Fendering configurations for DeLong "A" barge (sheet 1 of 2)



REACTION : 309 KIPS
ENERGY : 340 FT-KIPS
DEFLECTION: 18 IN.

ILLUSTRATION 3



REACTION : 370 KIPS
ENERGY : 405 FT-KIPS
DEFLECTION: 18 IN.

ILLUSTRATION 4

Fig. 93. (sheet 2 of 2)

326. From the first two examples, it can be concluded that the existing design of the DeLong "A" barge's side shell plate is not particularly well suited to cylindrical fender units. One alternative to loading the side shell plate is to install the caisson fenders described in reference 25. The spacing of these units at 65-ft intervals makes them ill-suited for absorbing berthing impacts except for those from small, highly maneuverable craft. These fenders, however, are of considerable value for preventing barges from being caught beneath the bottom of the pier during a rising tide.

327. Based on the results of a study conducted in 1965 by the Naval Civil Engineering Laboratory,[27] it was concluded that timber piles with rubber bearing blocks at deck level were the best method (at that time) for fendering Navy piers and wharves at exposed sites. The close spacing of the piles (usually 5 to 6 ft) and their projection into the bottom made them suitable for use by small vessels as well as by ships. However, this system requires considerably more time and effort to install than are needed to erect a DeLong barge. Therefore, it is not considered compatible for use with the DeLong barge.

328. A Bridgestone Super-Arch fender was selected for analysis and tentatively placed on 32.5-ft centers. This spacing permits the units to be placed in front of the caisson wells and the watertight bulkhead located at midspan between caissons. If the design procedures presented in the manufacturer's catalog[28] are followed, an FV009 series fender will absorb full berthing energy for vessels with hull radii of curvatures down to 80 ft. From the tables on the super-arch series,[28] it is found that with a type three elastomer, a size two unit will absorb 207.72 ft-kips of energy at a load of 185.2 kips. A Bridgestone FV009-2-3 Super-Arch fender will thus satisfy the requirement. The particular disadvantage of this system is that the face of the fender is only 59 in. long. The normal spacing of vertical bulkheads and horizontal ribs in a ship is from 10 to 15 ft. Ideally, the fender should be 15 ft long so that the ship's plating will not be overloaded. Because this was not practical, the relatively soft type 3 elastomer was selected. Because of the low horizontal load resulting,

no appreciable load will be taken by the barge.

Fendering for DeLong "A" and "B" Barges at Exposed Sites

329. Without adequate fendering, the DeLong "A" and "B" barges are limited to sheltered harbors where adequate tug support is available. In Vietnam, the piers were located in reasonably sheltered areas and fendered with large rubber tires. This inexpensive fender system was apparently quite adequate and involved very little maintenance. There is a good possibility, however, that in future operations well sheltered sites may not be available. In such a case, a pier may be exposed to ship berthing energies that are two to five times greater than those that occurred in Vietnam. The berthing energy of a 30,000-ton-displacement ship varies from 350 to 450 ft-kips. If the barge is initially assumed to absorb 50 ft-kips, a fender system capable of absorbing from 300 to 400 ft-kips is needed.

330. Fender units capable of absorbing this amount of energy and that are compatible with the structural aspects of the DeLong "A" barge are listed below along with dimensions and capacities as listed in reference 7:

a. Bridgestone Super-Arch FV009-4-3 (see illustration 3, fig. 93).
    (1) Energy: 340.28 ft-kips
    (2) Load: 308.7 kips
    (3) Length: 118-3/16 in.
    (4) Width: 78-3/4 in.
    (5) Depth: 39-3/8 in.

b. Siebu 1300 HV type rubber dock fender (two required).
    (1) Energy: 208.0 ft-kips
    (2) Load: 231.0 kips
    (3) Length: 157.48 in.
    (4) Width: 88.58 in.
    (5) Depth: 51.18 in.

c. Bridgestone Super-Arch FV009-5-3 (see illustration 4, fig. 93).

(1) Energy: 405.44 ft-kips
(2) Load: 370.4 kips
(3) Length: 137.81 in.
(4) Width: 78.75 in.
(5) Depth: 39.38 in.

d. Bridgestone Super-Arch FV009-6-4.

(1) Energy: 340.28 ft-kips
(2) Load: 288.8 kips
(3) Length: 157.50 in.
(4) Width: 78.75 in.
(5) Depth: 39.38 in.

331. The Super Arch FV009-43 will apparently satisfy the minimum requirements, and the FV009-5-3 will satisfy the maximum requirements. For maximum protection to the ship's hull, the longer FV009-6-4 unit should be selected. Because it uses a softer elastomer, the pressure on the hull is greatly reduced. Also, its increased length makes it more probable that at least one of the ship's ribs will be directly loaded.

332. Although two Seibu 1300HV fenders will satisfy the energy-asorption requirements, they would have the same basic properties as one Super Arch FV009-6-3. The FV009-6-3 would not only be cheaper, but would hold the ship only 40 in. from the pier rather than 51 in. Large tires from earth-moving equipment are also shown in the illustrations in fig. 93. These would provide protection for small vessels and barges that may be docked alongside the DeLong barge.

Dolphins

333. Dolphins are independent marine structures that consist of a group of timber piles bound at the top with cable or wire rope. The term "dolphin" also refers to any other structure that serves the same purpose as the timber pile cluster dolphin. In recent years, sheet-pile

cells, single large-diameter steel pipes such as those employed in the DeLong barge, and clusters of small-diameter steel pipe have been used with reasonable success.

334. Prior to selecting a design for a dolphin, the design engineer should have a reasonably good working knowledge of the following factors:

a. Foundation soils.

b. The probable use of the dolphin.

c. Characteristics of the design vessels.

d. Properties of available construction materials.

e. Environmental factors such as wind, waves, currents, etc.

335. If the soils of the foundation offer little resistance to lateral loads from an individual pile, a flexible timber cluster dolphin will be unsuitable. To evaluate the soil strength, the constructing unit can drive a single pile near the site of a proposed dolphin and cyclically apply horizontal loads of increasing magnitude until permanent deflection is observed. The results of this simple lateral pile load test will indicate whether the strength of the soil or the pile material will be critical. If the soil yields under very light loads, alternatives to the cluster dolphin sould be investigated.

336. Of equal importance to the soil conditions is the use for which the dolphin is intended. These uses may be broken down into five categories:

a. Absorbing berthing impact loads.

b. Resisting static mooring loads.

c. Guiding or warping vessels.

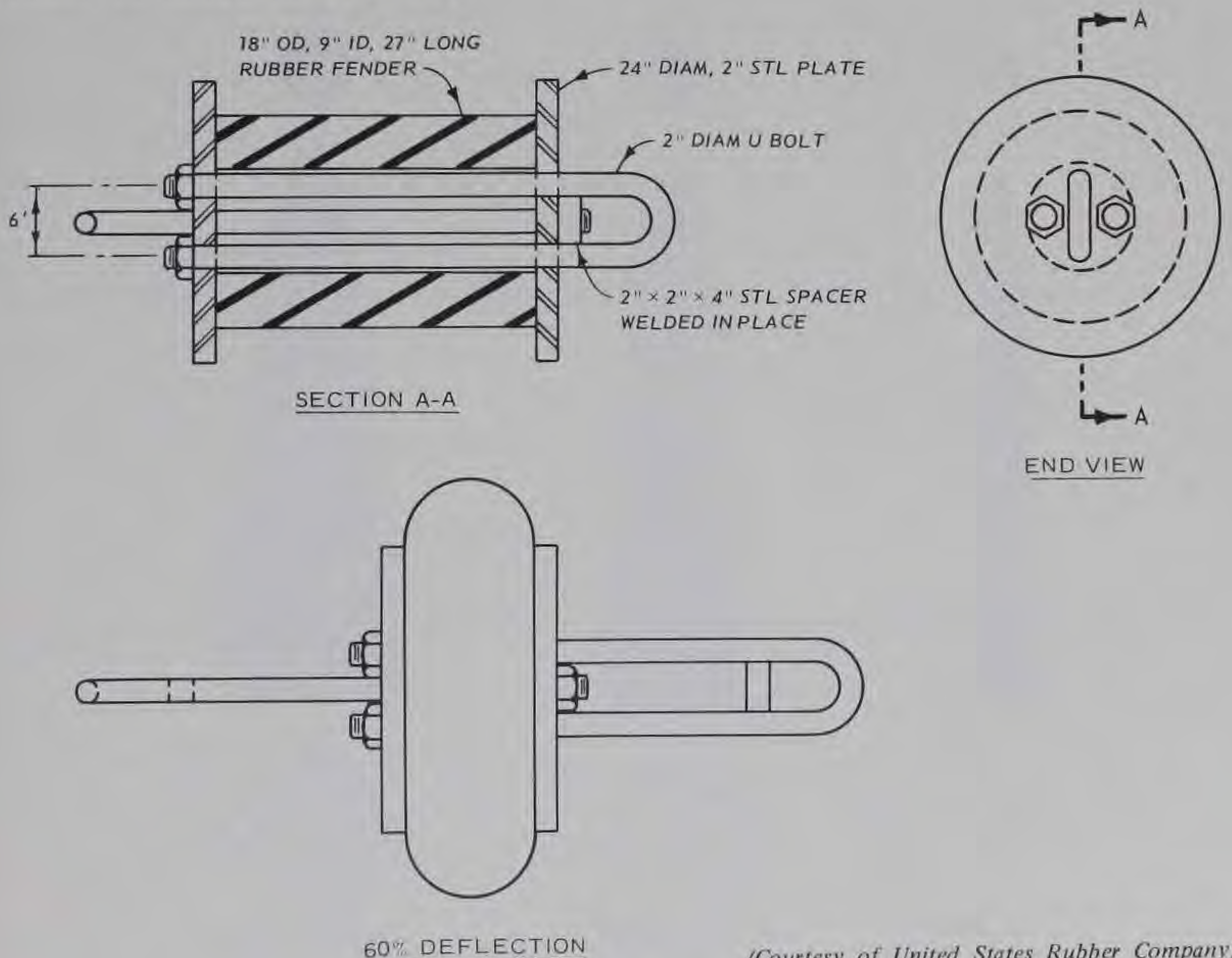
d. Protecting structures from collisions.

e. Supporting navigational aids.

337. When absorbing berthing impact loads, dolphins are usually positioned just outboard of the pier face. The individual dolphins can be neither too rigid nor too flexible. Dolphins that are highly flexible must be positioned some distance from the pier face. This may result in the vessel's being held too far from the face to permit efficient loading and off-loading operations. On the other hand, if the dolphin

is overly rigid and the deflection is too small, the force that must be applied to account for the energy being released by the ship may result in damage to the hull or to the dolphin. On ships with cruising speeds above 20 knots, slightly rippled hull plates will cause significant drag.

338. When a dolphin is to be used solely for mooring vessels, it is usually desirable to make the structure as rigid as possible. This is accomplished by installing raked or battered piles and a rigid cap to carry the horizontal mooring forces. If the mooring dolphins are placed sufficiently inboard of the pier face, the danger of their being struck is reduced, and the mooring lines can be long enough to absorb considerable energy caused by surge and wave action. Snubbers or constant-tension winches can also be installed in exposed locations. A snubber that can be constructed in the field from a section of tube-type fender is shown in fig. 94.

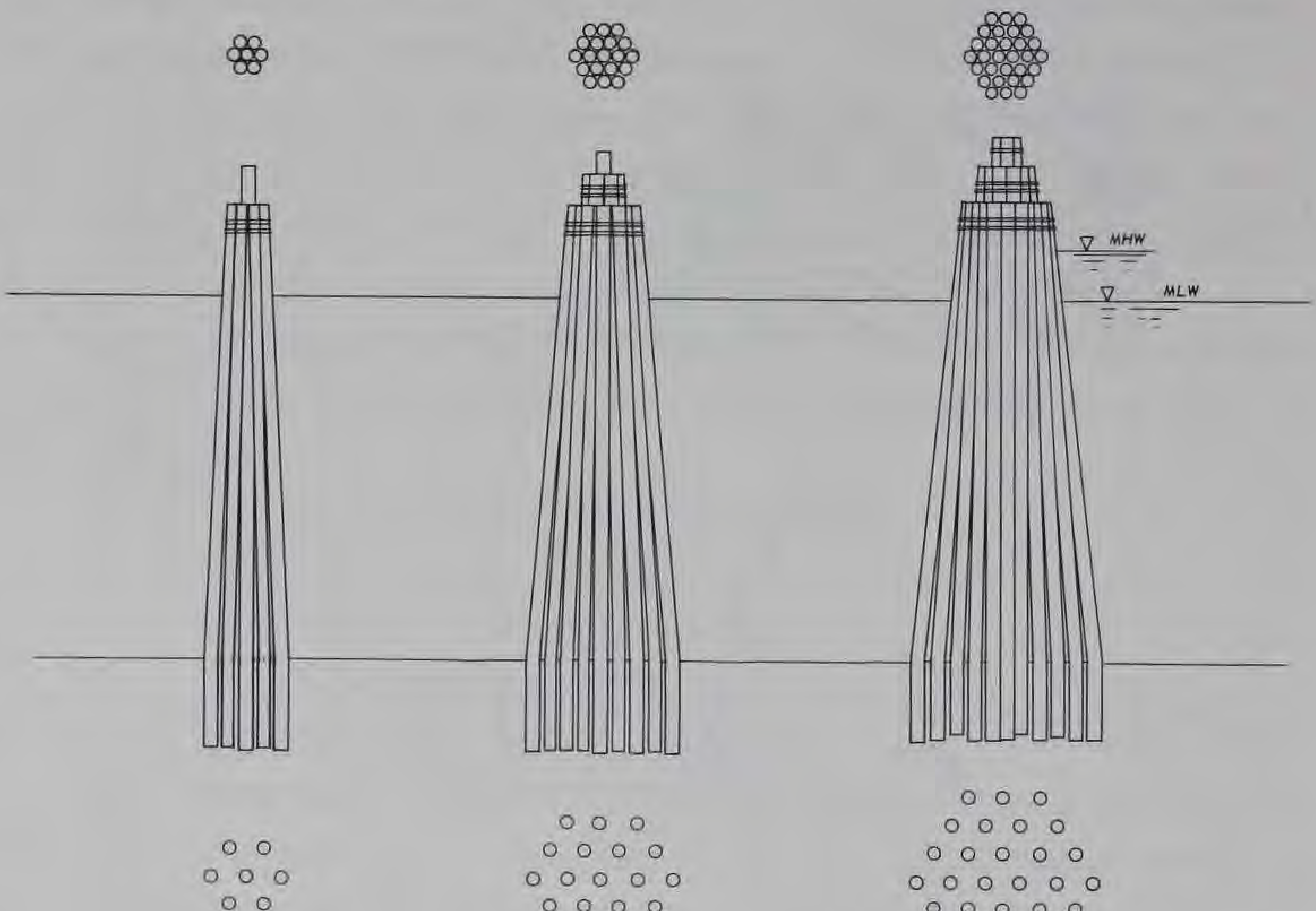


(Courtesy of United States Rubber Company)

Fig. 94. Snubber for mooring lines

339. The remaining three uses of dolphins are actually variations of the first two. They are used as guide walls at ferry slips and at the entrances to locks. Warping or turning dolphins are commonly constructed out of sheet-pile cells with fendering around exposed faces. Dolphins are also used to protect bridge piers from collisions and, in colder regions, from ice damage.

340. In the construction of dolphins, there are several items that should be taken into consideration. In timber pile cluster dolphins, the piles should be driven with the large end (butt) down. This technique is more consistent with the actual stress distribution in the pile during loading than is the normal practice of driving the pile with the small end down. Another consideration that should be made is the displacement of large amounts of soil when 19- and 30-pile dolphins are installed (see fig. 95). In impervious, cohesive soils, excess pore



7-PILE DOLPHIN 19-PILE DOLPHIN 30-PILE DOLPHIN

Fig. 95. Timber pile dolphins

water pressures may reach very high magnitudes. Because pore water pressure has a significant effect on the shear strength of the soil, excess pore water pressure may greatly reduce the load capacity of a dolphin until the pressure has dissipated. In some soils, dissipation of excess pore pressure may take three months or longer.

341. Design engineers interested in detailed treatises on dolphins should refer to "Analysis and Design of Dolphins."[29]

PART VI: SURFACING REQUIREMENTS FOR CONTAINER STORAGE AND MARSHALLING AREAS

Background

342. Many of the newer container ship terminals in the United States are being provided with from 12 to 18 acres of container storage and marshalling area per berth. If this were done in the TO, a port with only one container ship berth would require as much paved area as a medium-lift airfield in the support area. Wheel loads and tire pressures of container handling equipment used at the commercial ports have been determined to be as severe as those of a C-130 aircraft. Therefore, it is clear that it is absolutely essential that military planners be able to determine the amount of surfacing that is required so that sufficient resources can be programmed into a base development plan.

343. The task of determining surfacing requirements actually involves three decisions: the type of surfacing, the thickness required, and the amount required. All three of these elements are influenced by the characteristics of equipment operating on the surfacing. Unfortunately, the type of container handling equipment that will be adopted for military use has not yet been determined. Also, civil port authorities do not use any rational method to determine the types of equipment that are allowed to operate on facilities leased to commercial shippers.

344. To circumvent the problem of not knowing what type of equipment will be used, it was decided to select representative pieces of commercial equipment that appeared to be suitable for use in the TO. Each of these pieces of equipment could then be evaluated as to its surfacing requirements with respect to type, thickness and subgrade strength, and surface area.

Objectives

345. A study was initiated that had as its objectives to:

a. Determine the ability of sample container handling equipment to operate on unsurfaced soils.

b. Determine the suitability of M8A1 light-duty landing mat as an expedient surfacing for storage and marshalling areas.

c. Determine the types of container handling equipment that could be operated on storage and marshalling areas surfaced with M8A1 landing mat.

d. Determine the required thickness of flexible pavement for each piece of sample equipment.

e. Determine the surface area requirements for various types of container handling equipment.

346. M8A1 landing mat was selected because it was not felt that medium- or heavy-duty mat would be authorized for uses other than the surfacing of airfields in the TO. Although the steel M8A1 is almost twice as heavy per square foot as the aluminum medium-duty mats presently available, it costs less than one-third as much. It was felt that the additional weight would not present a significant disadvantage because the mat would not have to be transported by air and could be handled by material handling equipment available at the port.

Factors Affecting Surfacing Requirements

Vehicle characteristics

347. Vehicles with the same load-carrying capabilities may require extremely different surfacing, depending on individual vehicle characteristics. Surfacing requirements vary in type, thickness, and strength in accordance with wheel loads, the number of wheels and their arrangement, and tire contact pressure and contact area. Because of this variation in pavement requirements, the engineering construction and maintenance effort may be several times greater for one vehicle than for another with equal load-carrying capability.

Traffic volume and flow patterns

348. Traffic volume is a primary consideration in the selection of the type of surfacing and its required thickness. It is essential that an adequate study be made to determine the number of passes and the

operational flow patterns of each vehicle under consideration so that a reasonable design volume for a particular facility and vehicle can be selected.

Container selectivity

349. Container selectivity involves the relative ease with which individual containers can be located and removed from a storage area. If containers are not stacked or are mounted on a chassis, selectivity would normally be considered 100 percent because no other containers would have to be moved in order to locate and remove a specific container from storage.

350. Utilization of space is not particularly efficient, however, if containers are stacked two or three high or in blocks with very little space between containers. Space is maximized at the expense of selectivity. Both locating a container and removing it from the stack would be difficult. The need for selectivity varies considerably. Empty containers need virtually no degree of selectivity, but containers with cargo suitable for throughput need a high degree of selectivity.

Area requirements

351. Another important factor affecting the effort involved in constructing adequate surfacing at military ports is the amount of area to be surfaced. It is extremely important that the total surface area be limited in order to minimize construction and maintenance efforts. Area requirements vary with vehicle characteristics, operational patterns, container sizes and weights, driver skill, number of vehicles, and protective measures taken.

352. Trends at commercial ports in the Unites States indicate that up to 18 acres of storage and marshalling area may be required for each container ship berth with a maximum retention time of two to three days. With a discharge rate of sixteen 20-ft containers per hour, a storage capacity of 320 containers would represent a one-day, one-direction retention time. Because an equal number of containers must be placed back on the ship, this quantity will double to 640 containers per container ship berth per day. If these containers were temporarily stacked on a 40-ft trailer chassis, approximately 8 acres of surfacing would be

required. In a chassis operation of this type, the spacing between trailers in rows and the width of aisles depend on the skill of truck drivers and the characteristics of the vehicles. This variation can result in as much as a 20 percent reduction in the number of containers that can be stored per acre. If straddle carriers are employed, the 640 containers can be stacked two high in an area of only 3 acres.

353. At many facilities, two and sometimes three gantry cranes are teamed to discharge one ship. Under these circumstances, the storage area requirements and the amount of container handling equipment needed are basically proportional to the number of cranes. If two cranes are employed, a two-direction chassis operation will require approximately 16 acres, and a two-direction operation involving the use of straddle carriers would require approximately 6 acres. As a matter of interest, 16 acres is approximately equal in surface area to 6 miles of a 23-ft-wide road.

354. Presently, approximately 52 percent of the slots in U. S. flag container ships are owned by three companies having containers in primary lengths of 24, 27, and 35 ft. A facility handling more than one size container, other than sizes in even multiples such as 20 and 40 ft, will be less efficient with respect to area requirements than will a facility handling only one size. For example, only one 24-ft container will fit on a 40-ft chassis. Stacking different size containers is not possible because corner posts of the container on top must be aligned with the corner posts of the one below it. Also, locating the proper size container for backloading a ship would be inefficient and time-consuming. The storage area and operational flow patterns would have to be organized to provide separate facilities for each container size. The result would be an increase in area requirements because of a less efficient utilization of space and longer retention times for containers waiting for a ship with the proper size container cells.

355. Dispersion and/or camouflage may, in some instances, be a factor in area requirements. Although camouflage is somewhat limited in effectiveness as a passive defensive measure for military ports,

dispersion of materials awaiting shipment out of the port area is an important consideration. The number of required container handling vehicles is drastically increased in a vastly dispersed operation; also, the required amount of surfaced area is drastically increased.

Staging of construction

356. Considering the many factors that may affect the construction effort relative to surfacing requirements, the decision confronting the military planner may become one of balancing available engineer and transportation resources. In the early stages of a major base development operation, construction requirements usually greatly exceed the capabilities of available engineer units. Until critically needed facilities such as airfields become operational, all construction must be kept as austere as possible. The use of expedient surfaces such as landing mat is appropriate at this stage of the logistics support operation. The type of mat employed should be capable of withstanding sustained container handling operations over a several-month period without a major maintenance effort. After the demand for engineer troop units becomes less critical and sources of aggregate have been developed, the mat can be replaced with either flexible or rigid pavement.

Selection of Vehicles

Categories considered

357. The vehicles considered were selected on a random basis with consideration given to individual vehicle characteristics. At least one vehicle representative of each major category of equipment currently being manufactured and capable of handling a container weighing 30 long tons was considered. This payload was selected because it is the maximum allowed for 40-ft commercial containers. Data were not available on the average weight of military freight containers. Vehicles considered in this study were selected from the following categories:

- a. Forklift (front and side loading).
- b. Straddle carrier.
- c. Yard gantry.

d. Mobile crane.

e. Tractor-trailer combination.

Vehicles selected

358. Representative vehicles were selected from each major category with the assistance of the Mobility Equipment Research and Development Center (MERDC), Ft. Belvoir, Virginia. The vehicles selected for consideration in this study along with a brief statement relative to the reasons for selection of each are as follows:

a. LARC LX. The LARC LX (fig. 96), formerly known as BARC, was included in the program more or less as a control vehicle because of its known ability to operate on low-strength soils at a gross weight of 319,000 lb (120,000-lb payload). The LARC LX is capable of lightering 40-ft containers, which can be discharged from the LARC by cranes, by narrow-straddle carriers, or by rollers similar to those used in unloading cargo aircraft.

Fig. 96. LARC LX

b. Shoremaster (straddle carrier). The Shoremaster (fig. 97) is constructed in such a manner as to distribute the load evenly on eight wheels with a maximum single-wheel load of 16,500 lb at a rated gross weight of 132,000 lb. This vehicle is also narrow enough (13 ft, 3 in.) to negotiate the ramps of a LARC LX

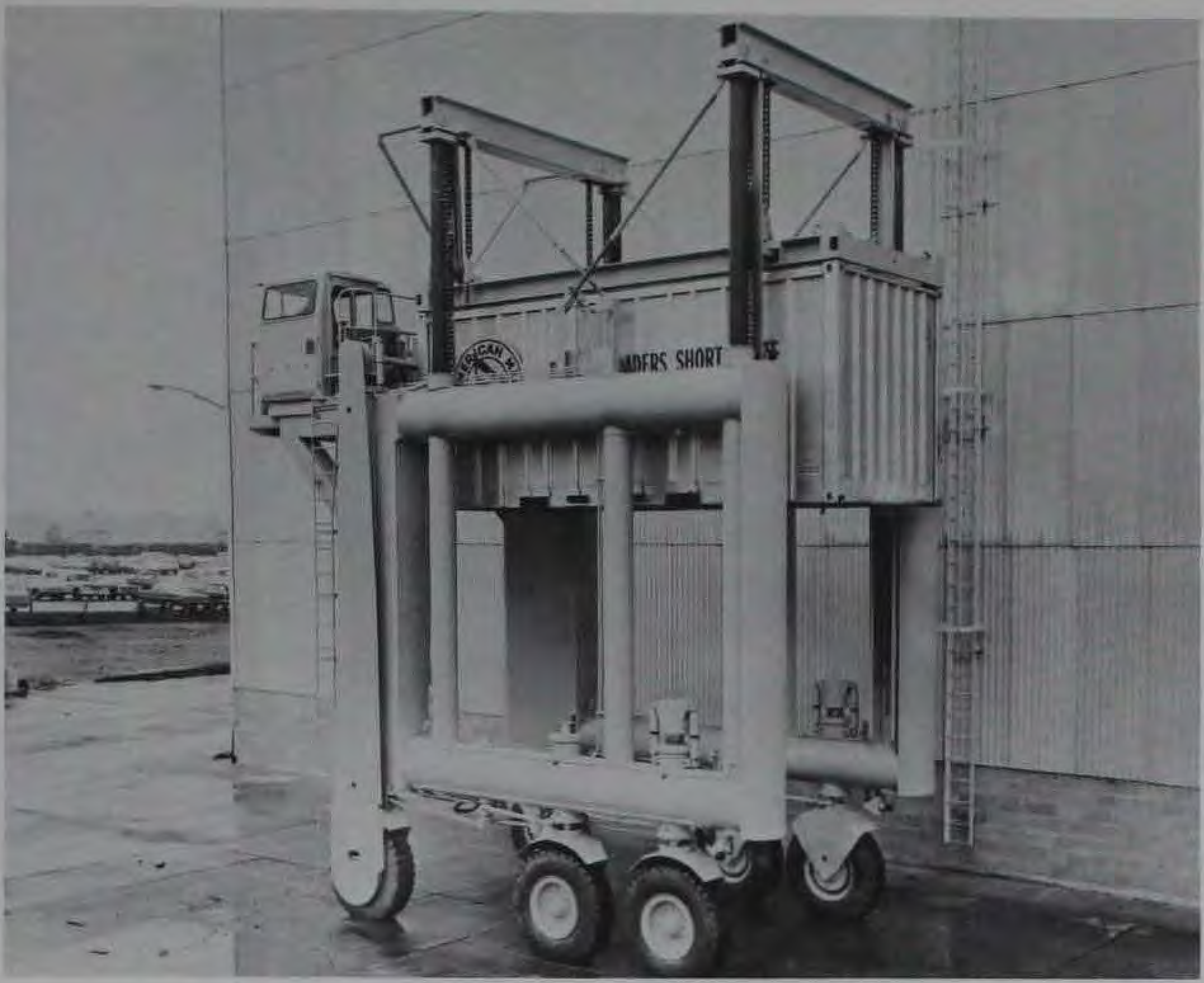
(Courtesy of Lake Shore, Inc., Iron Mountain, Michigan)

Fig. 97. Shoremaster

(13 ft, 8 in.), an LCM-VIII (14 ft, 6 in.), or a 1610 Class LCU (14 ft) and has a minimum overhead clearance of 14 ft.

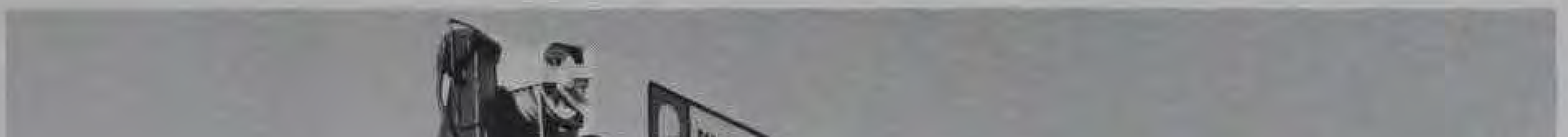
c. Clark 512 (straddle carrier). This vehicle (fig. 98) is widely used in commercial shipping. Its width of 13 ft, 6 in. allows it to enter the ramp opening of the LCM-VIII and the 1610 Class LCU.

d. Belotti B67b (straddle carrier). The Belotti B67b (fig. 99) has the ability to hoist 20-ft containers outboard its basic frame. This allows it to stack 20-ft containers three high as well as to load them aboard rail cars. Containers longer than 20 ft can be stacked only two high because they extend beyond the end frame members and cannot be shifted to the side.



(Courtesy of Clark Equipment Company, Battle Creek, Michigan)

Fig. 98. Clark 512



(Courtesy of Paceco, Alameda, California)

Fig. 99. Belotti B67b

e. Hyster H620B (front-loading forklift). This forklift (fig. 100) can handle 50,000-lb containers. The weight is distributed primarily on four front tires having single-wheel loads of 32,500 lb at a gross vehicle weight of 140,710 lb.

(Courtesy of Hyster Company, Portland, Oregon)

Fig. 100. Hyster H620B

f. LeTro-Porter 2582 (front-loading forklift). This vehicle (fig. 101) was selected because it reportedly is capable of operating on most sandy beaches; its articulated body also enhances its ability to operate on unsurfaced soils.

g. Lancer 3500 (side-loading forklift). The Lancer 3500 (fig. 102) can handle 30-long-ton container loads. It can transport these containers at 25 mph and stack the containers two high or load them on railroad cars.

h. Travelift CH 1150 (yard gantry). This yard gantry (fig. 103) was selected because of its ability to span six traffic lanes and because it is equipped with two large tires on each leg that distribute the load imposed by the weight of the gantry. Because individual containers do not exert highly concentrated loads when

(Courtesy of Marathon LeTourneau Company, Longview, Texas)

Fig. 101. LeTro-Porter 2582

(Courtesy of Allis-Chalmers, Matteson, Illinois)

Fig. 102. Lancer 3500

(Courtesy of Drott Manufacturing Company, Wausau, Wisconsin)

Fig. 103. Travelift CH 1150

stacked on the ground, use of this vehicle would allow five rows of containers to be stacked while requiring only two treadways and one 10-ft traffic lane to be surfaced. It was felt that a yard gantry of this size would permit the greatest concentration of containers for the least construction effort.

i. P&H 6250-TC (mobile crane). This large mobile crane (fig. 104) offers a quick solution to the problem of converting existing DeLong piers into container handling facilities. Of the four large-capacity truck cranes suitable for container discharge, the P&H 6250 truck crane is the only one that has wide usage in commercial operations at this time.

j. LeTro Crane GC-500 (mobile gantry crane). The portal lower works of this crane (fig. 105) could permit its operation on the deck of a DeLong barge while allowing traffic to pass beneath it. It has been reported by the Philadelphia Port Authority to be capable of handling up to 20 containers per hour. Although this vehicle is

(Courtesy of Harnischfeger Corporation, Milwaukee, Wisconsin)

Fig. 104. P&H 6250-TC

extremely heavy, its large, low-pressure tires may allow it to operate on beach sands.

k. M52 tractor-trailer. Some difficulty was encountered in selecting a representative tractor-trailer configuration for handling 30-long ton container loads. Models currently being tested do not appear to be capable of handling a fully loaded 40-ft commercial container. It was decided that for comparative purposes the 5-ton M52 tractor (fig. 106) would be used even though its capacity would be exceeded. The M123 tractor, normally used to tow a trailer weighing 40 tons, weighs approximately 62,200 lb, which greatly exceeds the weight of commercial tractors normally used for pulling container chassis.

(Courtesy of Marathon LeTourneau Company, Longview, Texas)

Fig. 105. LeTro crane GC-500

(U. S. Army Photograph)

Fig. 106. M52 tractor-trailer

Types of Surfacing Considered

359. The type of surfacing suitable for use in the TO varies with the design traffic, the materials, equipment, and labor available, and the required design life. To provide data for comparing (as regards engineering construction effort and a wide range of conditions) the relative surfacing requirements for the vehicles considered, each vehicle was evaluated for operational capability on soft and firm soils, M8A1 landing mat, and flexible pavements.

Operational Capability on Soft Soils

360. The WES vehicle cone index (VCI) system[30] for predicting vehicle performance for fine- and coarse-grained soft soils includes

determination of minimum soil strength requirements in terms of VCI, maximum towing force, and towed motion resistance while a vehicle is traveling in a straight line in unaccelerated motion on unobstructed level and sloping soil surfaces. All of the performance parameters are related to rating cone index (RCI) for fine-grained soils and to cone index (CI) for coarse-grained soils. The pertinent soil-vehicle performance relations were empirically derived from field test data, which included a range of vehicle characteristics and soil strengths, primarily developed for standard military vehicles used in off-road operations. In this respect, extrapolations were necessary for many of the vehicles considered in the study described herein. For example, the heaviest wheel loads tested (except for limited tests on the LARC LX) were about 10 tons for fine-grained soils, and, in most instances, the wheel loads were 5 tons or less when the tire inflation pressure exceeded 60 psi.

361. For the study reported herein, the only vehicle performance parameter considered was VCI_1 (defined as the minimum soil strength in terms of RCI or CI that will permit a vehicle to make one pass). Computations of VCI_1 were made for fine-grained soils by first computing mobility index, as shown in table 5, and then looking up VCI_1 in table 6. For coarse-grained soils, computations were made for wheeled vehicles as shown in table 7.

362. The following tabulation lists vehicles and VCI's for both fine- and coarse-grained soils. In the computations of VCI_1, adjustments were made for nonpowered wheels and unequal axle loads. Techniques for making these adjustments are too complicated for inclusion in this report, but they basically involve motion resistances caused by the soil.

Vehicle	One-Pass Vehicle Cone Index* Fine-Grained Soils	 Coarse-Grained Soils
LARC LX	793	46
Shoremaster:		
132,000 lb gross weight, 100 psi	367	940
106,800 lb gross weight, 50 psi	220	137

(Continued)

---

* Nonpowered wheels and unequal axle loads were considered in computations.

Vehicle		One-Pass Vehicle Cone Index	
		Fine-Grained Soils	Coarse-Grained Soils
Clark 512		822	1160
Belotti B67b		1012	2087
Hyster H620B		840	646
LeTro-Porter 2582		1255	100
Lancer 3500		1213	9250**
Travelift CH 1150		651	9014
P&H 6250-TC		935	920
LeTro Crane GC-500		712	45
M52 tractor-trailer		152	350
6000-lb forklift	†	30	96
10,000-lb forklift		45	48
824 forklift		831	320
834 forklift		719	190
LARC V		31	14
LARC XV		112	10

** If tire inflation pressure is reduced to 100 psi (from 149 psi), then VCI_1 for coarse-grained soils becomes 825.

† These six vehicles were included for comparative purposes. The caterpillar Model 834 forklift has never been built. It was included to demonstrate the ability to forecast the performance of vehicles still in stages of design. Although the 834 is heavier than the 824, its larger tires more than compensate for the increase in weight.

363. As mentioned earlier, extrapolations beyond measured field data were necessary in some cases. Also, as shown by the extra computation for the Lancer 3500, inflation pressure change can drastically change the VCI, particularly if the pressures are above 100 psi. The computations do, however, indicate that some relative performance comparisons can be made even though the actual values in some cases may seem unreal. Data available on the LARC LX indicate that it will travel many passes on coarse-grained soil with a CI of 80; therefore, a VCI_1 of 46 seems realistic. The tabulation in paragraph 362 lists VCI_1 for both fine- and coarse-grained soils; however, a VCI_{50} (soil strength requirements in terms of RCI for 50 passes) for fine-grained soils can be

Table 5

Mobility Index Equation for Self-Propelled Wheeled (All-Wheel Drive) Vehicles on Fine-Grained Soil

$$\text{Mobility index*} = \left(\frac{\text{contact pressure factor} \times \text{weight factor}}{\text{tire factor} \times \text{grouser factor}} + \text{wheel load factor} - \text{clearance factor} \right) \times \text{engine factor} \times \text{transmission factor}$$

where

Contact pressure factor: $\dfrac{\text{gross weight, lb}}{\text{nom tire width, in.} \times \dfrac{\text{outside diam of tire, in.}}{2} \times \text{No. of tires}}$

Weight factor:

Weight Range, lb**	Weight Factor Equations†
<2,000	$Y = 0.553X$
2,000 to 13,500	$Y = 0.033X + 1.050$
13,501 to 20,000	$Y = 0.142X - 0.420$
>20,000	$Y = 0.278X - 3.115$

Tire factor: $\dfrac{10 + \text{tire width, in.}}{100}$

Grouser factor: With chains = 1.05

Without chains = 1.00

Wheel load factor: $\dfrac{\text{gross weight, kips}}{\text{No. of axles} \times 2}$

Clearance factor: $\dfrac{\text{clearance, in.}}{10}$

Engine factor: >10 hp/ton = 1.00

<10 hp/ton = 1.05

Transmission factor: Automatic = 1.00 ; manual = 1.05

---

* After MI has been obtained, VCI_1 can be obtained from table 6.

** $\dfrac{\text{Gross weight, lb}}{\text{No. of axles}}$.

† Y = weight factor , $X = \dfrac{\text{gross weight, kips}}{\text{No. of axles}}$.

Table 6

Mobility Index Converted to Vehicle Cone Index for One Pass of a Wheeled Vehicle on Fine-Grained Soil

MI	VCI_1	MI	VCI_1	MI	VCI_1	MI	VCI_1
0	1.0	40	18.6	80	27.0	120	35.2
1	3.4	41	18.8	81	27.2	121	35.4
2	5.0	42	19.0	82	27.4	122	35.6
3	6.3	43	19.2	83	27.6	123	35.8
4	7.2	44	19.5	84	27.8	124	36.0
5	8.0	45	19.7	85	28.0	125	36.2
6	8.7	46	19.9	86	28.2	126	36.4
7	9.2	47	20.1	87	28.4	127	36.6
8	9.7	48	20.3	88	28.6	128	36.8
9	10.2	49	20.5	89	28.9	129	37.0
10	10.6	50	20.8	90	29.1	130	37.2
11	11.0	51	21.0	91	29.3	131	37.4
12	11.4	52	21.2	92	29.5	132	37.6
13	11.7	53	21.4	93	29.7	133	37.8
14	12.0	54	21.6	94	29.9	134	38.0
15	12.4	55	21.8	95	30.1	135	38.2
16	12.7	56	22.0	96	30.3	136	38.4
17	13.0	57	22.2	97	30.5	137	38.6
18	13.3	58	22.4	98	30.7	138	38.8
19	13.6	59	22.7	99	30.9	139	39.0
20	13.8	60	22.9	100	31.1	140	39.2
21	14.1	61	23.1	101	31.3	141	39.4
22	14.4	62	23.3	102	31.5	142	39.6
23	14.6	63	23.5	103	31.7	143	39.8
24	14.9	64	23.7	104	31.9	144	40.0
25	15.1	65	23.9	105	32.1	145	40.2
26	15.4	66	24.1	106	32.3	146	40.4
27	15.6	67	24.3	107	32.5	147	40.6
28	15.8	68	24.5	108	32.7	148	40.8
29	16.1	69	24.7	109	32.9	149	41.0
30	16.3	70	25.0	110	33.1	150	41.2
31	16.6	71	25.2	111	33.3	151	41.4
32	16.8	72	25.4	112	33.5	152	41.6
33	17.0	73	25.6	113	33.7	153	41.8
34	17.2	74	25.8	114	34.0	154	42.0
35	17.5	75	26.0	115	34.2	155	42.2
36	17.7	76	26.2	116	34.4	156	42.4
37	17.9	77	26.4	117	34.6	157	42.6
38	18.1	78	26.6	118	34.8	158	42.8
39	18.4	79	26.8	119	35.0	159	43.0
						160	43.2

Note: For MI above 160, VCI_1 can be obtained using the following equation:

$$VCI_1 = 11.48 + 0.2\ MI - \frac{39.2}{MI + 3.74}$$

Table 7

Computation of Vehicle Cone Index for One Pass of a Wheeled Vehicle on Coarse-Grained Soil

---

Vehicle ____________________

Equation: Vehicle cone index (VCI_1) = antilogarithm* - 0.350 (contact area factor, X_1) + 0.0526 (number of tires, X_2) + 0.0211 (tire pressure, X_3) + 1.5870

Vehicle and Soil Characteristics

(1) Gross vehicle weight, lb = ____________________

(2) Nominal tire width, in. = ____________________

(3) Rim diameter, in. = ____________________

(4) Number of tires = X_2 = ____________________

(5) Tire ply rating = ____________________

(6) Tire pressure, psi = X_3 = ____________________

Factors

(7) $\frac{\text{Nominal tire width, in.}}{\text{Rim diameter, in.}}$ = __________ ; if >2.4, factor (7) = 2.0; if <2.4, factor (7) = 5.0

(8) Wheel diameter factor = (7)** × (2) + (3) = ____________________

(9) Contact pressure factor = 0.607 × (6) + 1.35 $\frac{117.0 \times (5) - 4.93}{(8)}$

= 0.607 × _____ + 1.35 $\frac{117.0 \times \underline{\quad\quad}}{\underline{\quad\quad}}$ - 4.93 = ____________________

(10) Contact area factor = $X_1 = \log \frac{(1)}{(9)}$ = log (________) = ____________

(11) Strength factor = [-0.350 × (10) + 0.0526 × (4) + 0.0211 × (6) + 1.5870] = ____ = [-0.350 × ____ + 0.0526 × ____ + 0.0211 × ____ + 1.5870] = ____

Vehicle cone index (VCI_1) = antilogarithm (11) = antilogarithm (____) = ____________________

---

* Logarithm to the base 10.

** Number in parentheses indicates value assigned to that factor number.

computed from tables 5 and 7. For coarse-grained soils, only one-pass performance is determined because tests have shown that minimum soil strength for "go" on the first pass on coarse-grained soil is adequate for "go" on subsequent passes.

Soil Strength and Thickness Requirements for Vehicle Operation

Unsurfaced soils*

364. Strength and thickness requirements for unsurfaced soils were determined through use of the nomograph shown in fig. 107 (from reference 31) and the following equation (from reference 32).

$$t = (0.176 \log C + 0.12)\sqrt{\frac{P}{8.1\ \mathrm{CBR}} - \frac{A}{\pi}} \qquad (1)$$

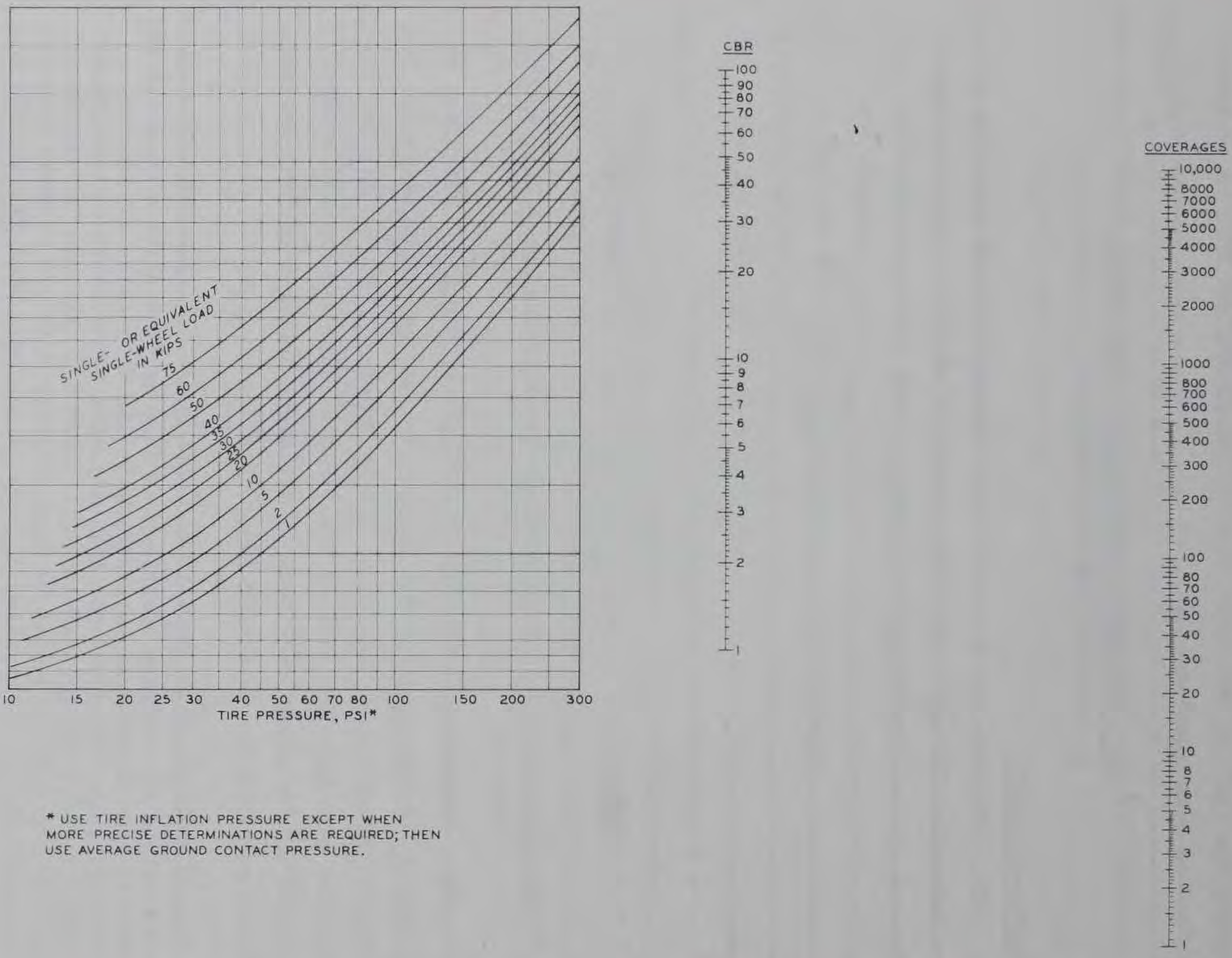
where

t = thickness of strengthening layer, in.
C = traffic volume, coverages
P = single- or equivalent single-wheel load (ESWL), lb
A = tire contact area, in.^{2}
CBR = measure of soil strength as determined by Test 101, reference 16

365. Example calculations of the soil strength and thickness requirements for operation of the Shoremaster on unsurfaced soils are given in Appendix A of WES Miscellaneous Paper S-72-34.[33] Similar computations were made for each of the vehicles included in this study; strength and thickness requirements are given in table 8. The determinations required the following input data:

---

* The method of analysis described in this section differs from the WES vehicle cone index system primarily in its definition of failure. This criterion was developed for operation of aircraft on unsurfaced soils of medium or greater strength (>CBR 4). Failure is considered to have occurred when ruts of approximately 3 in. or greater have developed. In the VCI system, failure occurs only when the vehicle becomes immobilized, regardless of the degree of rutting that has occurred.



* USE TIRE INFLATION PRESSURE EXCEPT WHEN MORE PRECISE DETERMINATIONS ARE REQUIRED; THEN USE AVERAGE GROUND CONTACT PRESSURE.

Fig. 107. CBR required for operation of aircraft on unsurfaced soils

Table 8

CBR and Thickness Requirements for 200 and 10,000 Passes of Container Handling Vehicles Operating on Unsurfaced Soils with Subgrade Strengths of 4 and 10 CBR*

						Passes					
						200			10,000		
							Thickness Requirements, in.			Thickness Requirements, in.	
	Gross Weight lb	Payload lb	Tire Pressure, psi		Tire Contact Area $in.^2$	Surface CBR	4-CBR Subgrade	10-CBR Subgrade	Surface CBR	4-CBR Subgrade	10-CBR Subgrade
Vehicle			Inflation	Contact							
Amphibian											
LARC LX**	319,000	120,000	42	42	1898	10	22	0	20	35	16
Straddle Carriers											
Shoremaster	129,200	67,200	100	105	154	9	11	0	17	18	10
Clark 512	164,500	67,200	132	133	210	14	14	9	26	20	12
Belotti B67b	159,800	67,200	125	115	380	14	17	9	27	28	14
Front-Loading Forklift											
Hyster H620B	140,710	62,000†	100	145	224	20	19	11	38	35	20
LeTro-Porter 2582	165,200	67,200	70	99	800	18	21	12	35	35	20
Side-Loading Forklift											
Lancer 3500	213,200	67,200	149	150	183	19	20	11	36	35	20
Yard Gantry											
Travelift CH 1150	223,200	67,200	146	146	280	24	22	12	45	36	21
Mobile Cranes											
P&H 6250-TC	396,021	0††	100	106	260	16	31	18	30	55	31
LeTro Crane GC-500‡	708,504	0††	35	69	1275	26	32	17	50	56	29
Tractor-Trailer Combination											
M52 Tractor and Trailer	100,000	67,200	80	68	82.5	5	10	0	10	18	0

* Unsurfaced soil criteria limited to approximately 10,000 passes.

** As is well known, the LARC LX was not specifically designed for container handling. It has been included in this study for comparative purposes because of its known operational capability on relatively low-strength soils.

† Maximum payload for the Hyster H620B.

†† Zero payload while moving.

‡ Criteria do not exist for loads imposed by vehicles on unsurfaced soils. Data shown are based on extrapolation and engineering judgment.

a. Vehicle characteristics, i.e., gross weight, wheel configuration, and tire contact area.

b. Anticipated traffic volume.

c. Subgrade strength (CBR).

Soils beneath landing mat

366. Strength and thickness requirements for soils beneath landing mat were determined through use of the following equations:

$$\mathrm{CBR} = \frac{P}{8.1\left[\left(\frac{\mathrm{TR}}{f}\right)^2 + \frac{A}{\pi}\right]} \tag{2}$$

$$t_{um} = \left[(0.2875 \log C + 0.1875)\sqrt{\frac{P}{8.1\ \mathrm{CBR}} - \frac{A}{\pi}}\right] - \mathrm{TR} \text{ (see equation 2, reference 34)} \tag{3}$$

where

CBR = measure of the soil strength as determined by Test 101, reference 35

P = single- or equivalent single-wheel load, lb

TR = thickness of flexible pavement structure replaced by landing mat, in.

f = repetitions factor

A = tire contact area, in.^{2}

C = volume of traffic, coverages

367. Example calculations of the soil strength and thickness requirements for operation of the Shoremaster on landing mat placed on a soil subgrade are given in Appendix A of reference 33. Similar computations were made for each of the vehicles included in this study; soil strength and thickness requirements are given in table 9. The input data for these determinations are the same as those stated in paragraph 365.

368. A test was performed at WES to determine if the corner posts of a 40-ft container would cause any serious damage to M8A1 landing mat laid on a 10-CBR subgrade. An 8-1/2- by 6-1/2- by 4-3/4-in. cast iron block is constructed in each corner of a commercial container. The corner block was placed on the landing mat, and a load of 17,000 lb was

Table 9

CBR and Thickness Requirements for 200, 10,000, and 50,000 Passes of Container Handling Vehicles Operating on Soils Surfaced with M8A1 Landing Mat and with Subgrade Strengths of 4 and 10 CBR*

						Passes								
						200			10,000			50,000		
							Thickness Requirements in.			Thickness Requirements in.			Thickness Requirements in.	
			Tire Pressure, psi											
Vehicle	Gross Weight lb	Payload lb	Infla-tion	Contact	Tire Contact Area in.^{2}	Surface CBR	4-CBR Sub-grade	10-CBR Sub-grade	Surface CBR	4-CBR Sub-grade	10-CBR Sub-grade	Surface CBR	4-CBR Sub-grade	10-CBR Sub-grade
Amphibian														
LARC LX**	319,000	120,000	42	42	1898	3.5	0	0	7	27	0	9	36	0
Straddle Carriers														
Shoremaster	129,200	67,200	100	105	154	3.5	0	0	8	22	0	10	32	0
Clark 512	164,500	67,200	132	133	210	5	6	0	11	28	7	14	37	11
Belotti B67b	159,800	67,200	125	115	380	5	8	0	11	26	7	14	34	11
Front-Loading Forklifts														
Hyster H620B	140,710	62,000†	100	145	224	6	10	0	13	40	6	19	51	20
LeTro-Porter 2582	165,200	67,200	70	102	800	12	21	6	22	51	21	25	65	27
Side-Loading Forklift														
Lancer 3500	213,200	67,200	149	150	183	6	13	0	14	43	13	17	56	21
Yard Gantry														
Travelift CH 1150	223,200	67,200	146	146	280	6	13	0	14	32	6	17	46	12
Mobile Cranes														
P&H 6250-TC	396,021	0††	100	106	260	14	36	10	26	81	32	35	82	32
LeTro Crane GC-500‡	708,504	0††	35	69	1275	15	37	11	23	82	33	25	99	44
Tractor-Trailer Combination														
M52 Tractor and Trailer	100,000	67,200	80	68	82.5	2.5	0	0	5	15	0	7	20	0

* M8A1 landing mat was not designed for use with large loads imposed by most of the equipment listed nor for traffic volumes exceeding about 2000 passes.

** As is well known, the LARC LX was not specifically designed for container handling. It has been included in this study for comparative purposes because of its known operational capability on relatively low-strength soils.

† Maximum payload for the Hyster H620B.

†† Zero payload while moving.

‡ Criteria do not exist for loads imposed by vehicles on M8A1 landing mat. Data shown are based on extrapolation and engineering judgment.

applied. The test indicated that there will apparently be no damage as long as the containers are stacked only one high.

Requirements for Flexible Pavements

369. It was beyond the scope of this study to consider strength requirements for elements of a flexible pavement structure above a subgrade of known strength. It was considered sufficient to develop only thickness requirements for flexible pavement. Thicknesses for flexible pavements, as presented herein, were determined through use of the following equation:

$$t = \alpha_1 \left\{ \sqrt{A} \left[-0.0481 - 1.1562 \left(\log \frac{CBR}{p_e} \right) - 0.6414 \left(\log \frac{CBR}{p_e} \right)^2 - 0.473 \left(\log \frac{CBR}{p_e} \right)^3 \right] \right\} \quad \text{(see equation 20a, reference 36)} \qquad (4)$$

where

t = total thickness of superior material required above a layer of known strength to prevent shear deformation within this layer of soil, in.

α_1 = load repetitions factor, which varies with number of wheels and volume of traffic (see fig. 82, reference 36).

A = tire contact area, in.^{2}

p_e = SWL or ESWL tire pressure, psi. For single-wheel loads, p_e = SWL/A . This is an actual tire pressure and is generally equal to the tire inflation pressure. For multiple-wheel configurations, p_e = ESWL/A where the ESWL* is determined by methods shown in Appendix A of reference 37. This is an artificial tire pressure, consistent with use of

---

* The ESWL is based on the ratio of maximum deflection beneath a multiple-wheel configuration and one wheel of that configuration computed assuming a homogeneous isotropic, half-space loaded by a uniformly distributed circular load. The ESWL varies with depth and is determined at sufficient depths to provide data for construction of an ESWL versus depth curve. This curve is required for each specific vehicle considered.

the contact area of one tire, and has no relation to actual tire inflation pressure

CBR = measure of the strength of soil as determined by Test 101, reference 35

370. Solution of equation 4 has been computerized for treatment of complex wheel configuration geometry, and the computer program was used in this study. The basic data required to determine thickness requirements for flexible pavements above a subgrade of known strength for the study vehicles are the same as required to determine thickness requirements of unsurfaced soils and soils beneath landing mat as discussed in paragraphs 364 and 366. Thickness requirements for each vehicle considered were determined for 200 and 50,000 passes through solution of equation 4, and the results of these computations are shown in figs. 108-118.

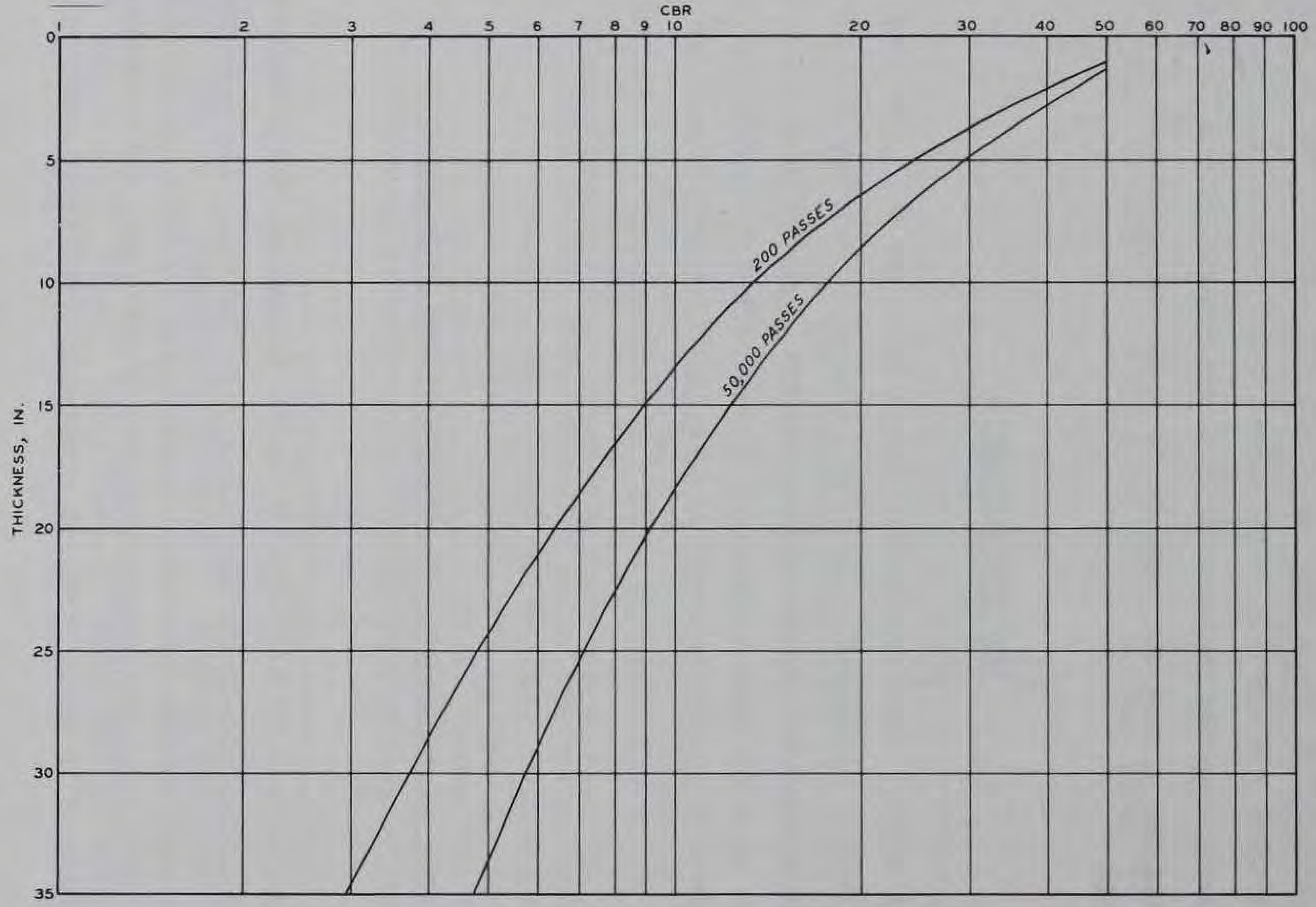
Area Requirements

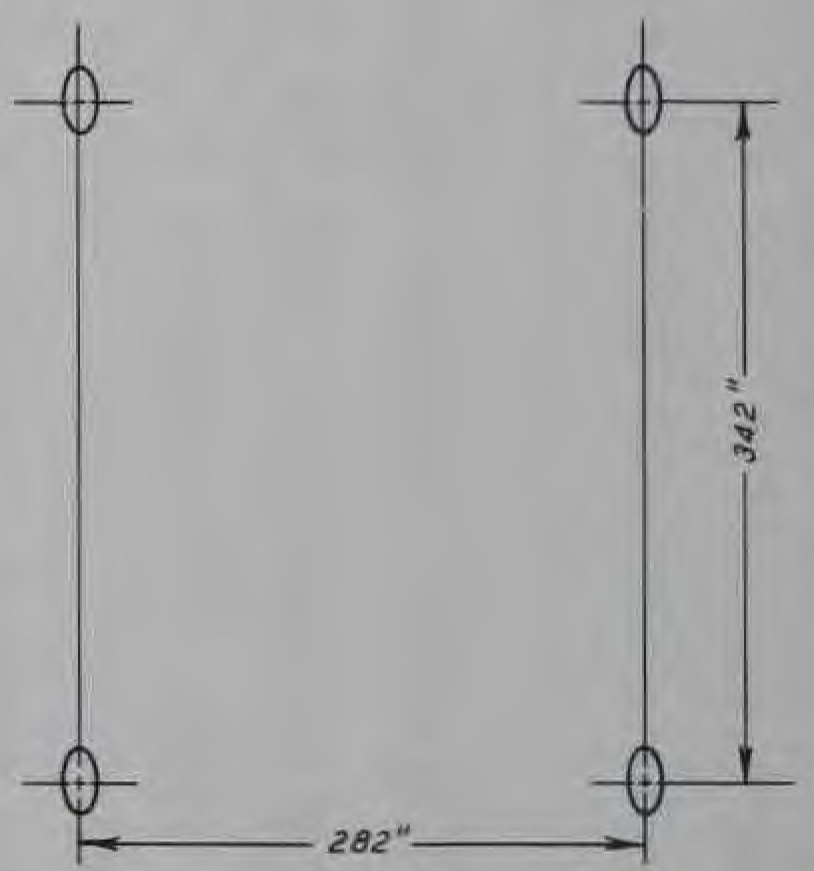
371. A study of area requirements was made based on the capabilities of the selected equipment. Typical layouts of storage and marshalling areas were scaled to determine the number of containers that could be stored in an area of approximately 5 acres. These layouts are shown in figs. 119-122. A layout for the front-loading forklift was not included because it is not normally used for stacking but is employed in the loading of railroad cars, trailer chassis, and general utility tasks.

Analysis of Soil Strength and Thickness Requirements

Soft soils

372. Examination of the tabulation in paragraph 362 indicates that the vehicles considered in this study, in general, are not capable of operating on soft soils because they have VCI's of 300 or greater. A cone index of 300 is approximately equal to a CBR value of 4, and soils having a CBR above this value are not generally considered soft soils.



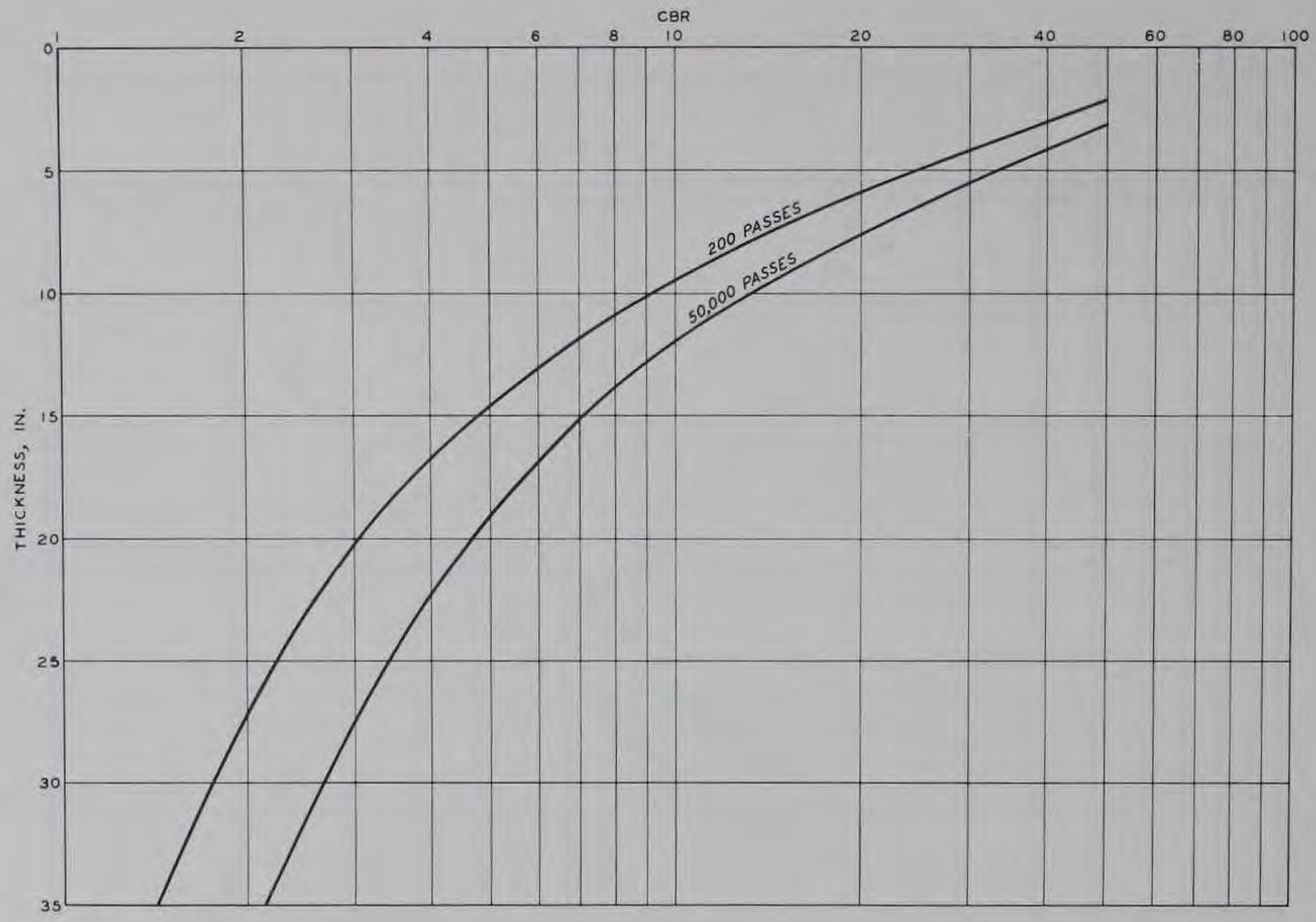


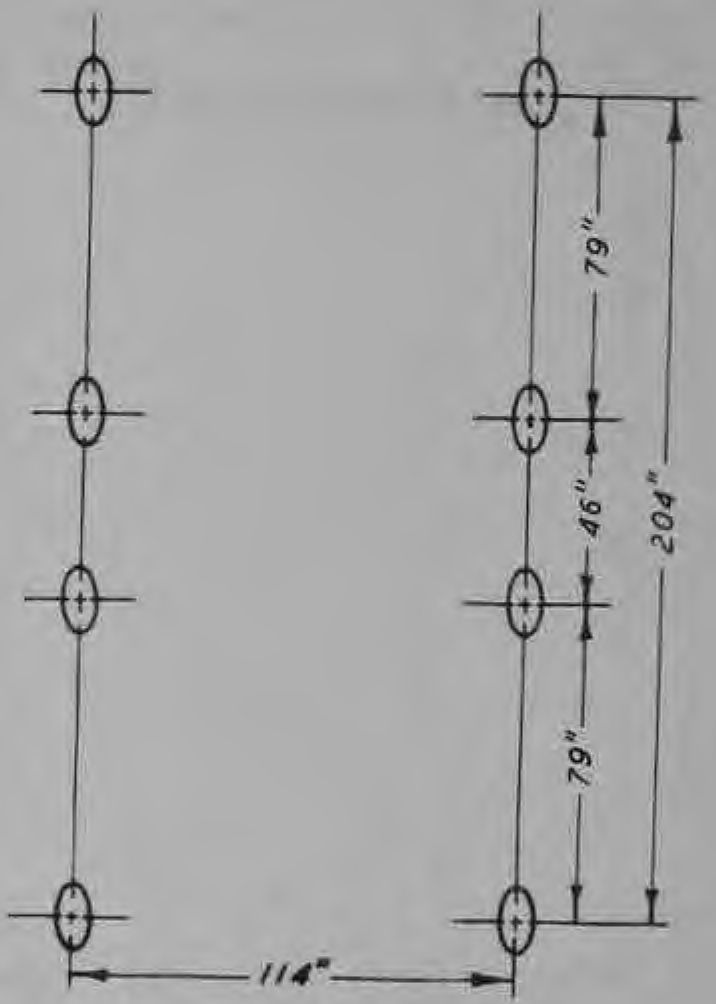
BASIS FOR DESIGN CURVES

GROSS WEIGHT	=	319,000 LB
SINGLE-WHEEL LOAD	=	79,750 LB
TIRE INFLATION PRESSURE	=	42 PSI
CONTACT AREA	=	1,898 IN.^{2}
PAYLOAD	=	120,000 LB

WHEEL CONFIGURATION

Fig. 108. Flexible pavement design curves for LARC LX (amphibian)



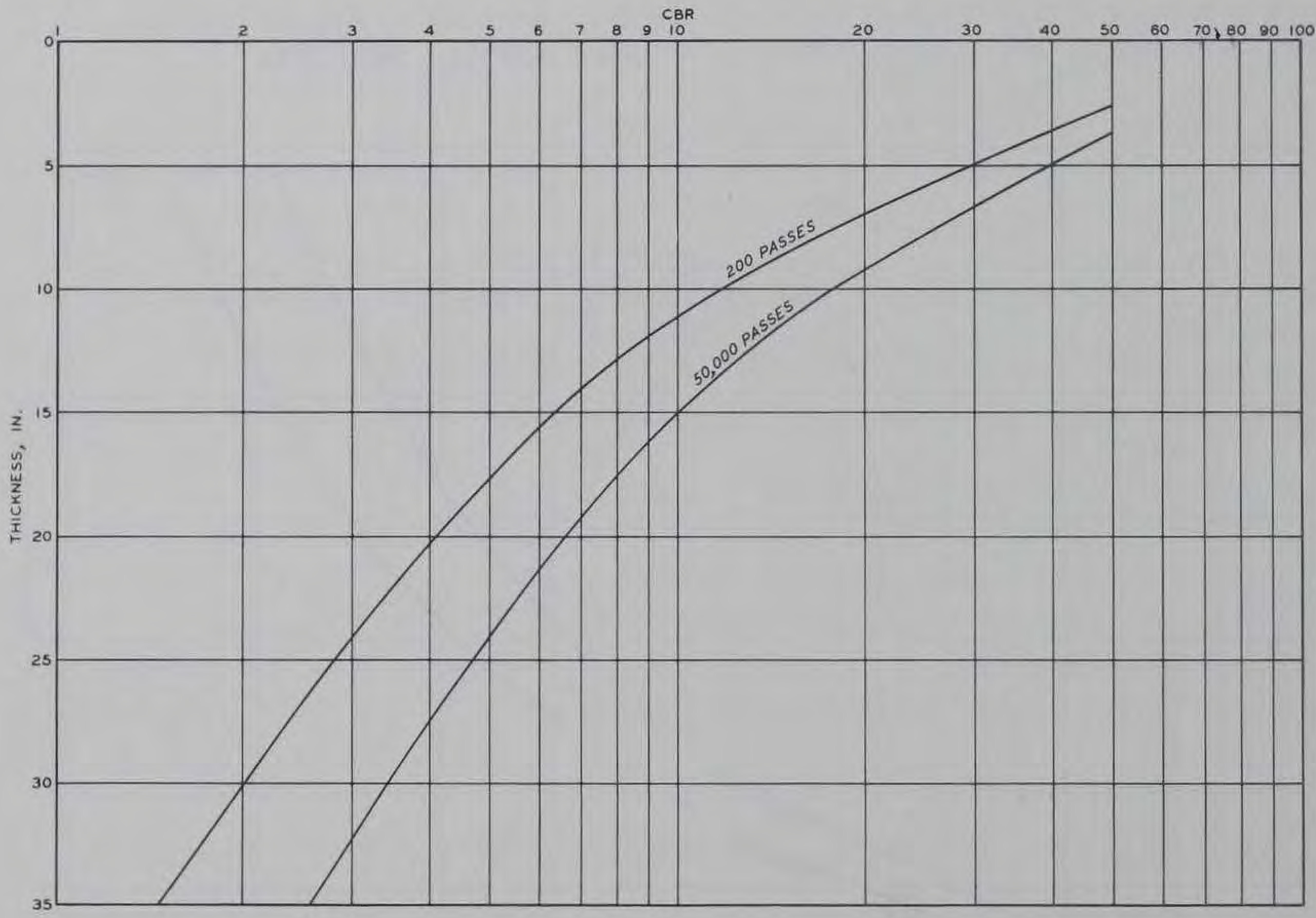


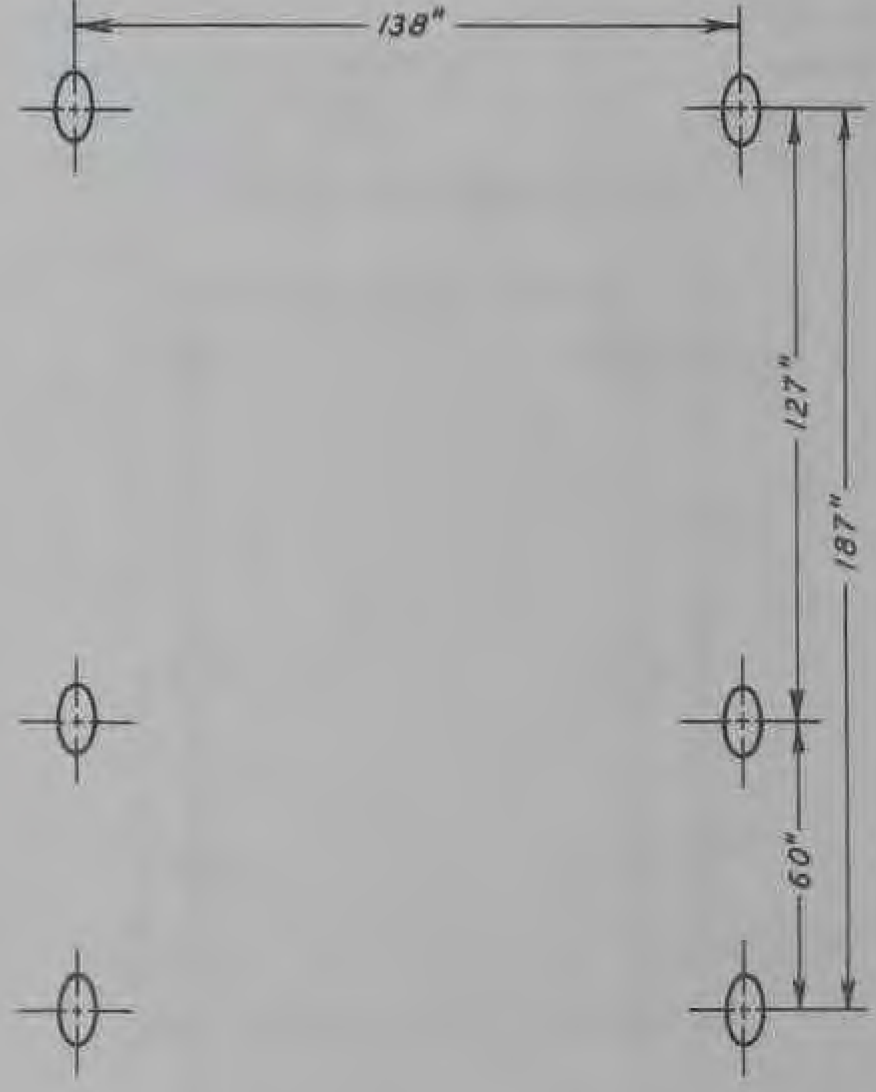
BASIS FOR DESIGN CURVES

GROSS WEIGHT = 129,200 LB
SINGLE-WHEEL LOAD = 18,150 LB
TIRE INFLATION PRESSURE = 100 PSI
CONTACT AREA = 154 IN.^{2}
PAYLOAD = 67,200 LB

WHEEL CONFIGURATION

Fig. 109. Flexible pavement design curves for Shoremaster (straddle carrier)

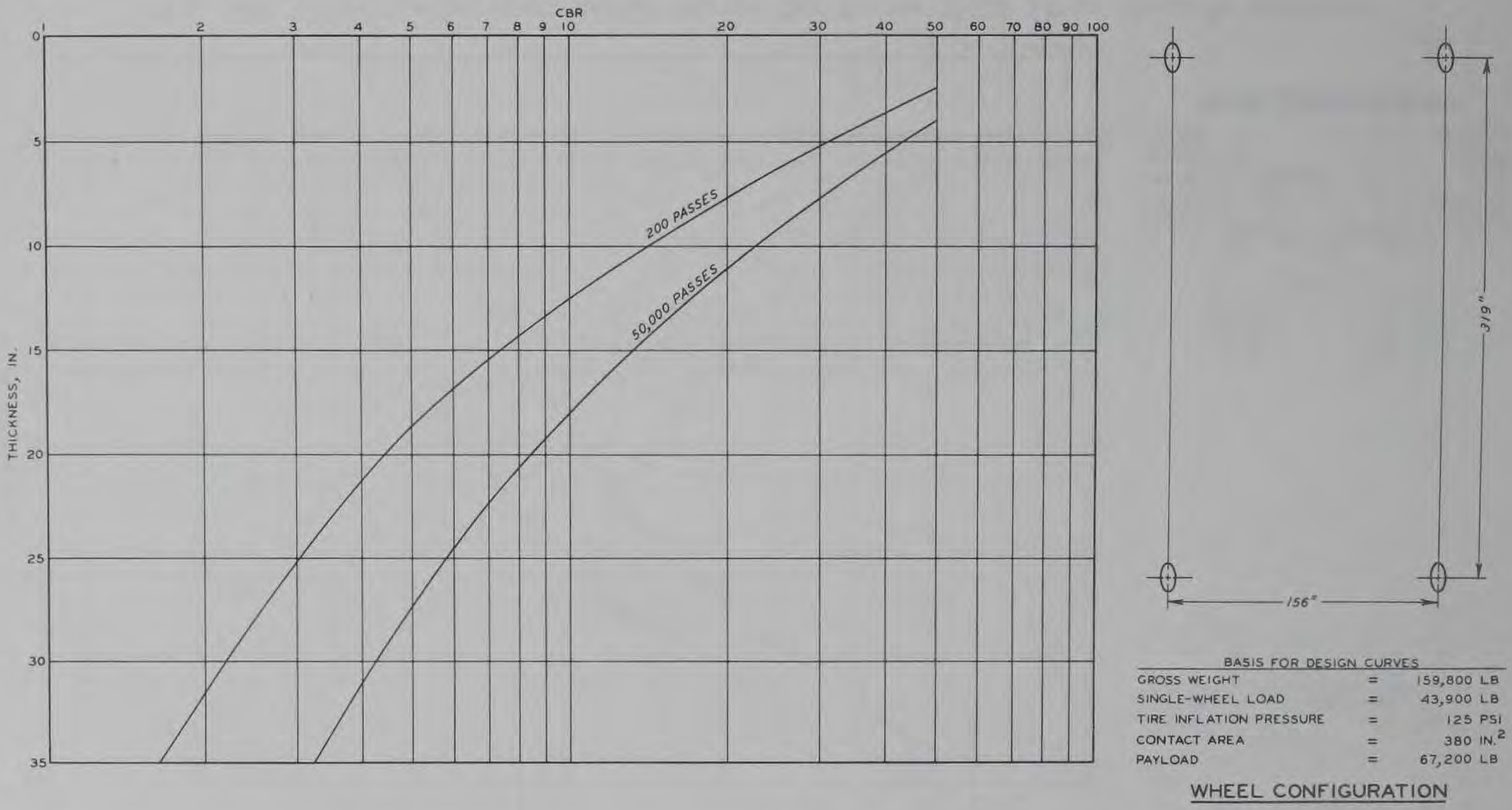




BASIS FOR DESIGN CURVES		
GROSS WEIGHT	=	164,500 LB
SINGLE-WHEEL LOAD	=	27,900 LB
TIRE INFLATION PRESSURE	=	132 PSI
CONTACT AREA	=	210 IN.^{2}
PAYLOAD	=	67,200 LB

WHEEL CONFIGURATION

Fig. 110. Flexible pavement design curves for Clark 512 (straddle carrier)

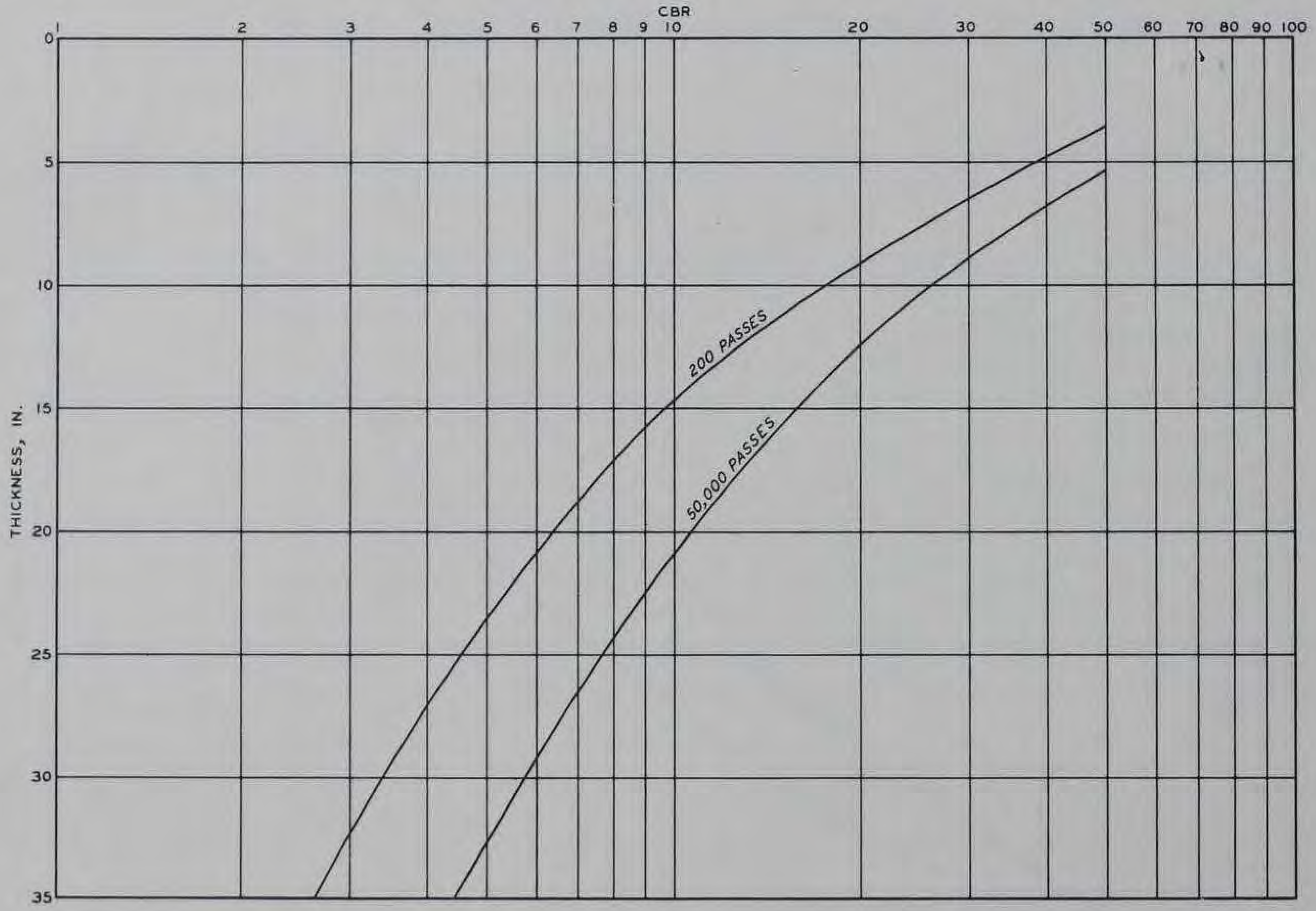


BASIS FOR DESIGN CURVES

GROSS WEIGHT	=	159,800 LB
SINGLE-WHEEL LOAD	=	43,900 LB
TIRE INFLATION PRESSURE	=	125 PSI
CONTACT AREA	=	380 IN.^{2}
PAYLOAD	=	67,200 LB

WHEEL CONFIGURATION

Fig. 111. Flexible pavement design curves for Belotti B67b (straddle carrier)

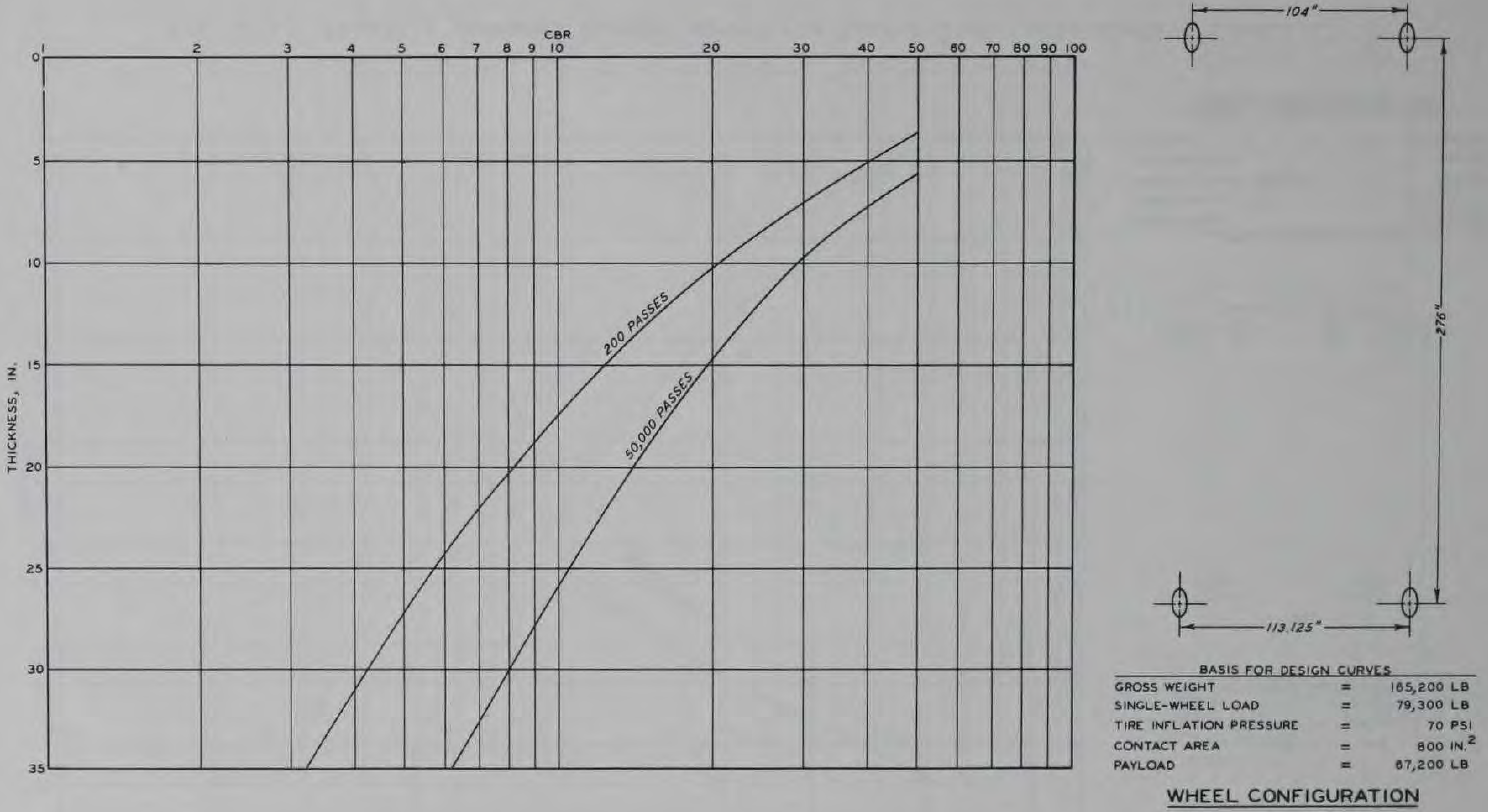


BASIS FOR DESIGN CURVES

GROSS WEIGHT	=	140,710 LB
SINGLE-WHEEL LOAD	=	32,500 LB
TIRE INFLATION PRESSURE	=	100 PSI
CONTACT AREA	=	224 IN.^{2}
PAYLOAD	=	62,000 LB

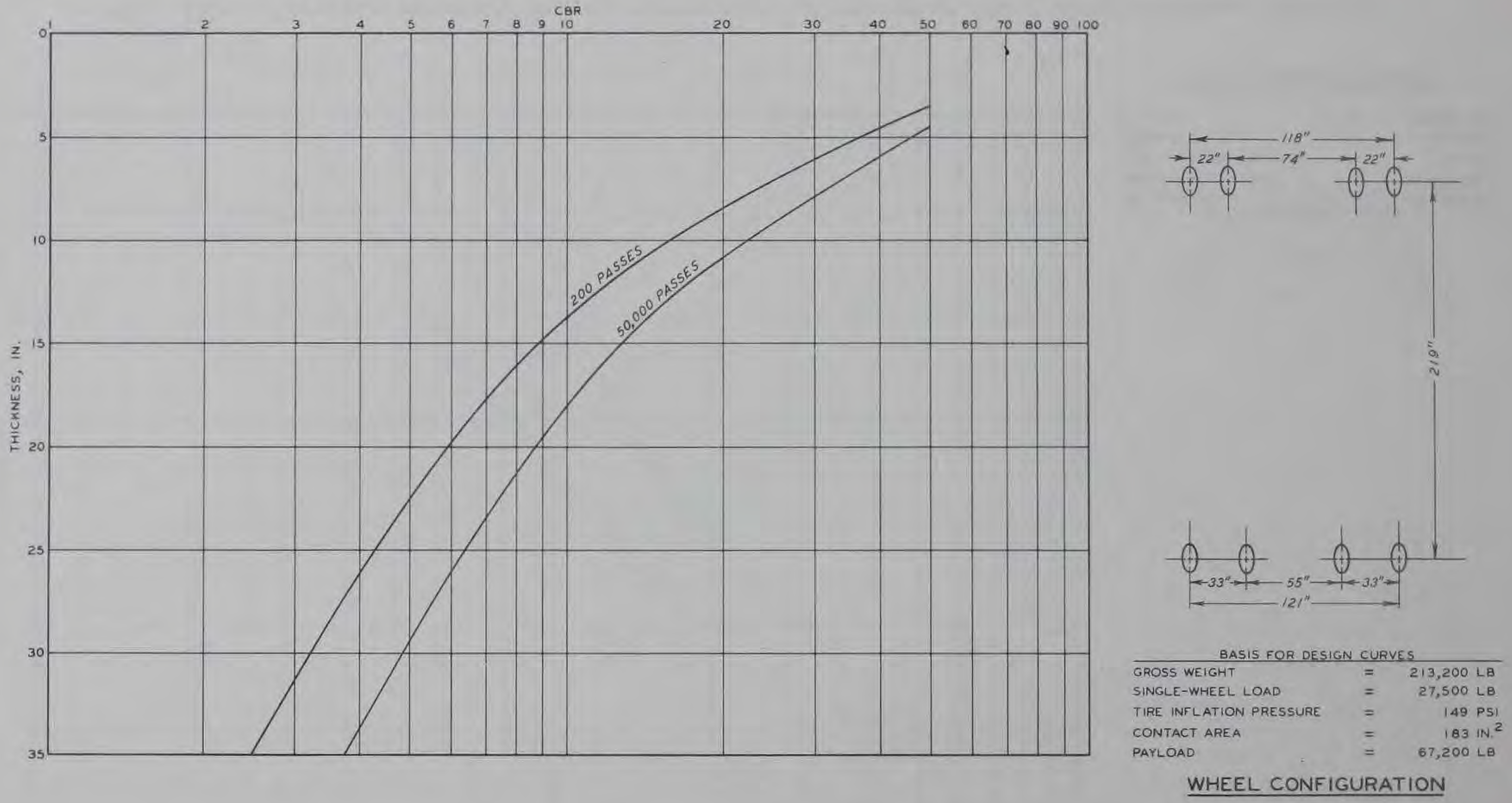
WHEEL CONFIGURATION

Fig. 112. Flexible pavement design curves for Hyster H620B (front-loading forklift)



BASIS FOR DESIGN CURVES		
GROSS WEIGHT	=	165,200 LB
SINGLE-WHEEL LOAD	=	79,300 LB
TIRE INFLATION PRESSURE	=	70 PSI
CONTACT AREA	=	800 $IN.^2$
PAYLOAD	=	67,200 LB

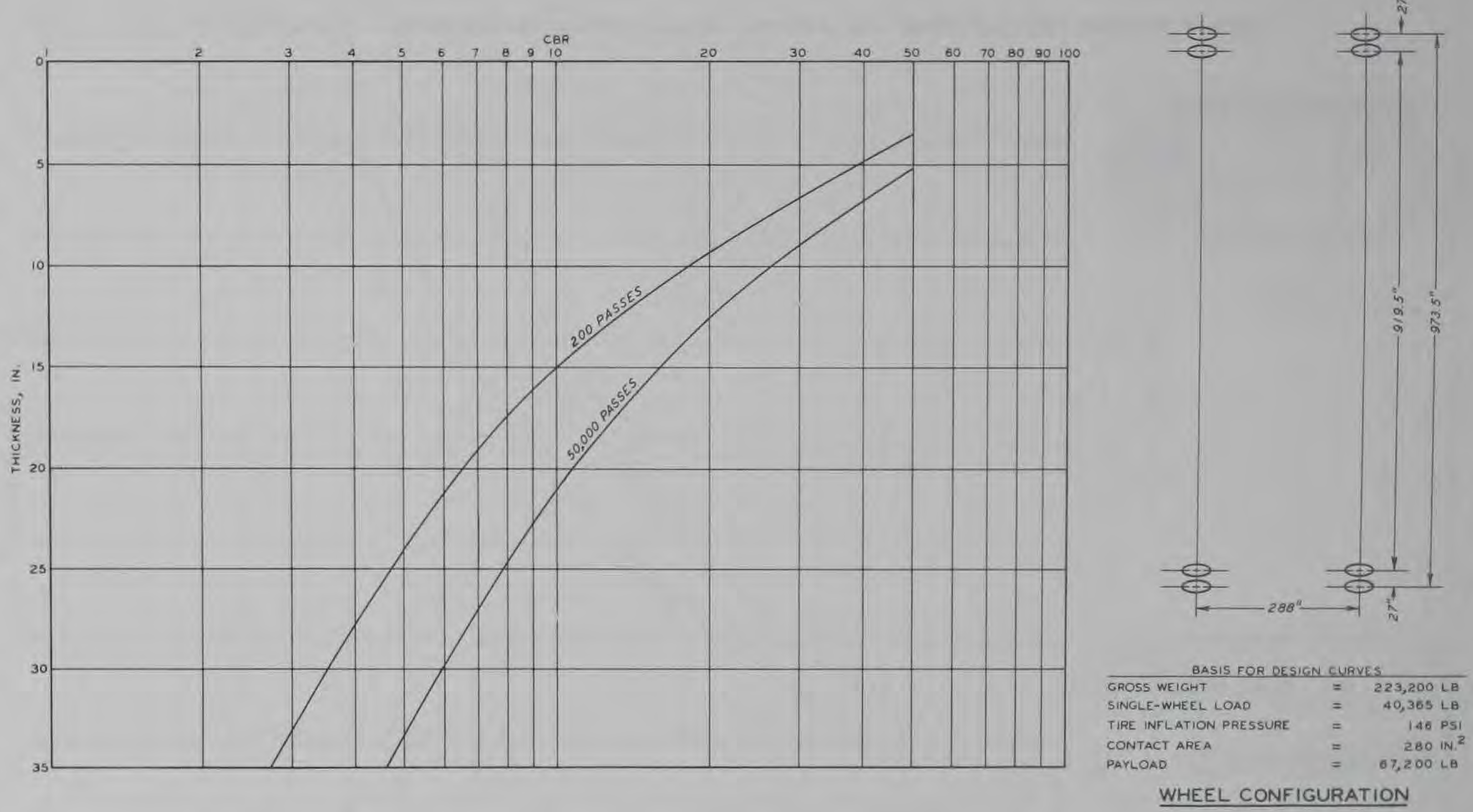
Fig. 113. Flexible pavement design curves for LeTro-Porter 2582 (front-loading forklift)



BASIS FOR DESIGN CURVES

GROSS WEIGHT	=	213,200 LB
SINGLE-WHEEL LOAD	=	27,500 LB
TIRE INFLATION PRESSURE	=	149 PSI
CONTACT AREA	=	183 IN.^{2}
PAYLOAD	=	67,200 LB

Fig. 114. Flexible pavement design curves for Lancer 3500 (side-loading forklift)



BASIS FOR DESIGN CURVES		
GROSS WEIGHT	=	223,200 LB
SINGLE-WHEEL LOAD	=	40,365 LB
TIRE INFLATION PRESSURE	=	146 PSI
CONTACT AREA	=	280 IN.^{2}
PAYLOAD	=	67,200 LB

Fig. 115. Flexible pavement design curves for Travelift CH 1150 (yard gantry)

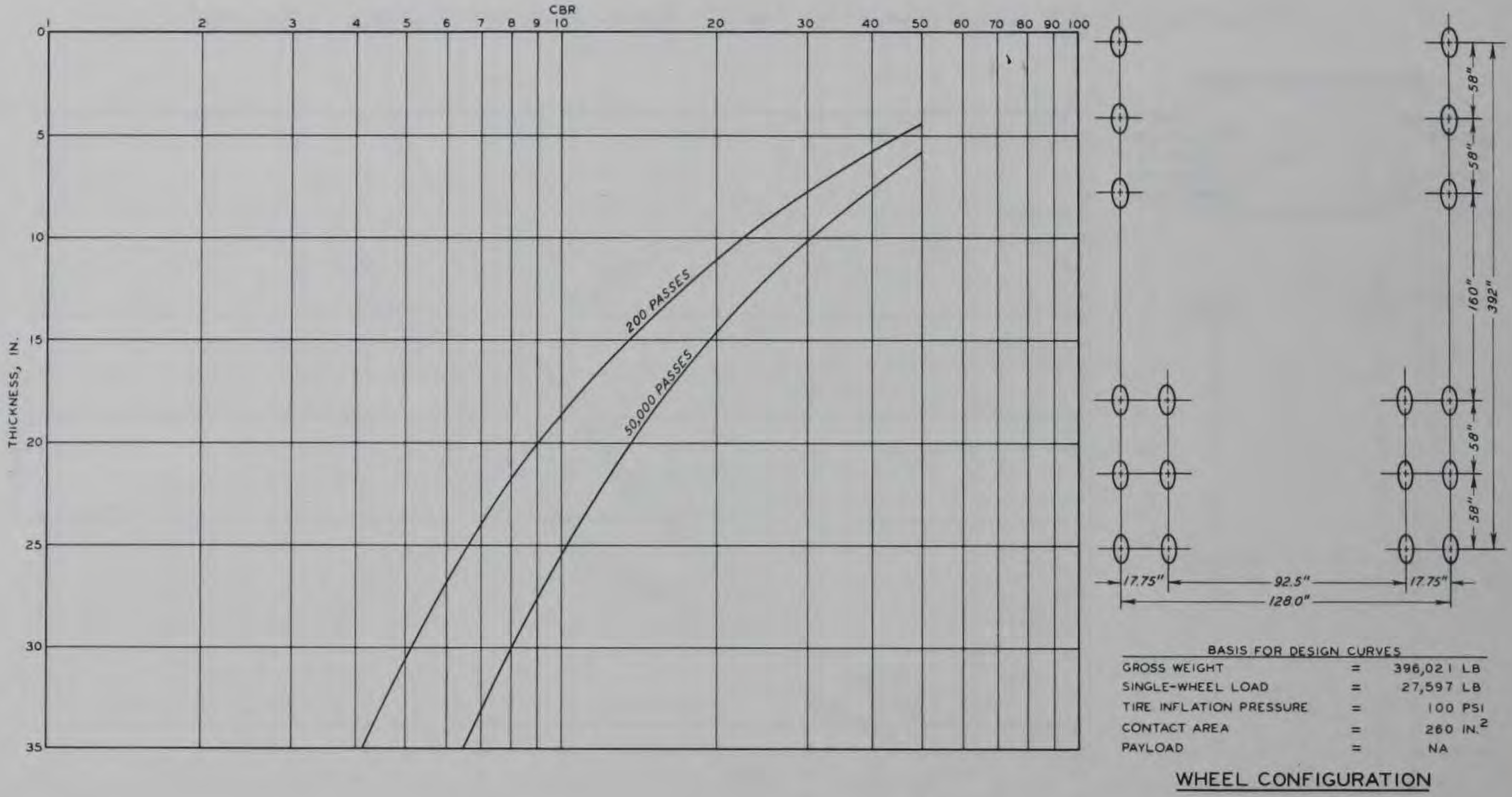
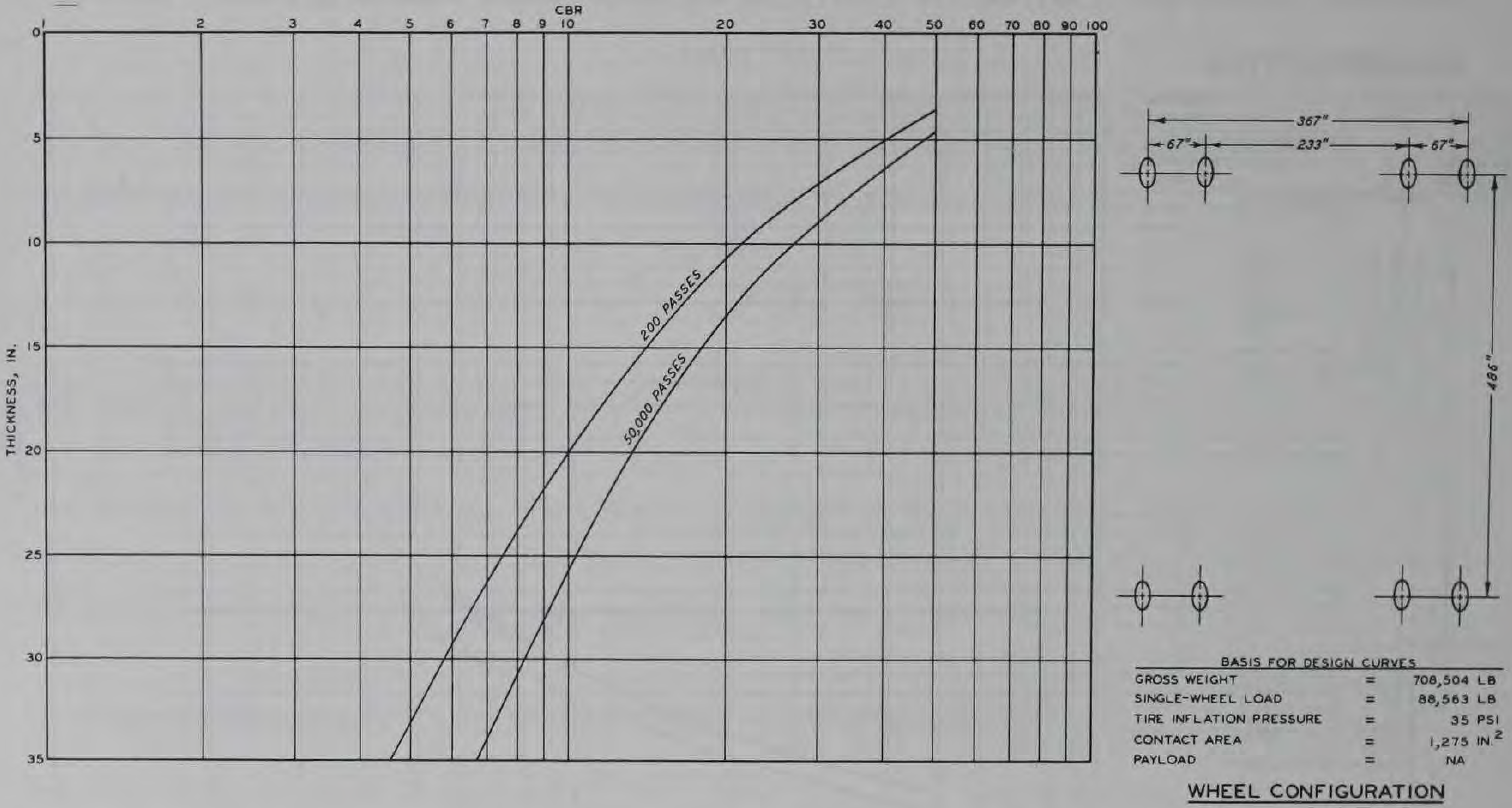


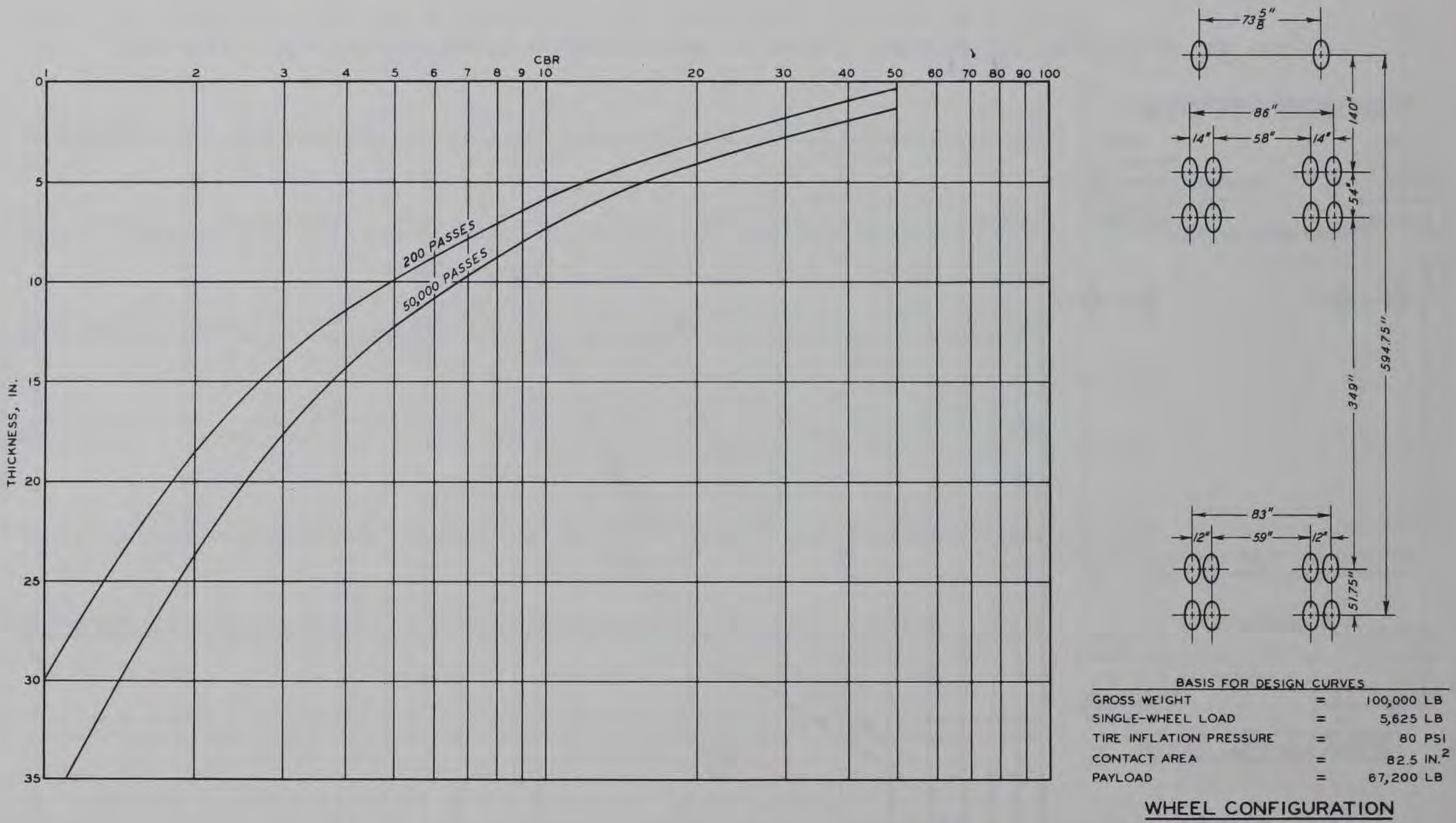
Fig. 116. Flexible pavement design curves for P&H 6250-TC (mobile crane)



BASIS FOR DESIGN CURVES

GROSS WEIGHT	=	708,504 LB
SINGLE-WHEEL LOAD	=	88,563 LB
TIRE INFLATION PRESSURE	=	35 PSI
CONTACT AREA	=	1,275 IN.^{2}
PAYLOAD	=	NA

Fig. 117. Flexible pavement design curves for LeTro Crane GC-500 (mobile gantry crane)



BASIS FOR DESIGN CURVES		
GROSS WEIGHT	=	100,000 LB
SINGLE-WHEEL LOAD	=	5,625 LB
TIRE INFLATION PRESSURE	=	80 PSI
CONTACT AREA	=	82.5 $IN.^2$
PAYLOAD	=	67,200 LB

Fig. 118. Flexible pavement design curves for M52 tractor and trailer (truck-trailer combination)

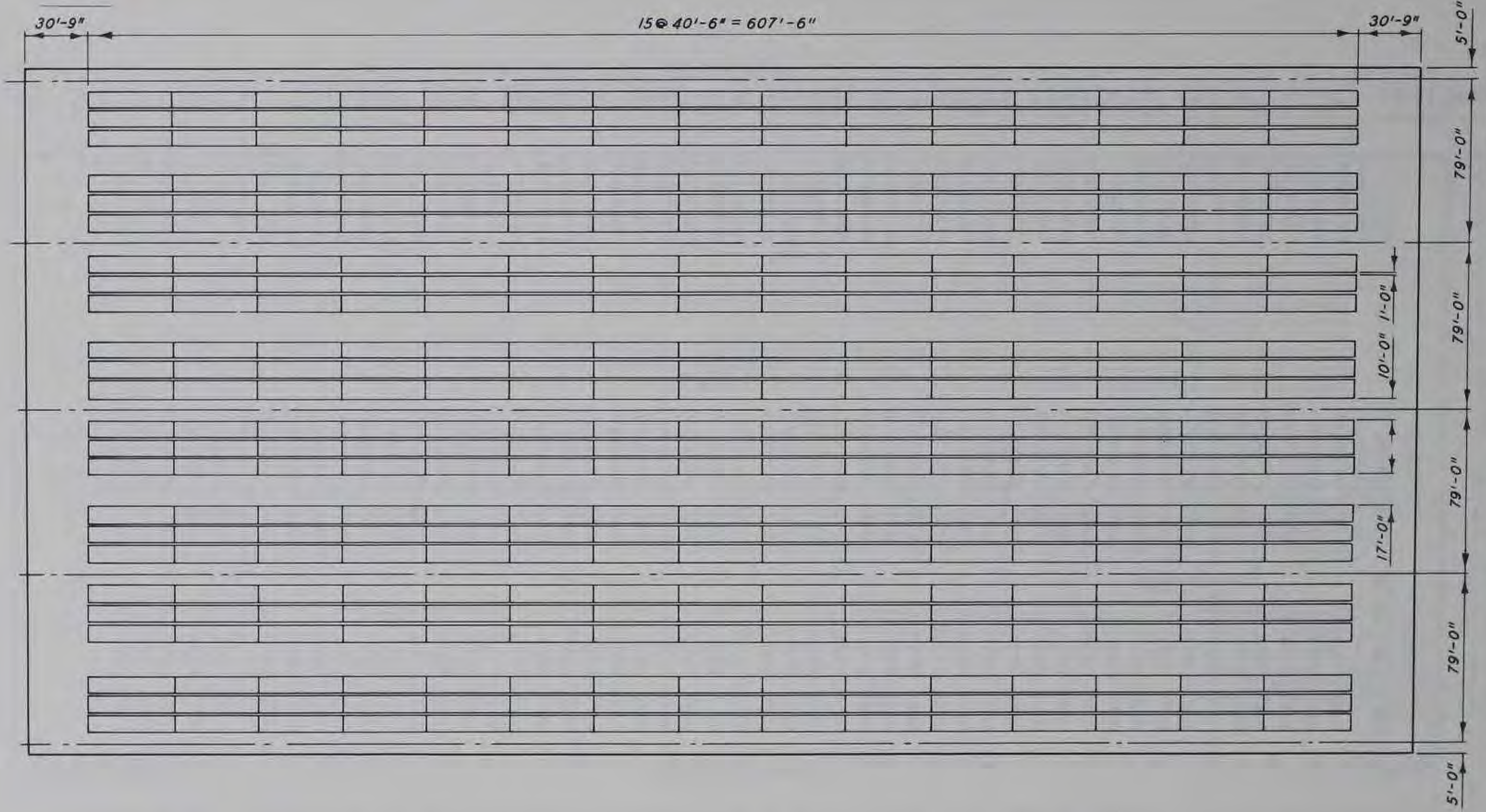


Fig. 119. Typical yard gantry layout; area ≈ 5 acres; 326 40-ft containers (one layer)

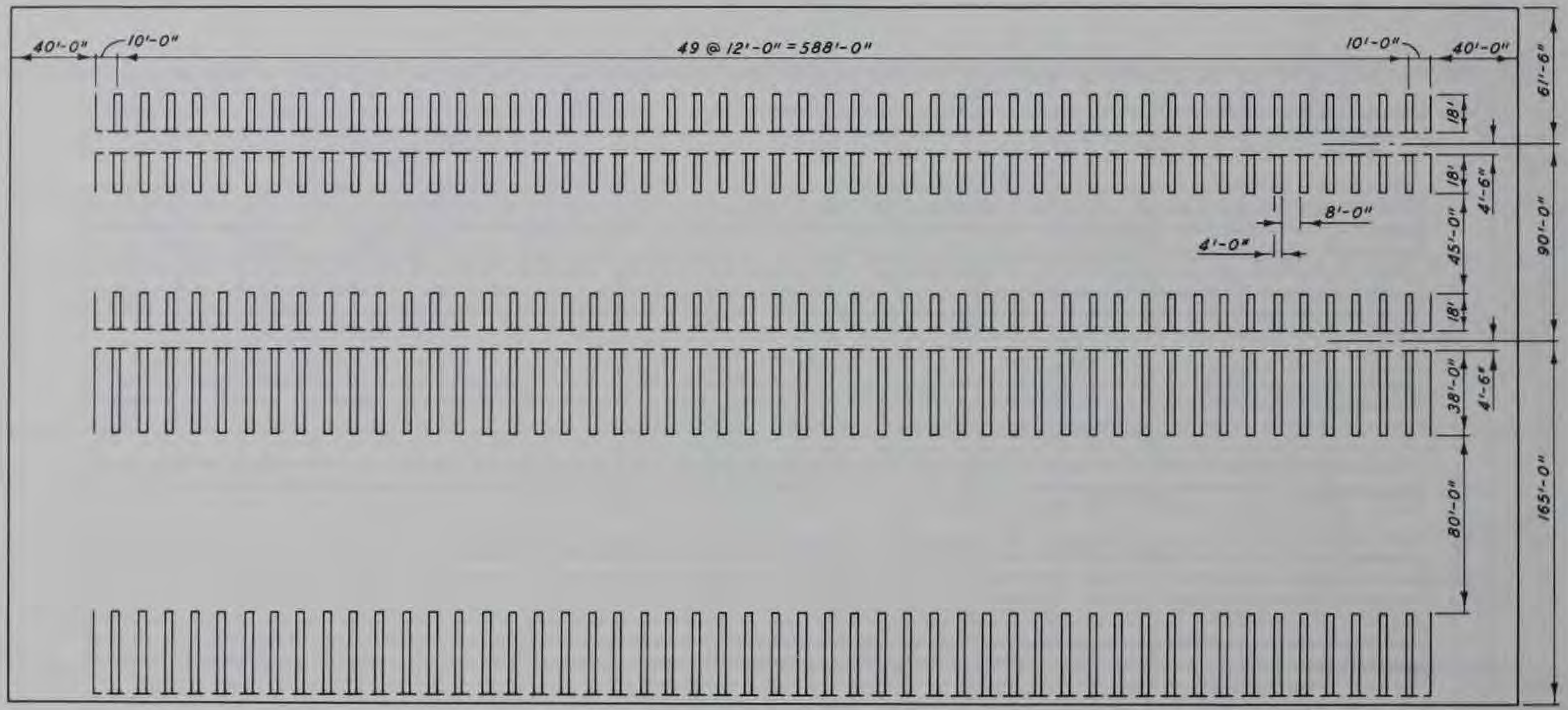


Fig. 120. Typical trailer park layout; area ≈ 5 acres; 147 20-ft trailers and 98 40-ft trailers

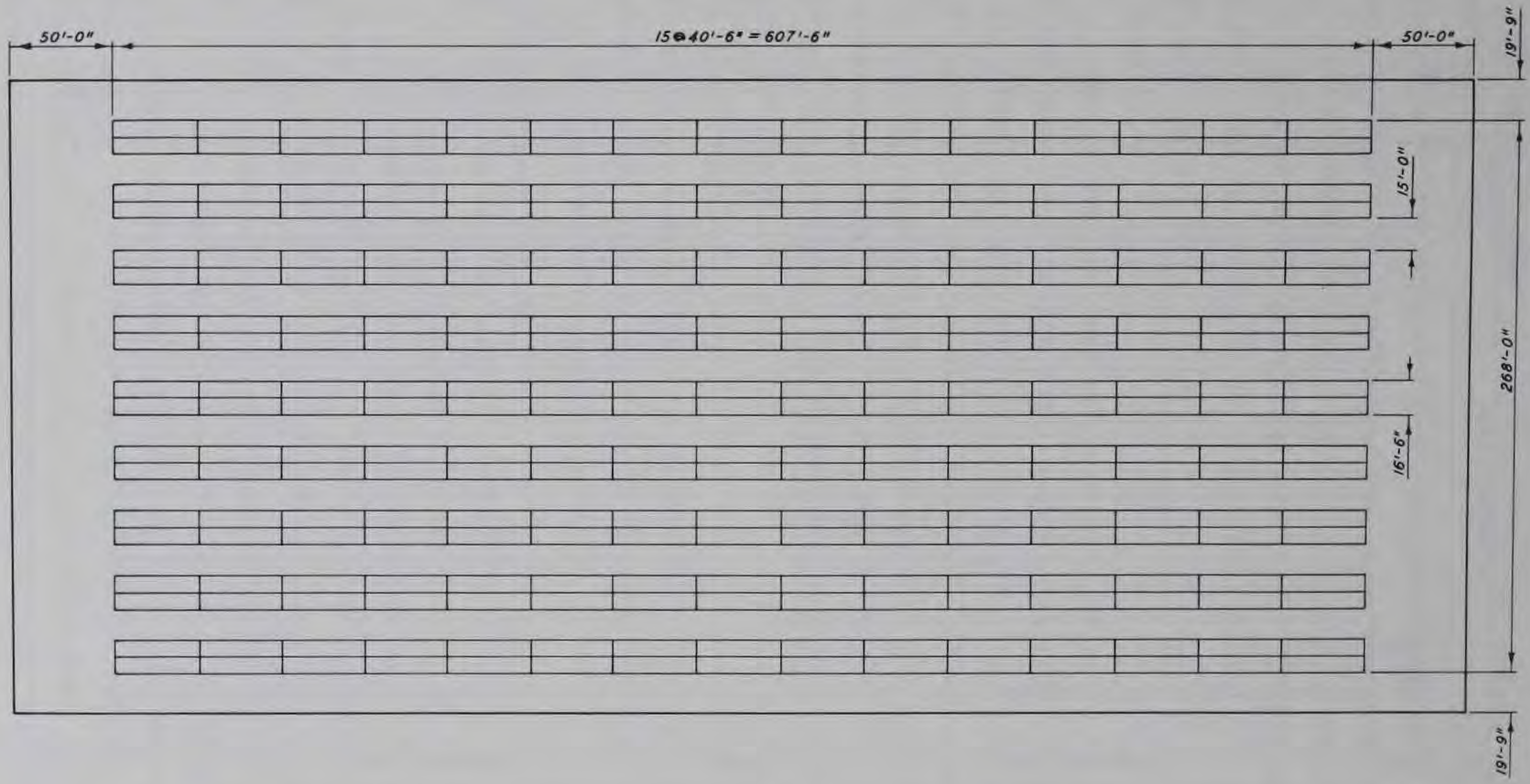


Fig. 121 Typical sideloader layout; area ≈ 5 acres; 270 40-ft containers (one layer)

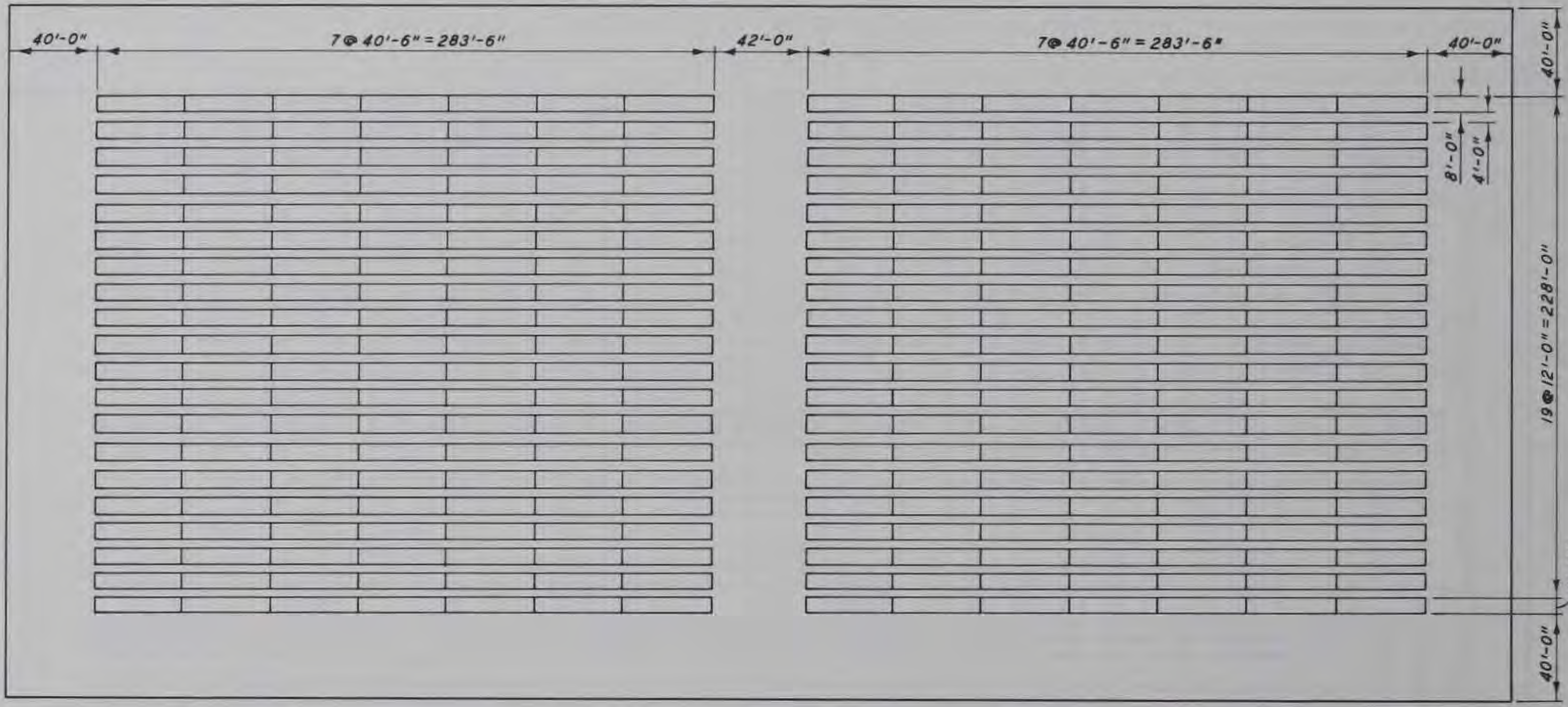


Fig. 122. Typical straddle carrier layout; area ≈ 5 acres; 280 40-ft containers (one layer)

The M52 tractor-trailer combination and the Shoremaster (at reduced load) were the only vehicles considered that have any apparent capability of operating on soft fine-grained soils. The Shoremaster (at reduced load and tire pressure), LeTro-Porter 2582, and LeTro Crane GC-500 apparently are capable of operating on soft coarse-grained soils (sandy beaches). It is evident from an examination of the operational capability of the container handling vehicles considered in this study that other vehicles must be evaluated if operational capability on soft soils is a major consideration.

Unsurfaced soils

373. Requirements for unsurfaced soils are given in table 8. It is emphasized that the criteria used to determine these requirements involved considerable extrapolation for application to the loads imposed on the soil by most of the vehicles considered. It is evident from an examination of the requirements given in table 8 that unsurfaced soils should not be considered if the design traffic volume is greater than 200 passes except perhaps for the Shoremaster and M52 tractor-trailer combination. It is anticipated that if the required strength of unsurfaced soil is greater than about 15 CBR, other types of surfacing will be more economical in most cases. Availability of materials and engineering construction units are important considerations in determining type of surfacing used for a specific facility.

Soils beneath M8A1 landing mat

374. Requirements for soils beneath M8A1 landing mat are given in table 9. It is emphasized that the criteria used to determine these requirements necessitated extreme extrapolation for application to the loads imposed on the mat by most of the vehicles considered. It is evident from an examination of the requirements given in table 9 that, in most cases, M8A1 landing mat does not have sufficient strength for use under the container handling vehicles considered. It appears that M8A1 landing mat may be used economically for up to 50,000 passes of the Shoremaster and the M52 tractor-trailer combination and for 200 passes of all other vehicles considered except the LeTro-Porter 2582 and the two large cranes. M8A1 landing mat was not designed for loads imposed

by most of the vehicles studied, and stronger mats should be considered in further studies relative to surfacing requirements for container handling vehicles. It appears that container corner posts will not seriously damage M8A1 mat laid on a 10-CBR subgrade if the load does not exceed 17.5 kips.

Analysis of Requirements for Flexible Pavements

375. Thickness requirements for flexible pavements for all vehicles considered are given in figs. 108-118. The criteria used to determine these requirements were developed for very heavy aircraft, and loads considered in development of the criteria were as great as or greater than the loads imposed by the container handling vehicles considered. Therefore, these criteria did not require extrapolation for application to development of the requirements given in figs. 108-118. A comparison of thickness requirements for flexible pavement for 50,000 passes of each vehicle considered is shown in fig. 123. This comparison indicates that the M52 tractor-trailer combination is the most efficient relative to flexible pavement requirements. Of the other vehicles considered, the Shoremaster requires the least thickness of flexible pavement. As a matter of interest, the variation in thickness requirements as a function of payload for the Shoremaster is given in fig. 124. This figure gives some indication of the effect that the variation of container weight has on pavement thickness.

Analysis of Area Requirements

376. The layouts shown in figs. 119-122 indicate that side-loading forklifts and straddle carriers can store approximately 200 20-ft container equivalents per acre by stacking containers two high as compared with 70 per acre for a chassis operation. The yard gantry has the potential of stacking almost 400 20-ft container equivalents per acre by stacking containers three high. These numbers are only approximate and will vary considerably with the size and shape of each storage

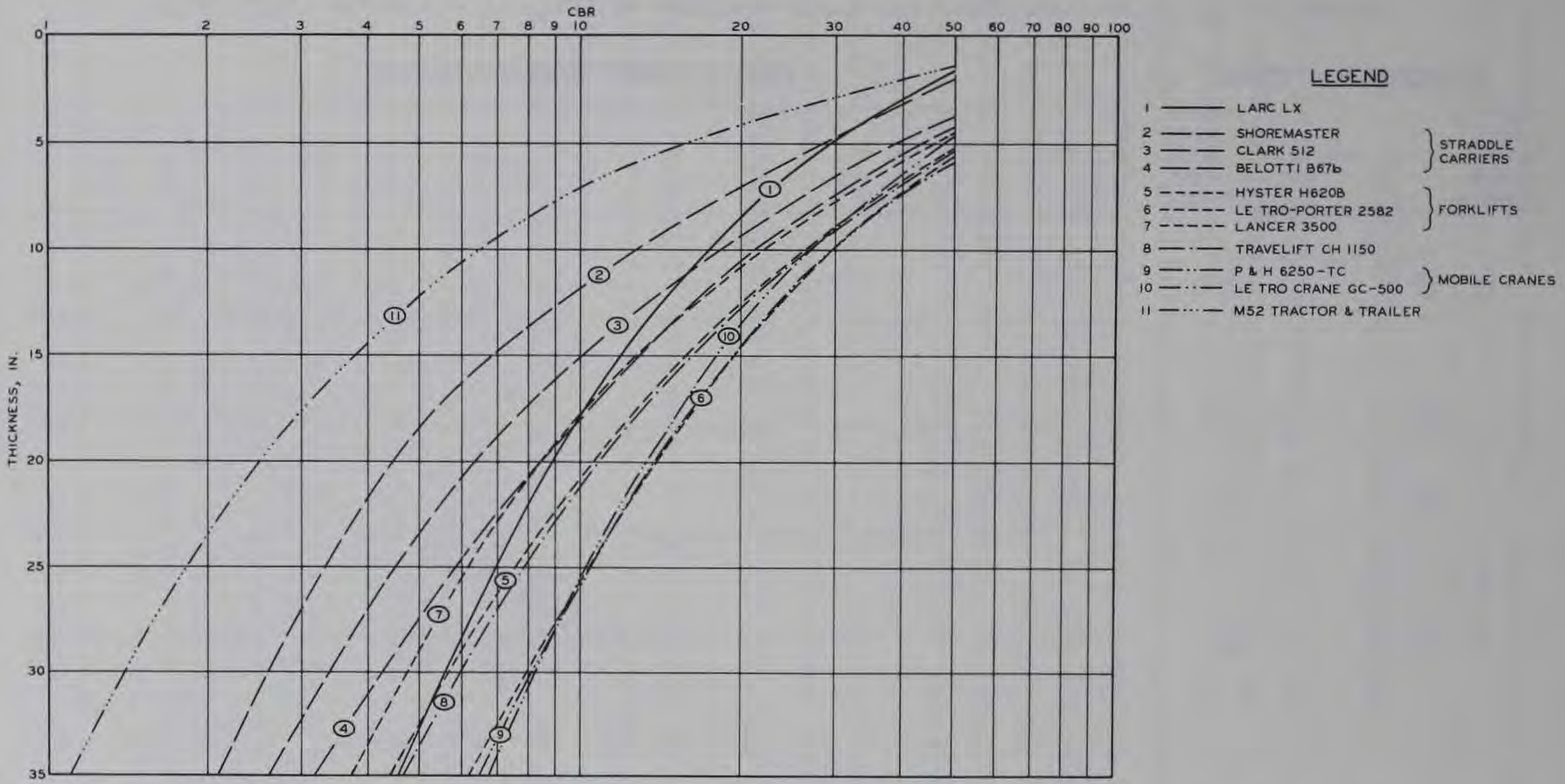
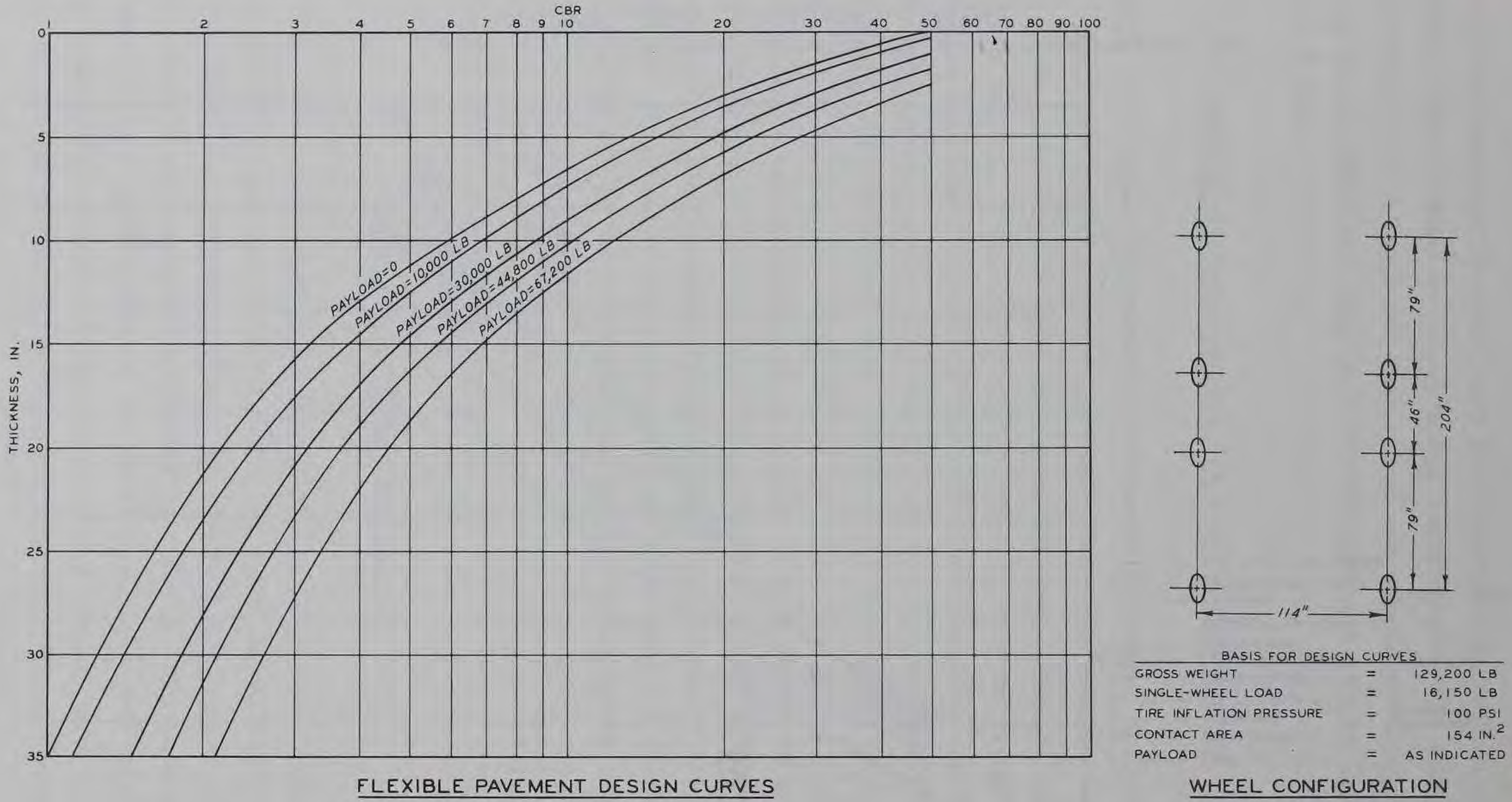


Fig. 123. Comparison of flexible pavement thickness requirements for 50,000 passes of vehicles studied



BASIS FOR DESIGN CURVES		
GROSS WEIGHT	=	129,200 LB
SINGLE-WHEEL LOAD	=	16,150 LB
TIRE INFLATION PRESSURE	=	100 PSI
CONTACT AREA	=	154 IN.^{2}
PAYLOAD	=	AS INDICATED

FLEXIBLE PAVEMENT DESIGN CURVES

WHEEL CONFIGURATION

Fig. 124. Variation in flexible pavement thickness requirements for 50,000 passes of the Shoremaster with various payloads

area. They will also vary considerably if different size containers are handled at the same facility.

Restrictions on Surfacing Requirements

377. The relative requirements presented in figs. 108-118 and tables 5 and 6 were developed primarily for the purpose of providing a basis for evaluation of the effects of vehicle characteristics on engineering construction effort relative to surfacing requirements. For purposes of comparison, these requirements were determined for traffic volumes of 200, 10,000, and 50,000 passes. In some instances, particularly with reference to M8A1 landing-mat-surfaced and unsurfaced soils, combinations of variables (load, tire pressure, CBR, traffic volume, etc.) used in determining the surfacing requirements are outside the limits of basic field test data used in development of the procedures for determining these requirements. In such cases, extrapolation beyond the limits of basic test data was required. Therefore, these requirements are not intended for general use as design criteria in engineering manuals.

378. The surfacing requirements presented herein may be used as design criteria in accordance with the restrictions stated in the following subparagraphs:

a. Flexible pavement design curves: The characteristics, such as load, tire pressure, etc., of all container handling vehicles considered are within the limits of field test data used in development of equation 4; therefore, the thickness requirements shown for flexible pavements in figs. 108-118 can be used as design criteria with no restrictions.

b. CBR and thickness requirements for unsurfaced soils: The characteristics, such as load, tire pressure, etc., of some of the container handling vehicles considered (LeTro-Porter 2582, Travelift CH 1150, LARC LX, and LeTro Crane GC-500) are outside the limits of the basic data* used to develop equation 1 and the nomograph shown in fig. 107, both of which were used to determine the

---

* See table III in reference 31 and tables 1 and 2 in reference 32.

CBR and thickness requirements for unsurfaced soil given in table 8. These requirements may be used as design criteria in accordance with following restrictions:

Traffic Volume in Passes	Restrictions on Use as Design Criteria
200	CBR and thickness requirements shown in table 8 may be used without restriction for the Shoremaster, Clark 512, Belotti B67b, Hyster H620B, Lancer 3500, P&H Crane 6250-TC, and M52 tractor-trailer. CBR and thickness requirements given in table 8 may be used if necessary and identified as "tentative criteria" for the LARC LX, LeTro-Porter 2582, and Travelift CH 1150. CBR and thickness requirements given for the LeTro Crane GC-500 should not be used for criteria in any case except under emergency conditions. The reliability of these requirements is unknown.
10,000	Basic test data for operations of vehicles on unsurfaced soils are limited in scope to data from traffic volumes of less than about 5000 passes. The reliability of requirements developed by extrapolation for volumes beyond the limits of basic test data is questionable. The thickness and CBR requirements shown in table 8 for 10,000 passes should not be used for criteria except under emergency conditions.

c. CBR and thickness requirements for M8A1 landing mat: The characteristics, such as load, tire pressure, etc., of some of the container handling vehicles considered (LARC LX, LeTro-Porter 2582, P&H 6250-TC, and LeTro Crane GC-500) are outside the limits of the basic data* used to develop equations 2 and 3, which were used in determining the CBR and thickness requirements for M8A1 landing mat given in table 9. These requirements may be used as design criteria in accordance with the following restrictions:

---

* See table 4 in reference 38, and table 2 in reference 34.

Traffic Volume in Passes	Restrictions on Use as Design Criteria
200	CBR and thickness requirements given in table 9 may be used without restrictions for the Shoremaster, Clark 512, Belotti B67b, Hyster H620B, Lancer 3500, Travelift CH 1150, and M52 tractor-trailer.
	CBR and thickness requirements given in table 9 may be used if necessary and identified as "tentative criteria" for the LARC LX, LeTro-Porter 2582, P&H 6250-TC, and the LeTro Crane GC-500.
10,000	CBR and thickness requirements given in table 9 may be used if necessary and identified as "tentative criteria" for the Shoremaster, Clark 512, Belotti B67b, Hyster H620B, Lancer 3500, Travelift CH 1150, and M52 tractor-trailer.
	CBR and thickness requirements given in table 9 for the LARC LX, LeTro-Porter 2582, P&H 6250-TC, and LeTro Crane GC-500 are not recommended for use as criteria except under emergency conditions.
50,000	A traffic volume of 50,000 passes is so far outside the limits of basic field test data that the reliability of requirements shown in table 9 is not known. The CBR and thickness requirements shown in table 9 should not be used as criteria except on an experimental basis.

PART VII: EQUIPMENT

Introduction

379. It is not within the scope of this report to discuss the capabilities or missions of the Army's port construction companies. A thorough study of the organization and equipage of the port construction battalions and separate companies was completed in March of 1970 with the publication of TOE's 5-166T[39] and 5-167T.[40]

380. Some discussion of equipment is considered justified because of the tremendous influence it has on the efficiency of marine construction operations. As mentioned earlier, the Chief Engineer of the European Theater during World War II considered the availability of modern large-capacity construction equipment of the utmost importance. The validity of his observation was supported by experience in marine construction operations conducted by commercial contractors in Vietnam. The equipment used in constructing port facilities was outfitted for specific construction tasks. Cranes were of adequate capacity and were provided with hoists having torque converters and pneumatic controls, booms designed to take the lateral thrust of side-battered leads, and crawler assemblies with extendable side frames. Barges were equipped with anchor fairleaders, compressed air receiver tanks, and fuel and water storage tanks and were suitable for ocean touring.

Construction Cranes

381. Some of the lifting requirements for cranes used for military port construction are:

a. Placing 140-ft DeLong caissons through the openings in the DeLong barge. With the block and tackle, the load would be approximately 84 tons raised to a height of 160 ft.

b. For driving the DeLong caissons, handle a 120,000-ft-lb pile hammer with hanging leads. With the block, the load would be approximately 70 tons raised to a height of 100 ft at a radius of 25 ft.

c. For dredging and wreckage removal, a 6- to 8-cu-yd-capacity clamshell. The load would be approximately 22 to 35 tons at a radius of 60 ft.

d. For piledriver attachments with commercial 26-in. leads, the load would be 20 tons at a radius of 35 ft.

e. Lift a LCM-8 for repairs. The load would be approximately 63.6 tons at a radius of 35 ft.

f. Lift an Ammi pontoon. The load would be approximately 50 tons at a radius of 35 ft.

382. These lift requirements are not completely rigid, and it appears that there is a definite need for a crawler crane with a commercial lift rating of 165 to 200 tons. One of a number of different cranes that will satisfy these requirements is the American Model 9299 crane equipped with the Skyhorse counterweight attachment. The largest standard crane in the Army's inventory is the 60-ton crawler. This crane is rated at a lifting radius of 25 ft and, therefore, it is comparable to a commercially rated 110- to 120-ton crane.

383. Crawler cranes above 40 to 50 tons capacity are not generally transportable over a road unless the upper and lower units are separated. Larger cranes (100 tons) are not considerably less transportable than the 40- and 50-ton cranes. Normally a large crane can be made transportable by removing the crawler side frames from the crawler lower assembly. However, it is doubtful that large-capacity cranes would be needed at locations other than the immediate port area or along navigable waterways. Use in either of these locations would not require disassembly.

384. If it is determined by the Army Combat Development Command that a large crane will be operating on a barge, consideration should be given to the use of a stiffleg derrick or crane. Stiffleg derricks and cranes cost about half as much as mobile cranes of similar capacity. The stiffleg derrick sacrifices the capability of full rotation and mobility for the advantage of using the barge as a counterweight. Stiffleg cranes are relatively easy to erect, and the hoist and other components can be replaced if they are damaged. Fig. 125 shows an

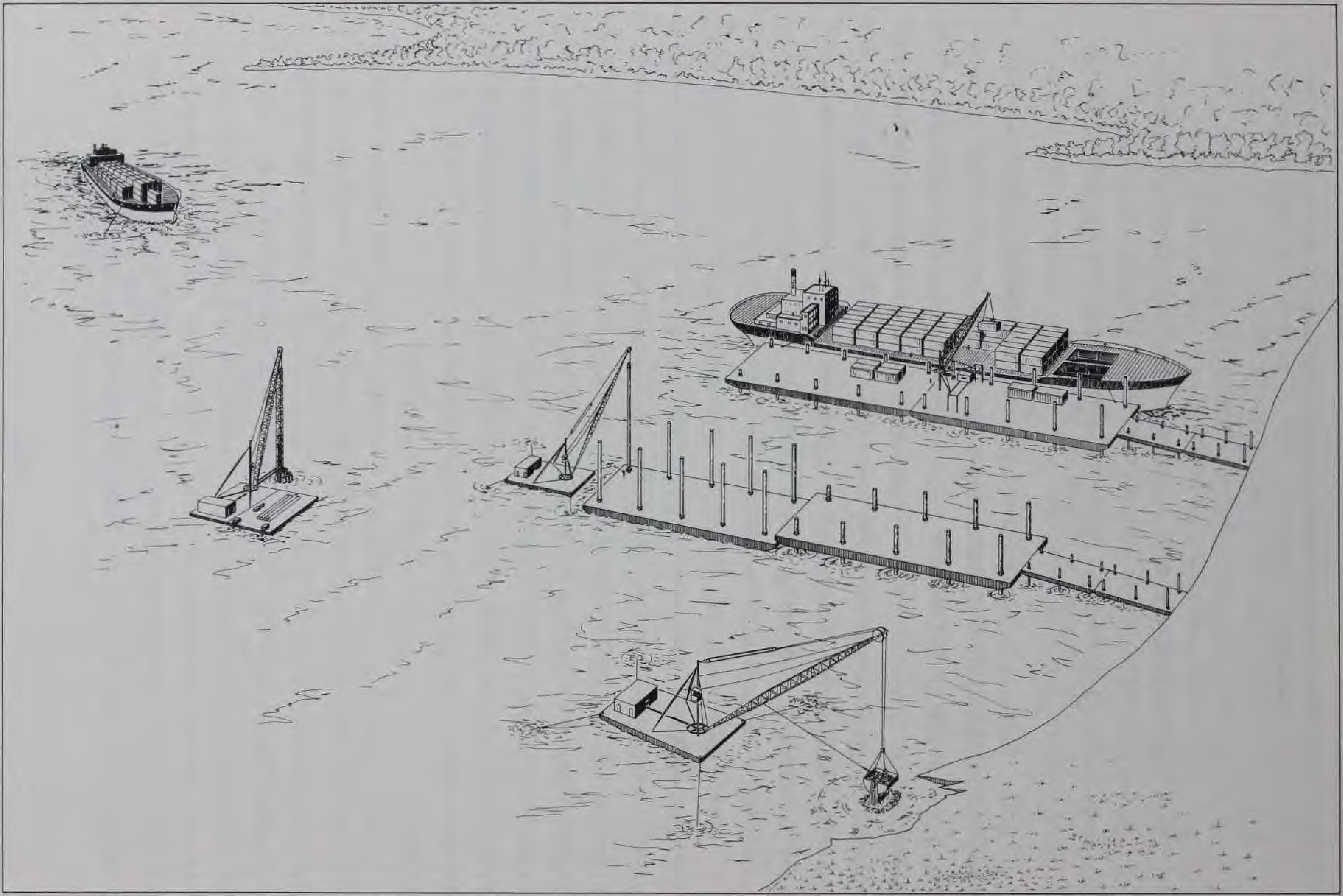


Fig. 125. Artist's concept of crane uses in port area

artist's concept of several construction applications that cranes will be needed for in a port area.

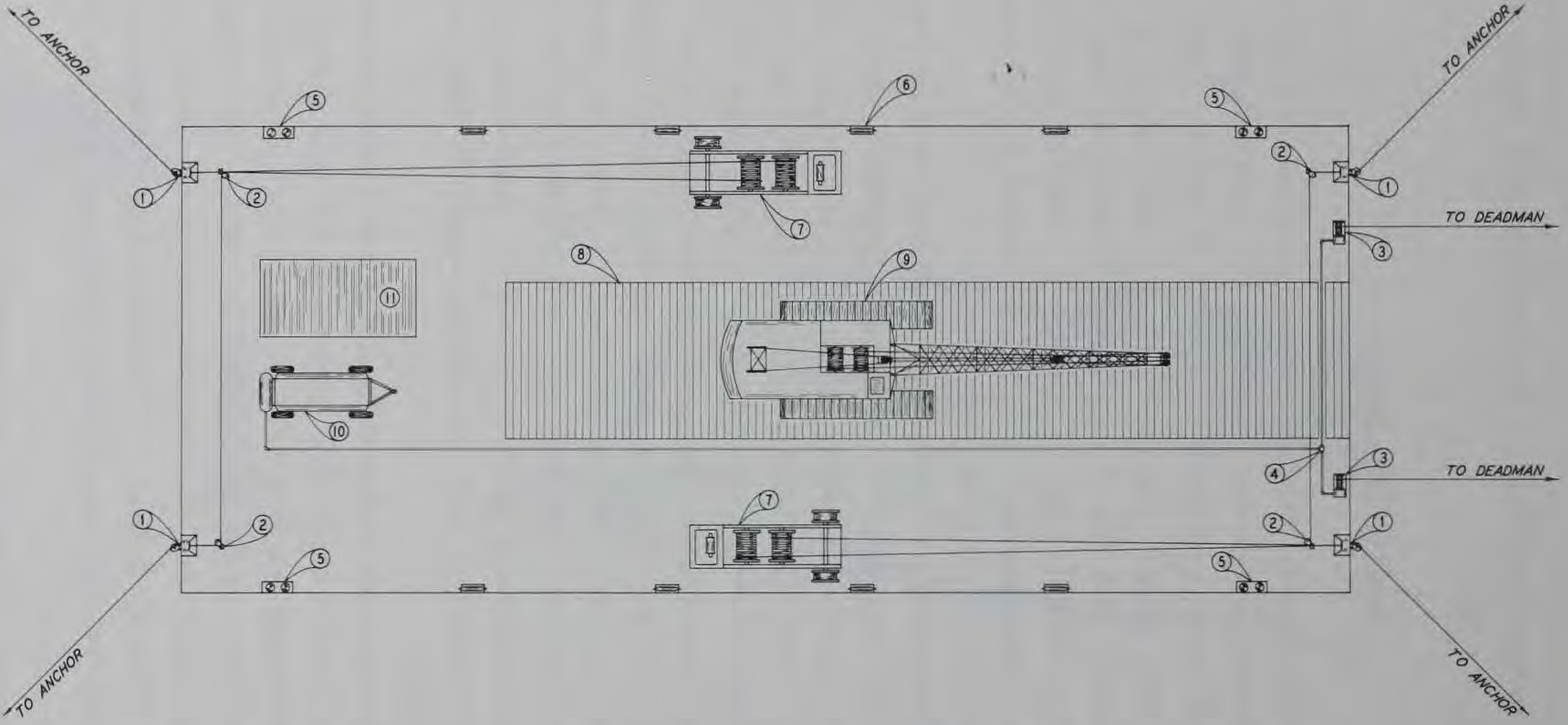
Construction Barges

385. Construction barges provide a mobile platform from which men and equipment can operate over water. Ideally, the barges should be relatively insensitive to wave actions and should be able to carry highly concentrated deck loads. Figs. 126 and 127 show layouts of marine construction barges, with one equipped with a mobile crawler crane and the other a stiffleg crane. The barges are illustrated with anchor mooring winches, tool storage sheds, and air compressors for the operation of pneumatic winches, tools, and pile hammers.

386. The anchor hoists and wire rope should have adequate capacity to position and hold the barge in anticipated currents. Fig. 128 shows the approximate capacity required for various size barges and current velocities. The chart can also be used to select the size of hoists employed as barge movers. A hoist having a single-line pull of 10 tons should normally be adequate for mooring most barges. The 5-3/4-ton hoists shown in fig. 126 are those currently in the inventory and are designed for use with a skid-mounted pile driver. The hoists are adequate for small barges, and, when they are rigged as shown, one operator can control the bow and another the stern. Some construction foremen, however, may prefer to have the anchors rigged to each side, rather than fore and aft.

387. A matter often overlooked when laying out a construction barge is the position of the winch with respect to the line sheave. The hoist line should lead from the drum to a sheave that is 1-1/2 to 2 times the distance in feet of the drum length in inches. For example, if the drum is 26 in. long, the line from the drum should lead to a sheave that is from 39 to 52 ft away. If adequate lead distance is not provided, the wire rope will be damaged from uneven spooling and its capacity significantly reduced.

388. Balanced-head fairleaders are mounted on the barge fore and



① DECK-MOUNTED BALANCED HEAD FAIRLEADER
② SWIVEL BLOCK
③ PNEUMATIC HOIST
④ COMPRESSOR AIR LINE
⑤ DOUBLE BOLLARD
⑥ CLEATS
⑦ 2-DRUM HOIST WITH BOOM SWINGER (5-3/4 TONS)
⑧ TIMBER MAT
⑨ CRAWLER CRANE
⑩ 600-CFM AIR COMPRESSOR
⑪ TOOL SHED
BARGE: 60'-0" X 150'-0"

Fig. 126. Typical marine construction barge

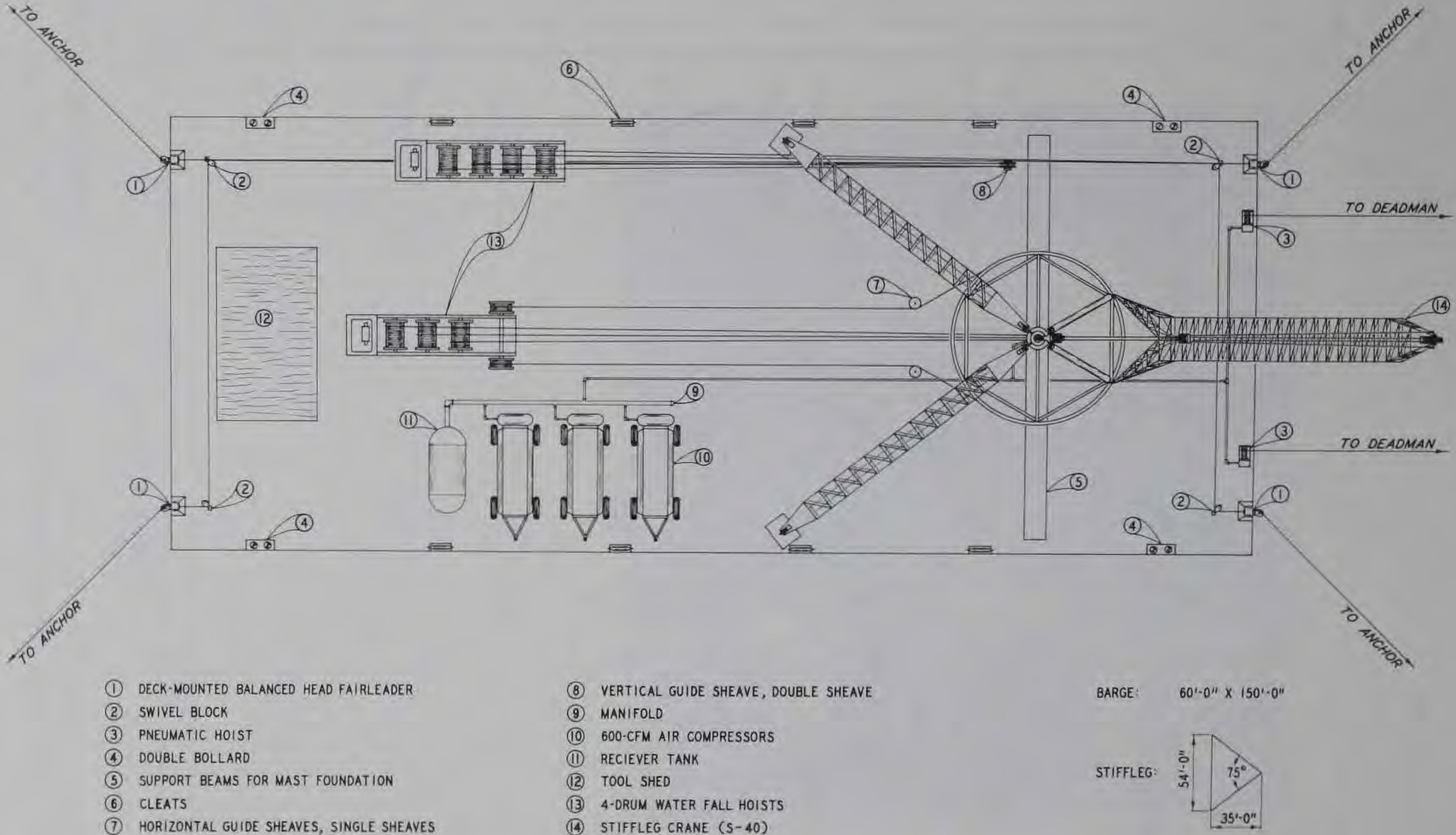
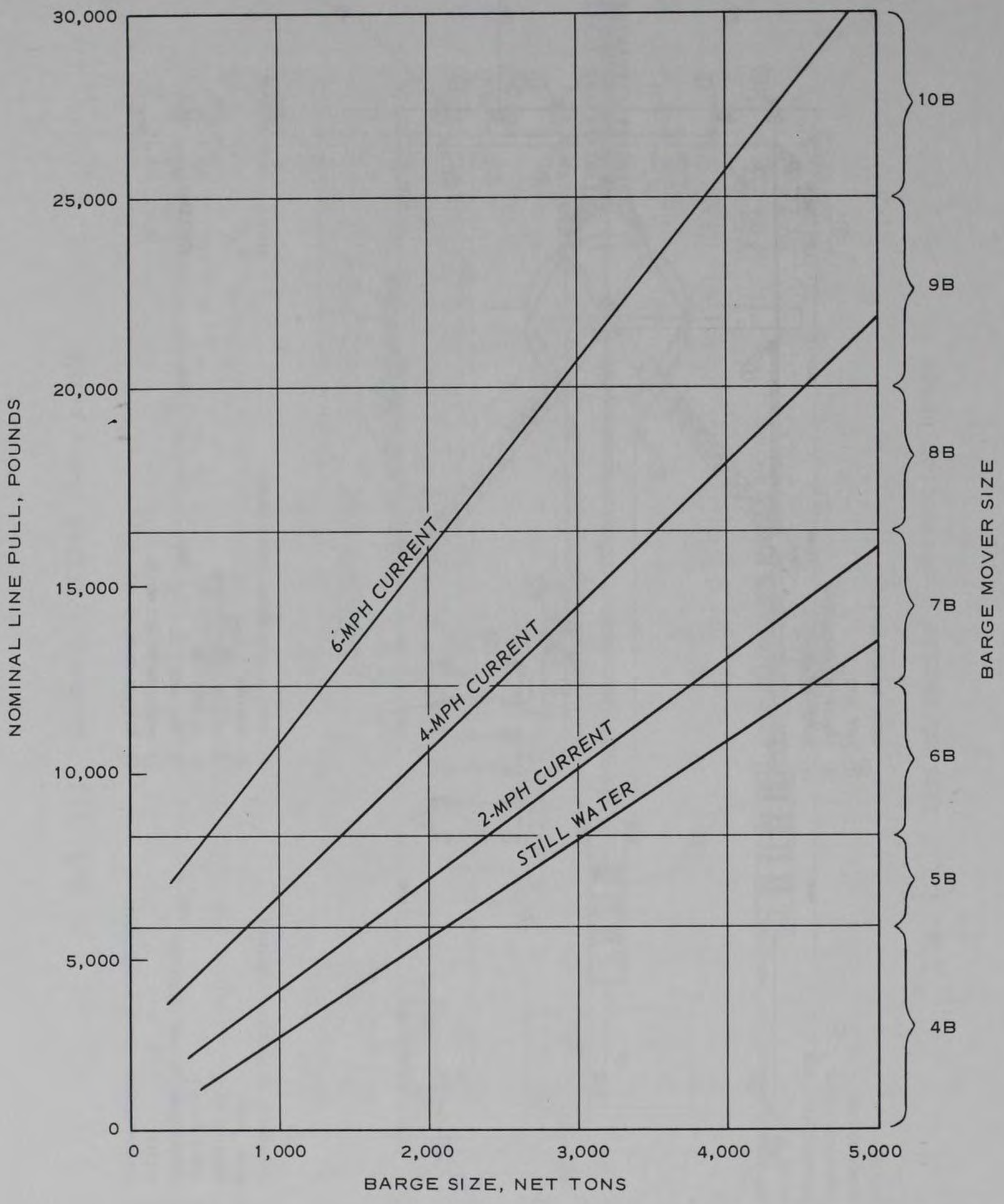


Fig. 127. Typical stiffleg crane barge



(Courtesy of Clyde Iron Works, Duluth, Minnesota)

Fig. 128. Line pull versus barge size for various current velocities

aft (fig. 129). These units prevent the anchor line from being damaged and also hold the anchor away from the side of the barge when it is being retrieved.

(Courtesy of Smith-Berger, Seattle, Washington)

Fig. 129. Fairleaders

389. The barges shown in figs. 126 and 127 are equipped with two double ballards on each side for securing material barges and large harbor craft. The ballards should be of sufficient strength to withstand the pull of tow bridles during ocean towing. The cleats are positioned at 25-ft intervals to permit the securing of small watercraft and fenders.

390. The most ideal barges for construction use are flat-deck, dry-cargo barges from 100 to 150 ft in length and 30 to 40 ft in beam. Once the equipment to be employed on the barge has been selected, a survey of the barge should be performed to determine if it is structurally adequate. A conservative approach would be to assume that the frame

will carry the entire load and the strength of the skin will provide a factor of safety. Periodic inspection should be made of the barge to ensure that it has not been damaged.

391. As was mentioned in Part IV, it appears that a barge similar to the Navy's Ammi pontoon could be constructed that would satisfy requirements for construction barges as well as pier and causeway modules. A study should be made to determine if these barges should be adapted to either the LASH or the Seabee system.

Pile Driving Equipment

392. Pile driving equipment can be found in all sizes and configurations. Hammers range in size from pavement breakers to large offshore hammers weighing more than 125,000 lb. The diving rigs may be simple (fig. 130) or sophisticated (fig. 131).

393. To drive long timber piles efficiently, a pile driver with 100 ft of extended commercial 26-in. leads would be suitable. The crane to support the leads, hammers, and pile should have a commercial rating of 100 to 125 tons and be equipped with a power-operated brace or spotter. A pile hammer with an energy rating from 24,000 to 30,000 ft-lb should be used. The hammer should be single-acting, and the ram should be equipped with a mechanism that will permit a variable-length stroke. This provision will help reduce damage that often occurs during the initial stages of driving long slender piles. The crane boom, driving leads, and brace should have sufficient strength to tolerate fore and aft batters of 4:12 and side batters of 2:12. Appendix B describes different lead types, advantages and disadvantages of each, and a method for the calculation of the crane load used as a pile driver. If a pneumatic hammer is used, provisions should make it possible to mount the air compressor behind the crane's counterweight. This eliminates the clutter of hoses and pipes running over the deck or ground and eliminates the problem of moving the compressor when driving piles on land. The driving of large concrete or steel piles require hammers with energy ratings greater than 30,000 ft-lb. If this requirement exists, the

(U. S. Army Photograph)

Fig. 130. Army skid-mounted pile driver

(U. S. Army Engineer District, Vicksburg)

Fig. 131. Commercial pile driver

necessary equipment should be included in the base development plan for early procurement.

394. For pile driving operations involving a small number of piles within a limited area, a skid-mounted pile driver can be effectively employed. A typical application could be the driving of two or three pile bents for a highway bridge. The Army's skid rig can be transported to the site on two trucks and assembled by a crane or wrecker. If necessary, the skid rig can be erected using only the dual-drum wench that comes with the rig.

395. The Army's skid rig has undergone little modification since World War II and should be modified to provide a boom hoist and powered fore, aft, and side batter capability. The powered batter provision allows the leads to be returned to a nearly vertical position for picking up piles and assuming the desired batter for driving within a realistic period of time. A torque converter on the hoist would allow more precise control of the pile and hammer and, consequently, improve both efficiency and safety.

396. The driving of the DeLong caissons requires a large offshore pile hammer with a ram weight of approximately 40,000 lb and a stroke of 3 ft. Hammers of this size weigh approximately 50 to 55 tons. The hanging lead sections and hook block required to support the hammer may weigh up to 20 tons. Cranes capable of handling loads of this magnitude have commercial ratings of 150 to 200 tons.

397. The limited time available for construction of military port facilities requires that pile driving equipment be as efficient as possible. The Army should make a realistic appraisal and define in specific terms what minimum pile driving capability it requires. Equipment capable of satisfying these needs should be procured.

Dredging Equipment

398. Dredging in conjunction with military port construction projects allows a port to service large vessels without first lightening them to reduce their draft. It also permits facilities to be constructed closer to shore with a net reduction in both the total construction effort and materials required. Also, dredging may in some cases be more efficient than land-based operations for moving fill material and the borrowing of aggregate.

Problems with dredging projects

399. Experience during World War II and during the Vietnam conflict indicates that there are a number of problems associated with dredging projects in the TO:

a. Transportation of dredges to the TO is a major problem.

Hopper dredges and sidecasting dredges are the only ones that are seagoing. Other dredges either have to be towed to the site or assembled from components transported aboard cargo ships.

b. Security of dredges within the TO presents a number of difficulties. The routine patterns followed by dredges greatly limit the effectiveness of any passive defensive measures. Pipeline dredges are virtually stationary targets. In Vietnam, dredges were attacked on a number of occasions and several were sunk. Because munitions can also be ingested into the pump, provisions must be made to limit the damage that would result from a detonation within the hull of the dredge.

c. The availability of dredges and crews for use in early stages of deployment in a TO is a major problem. The U. S. Army at the present has no trained military dredge crews or portable dredges suitable for use in a TO.

d. Although dredging equipment was available in past operations, it was not always suited to the particular projects for which it was utilized. A better understanding of the capabilities of various types of dredges is necessary for military planners to program the requirements for proper dredge equipment.

Transportation of dredges

400. As previously stated, hopper and sidecasting dredges are seagoing vessels and present no major problem for deployment other than their relatively slow cruising speed (below 15 knots). Dustpan dredges, however, usually have flat-bottom, shallow-draft hulls with a low freeboard. These characteristics make them undesirable for ocean towing. The larger cutterhead dredges are normally designed for ocean towing after a certain amount of preparation that is similar to that performed on floating cranes. Small portable cutterhead dredges are small enough to be transported over the road on tractor trailers. Ellicott Machine Corporation (Baltimore, Md.) has actively undertaken a development, design, and building project of a dredge of their proprietary design that is compatible with International Standards Organization container standards. A prototype will be tested in mid-1973. An investigation of the transportability of dredges aboard barge ships revealed that a 24-in. standard cutterhead dredge could be transported aboard the Seabee. All Navy cutterhead dredges are transportable in the well deck of an LSD.

Security of dredges

401. There appears to be no sure means of securing a dredge against enemy attack. The best passive measures would be to vary the dredging operation so that routines would not be readily apparent and to move the dredge after dark if it is under potential enemy observation.

402. Mine booms and patrol craft equipped with side-scanning sonar should provide reasonable protection against mining. The dredge hull should be compartmentalized, and the stove box and pump should be partially enclosed by a blast deflector.

Availability of dredge crews

403. Although dredges could be procured from civilian sources and transported overseas aboard barge ships, enticing their civilian crews to go with the dredge might prove to be a problem. The only trained military crews are currently part of the naval construction battalion and are trained at the Naval Construction Battalion School at Davisville, R. I. Figs. 132 and 133 show a 14-in. cutterhead dredge and a small tender employed in the training at Davisville. A study should be

Fig. 132. Navy dredge

(U. S. Navy Photograph)

Fig. 133. Dredge tender boat

performed to determine if the school facilities could be used for training Army dredge crews and what prerequisite qualifications should be established for personnel who would attend the school.

Selection of dredge plant

404. The selection of dredge equipment for use in military port construction operations has been simplified in the past by the lack of transportability. In many cases, hoppers and sidecasters were employed on projects better suited for a pipeline dredge simply because they were the only dredges capable of getting to the sites.

Hopper dredge

405. A hopper dredge (fig. 134) is a seagoing, self-propelled ship with trailing suction drags that pick up material and discharge it into compartments in the ship's hull. When the compartments are loaded, the dredge moves to the spoil area and dumps the material through doors in the bottom of the hull.

406. Hopper dredges deepen and widen channels by making multiple

(U. S. Army Engineer District, New Orleans)

Fig. 134. Hopper dredge

passes over an area and taking up thin layers of material under the drags on each pass. A hopper dredge works best in open water over long cut areas. A hopper dredge's efficiency drops greatly when used inside harbors where the cut lengths are shortened and the area for maneuvering is limited.

407. Hopper dredges are suited for use in open water where wave action would preclude the use of a cutterhead dredge or where a pipeline would be a hazard to navigation. The hopper dredge is highly maneuverable but draws considerable water when loaded. For this reason, many are equipped with sidecasting booms to open a channel from which they can begin to work.

Sidecasting dredge

408. A sidecasting dredge (fig. 135) is also a seagoing, self-propelled ship with trailing suction drags that pick up thin layers of material under the drags. The sidecasting dredge discharges material through a pipe over the side of the dredge rather than pumping the

(U. S. Army Engineer District, New Orleans)

Fig. 135. Sidecasting dredge

dredged material into hoppers. This permits the dredge to operate continuously and maintain a very shallow draft.

409. The sidecasting dredge is most effective where there is a littoral current across the channel to take the discharged material away from the cut area. The littoral current is more effective in carrying light material.

410. When there is no littoral current, dredging starts in the center of the channel and progresses outward. Material is redredged until it is moved outside the channel area. The sidecasting dredge has the same characteristics as the hopper dredge and is limited in efficiency where maneuverability is restricted.

411. A hopper dredge can be used in a manner similar to that used by a sidecasting dredge. If the littoral drift is strong and the material is very light, the hoppers can be allowed to fill and overflow. This type dredging is referred to as "agitating." Two of the Corps of Engineers' hopper dredges are equipped with sidecasting booms that allow them to operate either as a hopper dredge or a sidecasting dredge.

Cutterhead dredge

412. The cutterhead dredge (fig. 136) is the most functional of all dredges because it can operate in materials up to a consistency of soft rock. It is normally not self-propelled and must be moved aboard ships or barges or be towed to the worksite. The cutterhead dredge is capable of pumping through long floating lines or onto shorelines. It can build hydraulic fills to elevations above the floodplain at the same time that it is cutting a channel. The dredge works most efficiently when making a deep cut in relatively calm waters. Most cutterhead dredges can work in currents up to 7 mph, but the spud ladder and floating pipeline severely limit its use in waters subject to wave action over 2 or 3 ft high.

Bucket dredges

413. Bucket dredges are classified as grab, dipper, and ladder. They are basically mechanical in their manner of operation and require the support of barges to carry away the spoils.

414. The grab dredge (fig. 137) is nothing more than a crane and a clamshell or orange peel bucket. It is capable of working in rough water but requires the use of barges to carry spoil away from the dredge areas. It is also well suited to removing debris from ships and channels. A crane capable of using a 6- to 8-cu-yd-bucket is most suitable for military construction.

415. The dipper dredge (fig. 138) is essentially a crane shovel mounted on a barge. Its primary advantage is its ability to work in relatively hard rock. It may consist of a backhoe mounted on a barge.

Ladder-bucket dredge

416. A ladder-bucket dredge has an endless chain with buckets attached that move about a ladder. The buckets cut the material from the bottom, bring it up the ladder, and dump it into a sluice that lets it fall into barges. The barges may be self-propelled or may be moved by tugs. The ladder dredge works on cables running to anchors to hold the desired position and to advance the dredge. The dredge is capable of working in most types of material. It is adaptable to working in areas with little maneuvering room, such as docks and piers. It is not

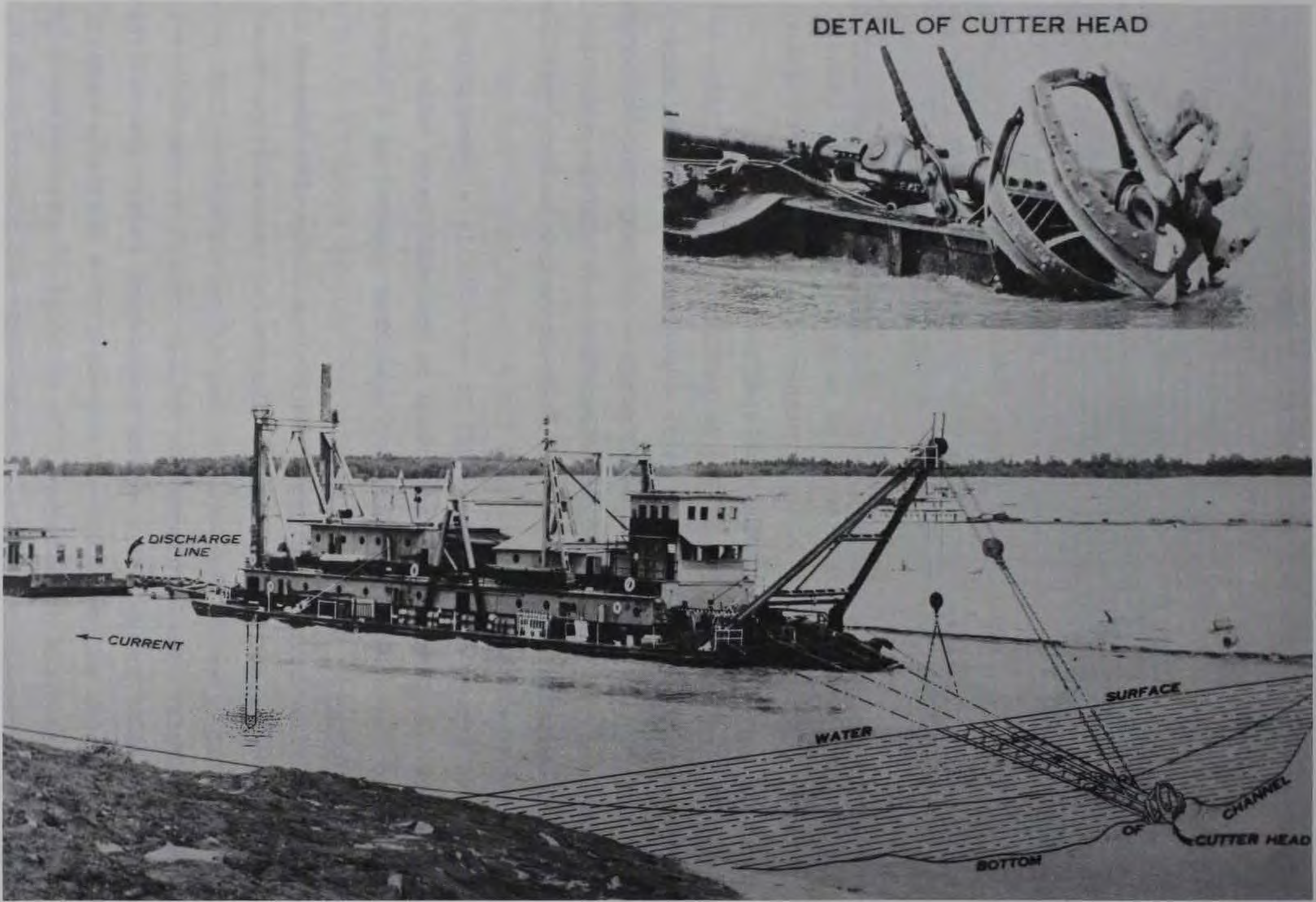
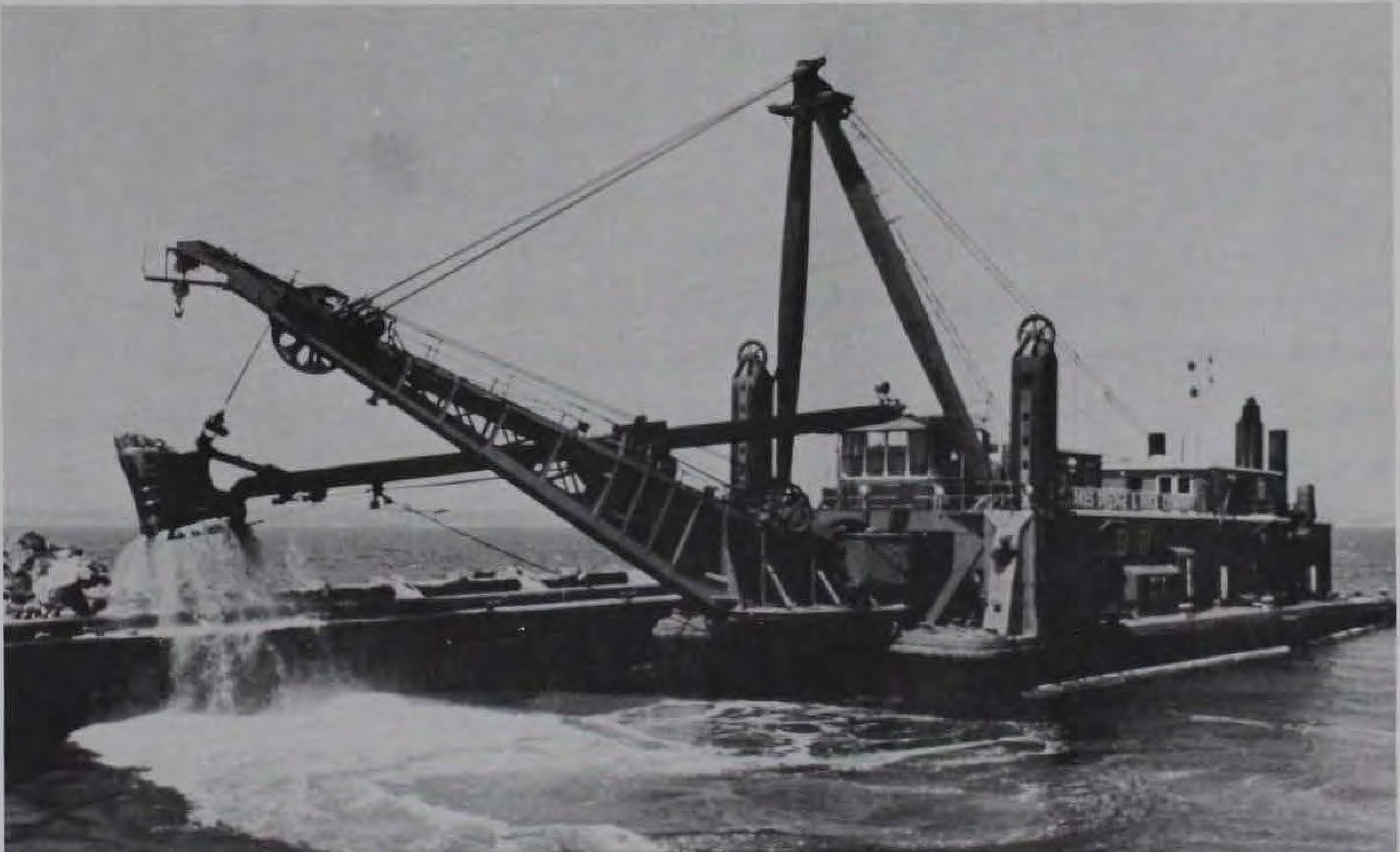


Fig. 136. Cutterhead dredge

(Courtesy of Great Lakes Dredge and Dock Company,
Union, New Jersey)

Fig. 137. Clamshell dredge



(Courtesy of Great Lakes Dredge and Dock Company,
Union, New Jersey)

Fig. 138. Bucket dredge

self-propelled and is limited by moderate wave action. Ladder-bucket dredges are not widely used in the United States; however, they are used in most other parts of the world.

PART VIII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

417. A study of past reports of port construction activities indicates that there is a general lack of marine construction equipment of adequate capacity.

418. Containerization of cargo passing through military ports requires that new facilities be designed for the Army Facilities Component System. However, design live loads imposed by containers and container handling equipment must be determined. This will require some knowledge of equipment that will be employed in the future.

419. The Seabee and LASH barge ships offer a means of delivering large prefabricated structural components and large floating equipment to an overseas theater much faster and more reliably than previously possible. Their cargo could include:

- a. Pier and wharf modules
- b. 24-in. cutterhead dredges
- c. Construction barges
- d. Tanker mooring terminals
- e. Floating cranes
- f. Causeway sections
- g. Landing craft and harbor craft

420. Military engineers in the field should have available basic engineering texts on the construction of port facilities.

421. A model is a very simple and straightforward tool for use in port planning. It aids in the coordination of staff activities and helps planners to visualize potential problem areas.

422. There is a definite need for methods and equipment that will permit rapid and thorough collection of terrain intelligence data within a port area. These data are essential for the making of sound and timely decisions on foundation design, dredging, and site layout.

423. It appears feasible to fabricate transportable concrete pier modules that are capable of supporting large container gantry cranes as

well as extremely high wheel and axle loads. These units could be transported aboard barge ships and would require considerably less maintenance than steel barges.

424. Glue-laminated wooden panels offer significant savings in both construction effort and transportation requirements within the TO. In general, they were found to reduce deck thickness requirements by 50 percent.

425. The wide variation in the configuration of commercial roll-on/roll-off ships precludes the development of a standard facility to service them.

426. Reel-type pipe laying barges are in use commercially and offer a means of rapidly installing submarine pipelines up to 12 in. in diameter. This equipment can be installed on DeLong "A" barges presently in the Army's inventory.

427. A rigid-arm tanker mooring terminal investigated during the study appears to possess several advantages that would be of value to military engineering:

a. Rapid installation

b. Simplicity

c. No need for special installation equipment

428. The DeLong self-elevating barge has demonstrated its adequacy for use as a discharge facility for existing break-bulk general cargo vessels. However, a thorough analysis must be made if these units are to service vessels with displacements exceeding 20,000 tons in 35 ft or more of water at sites where currents run perpendicular to the axis of the pier, or in areas where the approach velocities may exceed 0.5 ft/sec perpendicular to the pier face.

429. Various types of large-capacity container cranes can be mounted on the decks of DeLong barges, but a detailed structural analysis should be made for each piece of equipment selected. In most cases, modifications will be necessary to adequately strengthen the structure.

430. If installed at exposed locations, DeLong barges should be equipped with adequate fendering. The use of large rubber tires should not be expected to offer adequate protection except when small vessels

are involved. The Bridgestone Super-Arch Fender (FV 009-5-3 or FV 009-6-4) appears to be the most practical for fendering at exposed locations.

431. Caissons and jacks left extending above deck level of elevated piers will hinder the operation of truck- and crawler-mounted whirley cranes. A thorough settlement analysis should be performed prior to welding off the spuds. This analysis should preferably include the recording of time-settlement data for each caisson.

432. One-dimensional stress wave analysis indicates that yield stresses may be exceeded in the DeLong caissons during driving if a massive soil plug is permitted to form at the bottom. The stress wave analysis also indicates that not less than a 120,000-ft-lb hammer should be employed to drive the caissons.

433. DeLong "B" barges can be transported on the top deck of the Seabee barge clipper provided that approximately 50 ft of the stern of the barge is removed.

434. There is a need for a small spud barge which can be transported to the TO aboard a barge ship and be employed as a prefabricated module. This barge should also be capable of serving as a flat-deck cargo or construction barge.

435. The relative surfacing requirements developed for representative container handling vehicles provide data for comparison of surfacing requirements as a function of vehicle characteristics. The relative surfacing requirements developed for this investigation show that it is absolutely essential that surfacing requirements be evaluated prior to selection of container handling equipment in order to minimize construction effort associated with provision of adequate operating and storage area at military ports.

436. The vehicles considered in this study do not generally have adequate operational capability for use in over-the-beach operations.

437. Unsurfaced soil should not be considered for storage and marshalling areas where the design traffic volume is much greater than 200 passes.

438. M8A1 landing mat is not adequate for general use as surfacing for storage and operating areas at military ports without

restricting the types of equipment employed and/or the gross weight of containers. Only two pieces of equipment, the tractor-trailer and the Shoremaster are suitable for continuous operations on M8A1 landing mat.

439. It was not possible to determine the exact thickness of flexible pavement required for each piece of sample equipment. The reason for this inability was that no statistical data were available to allow correlation of the number of passes being applied to a given section of pavement with the number of containers being handled. Also, no data were available on the statistical distribution of container weights.

440. The surface area requirement varies considerably with a host of different parameters. It is apparent that up to 20 acres of marshalling and storage area may be required for each container ship berth, depending on the type of operation.

441. Sufficient information is not available on the operational traffic pattern of container handling equipment.

Recommendations

442. The Army should develop specific performance requirements for marine construction equipment including dredges, construction, barges, large pile drivers, and heavy construction cranes.

443. The Office of the Chief of Engineers should actively participate in the Army's containerization program. It is believed that this will permit rational tradeoffs to be made of container handling methods and equipment against the engineering effort required to support them.

444. The availability of the LASH and Seabee barge ships to deploy marine construction equipment and large prefabricated construction modules should be determined. All future equipment procured should be deployable by one of these two systems.

445. A book set consisting of civilian texts (Appendix A) should be included in the Table of Organization and Equipment (TOE).

446. Appropriate documents in the training literature program should recognize the value of using a model in the planning of a military port.

447. The methods and equipment described herein for the rapid collection of terrain data should be evaluated for adoption in the TO.

448. If current DeLong barges are determined not to be structurally adequate for container facilities, serious consideration should be given to the use of a concrete pier module.

449. Further investigations should be performed to determine possible application of glued-laminated panels in TO structures. The investigations should determine if the 4- by 20-ft panels would be practical for the Army's needs and if the equipment necessary for field erection is available.

450. A rigid-arm tanker mooring terminal should be further investigated to determine its suitability to military applications.

451. A thorough structural analysis should be performed on the DeLong barges to define their ability to support container operations and equipment.

452. Either the 18-in.-diam, 9-in.-ID or the 21-in.-diam, 11-1/2-in.-ID cylindrical rubber fender appears to offer a wide range of uses and ease of installation by troop units. Therefore, they should be incorporated into the Army Facilities Component System. If contingencies call for DeLong barges to be installed at exposed sites, a fender system with a high energy-absorption capability should be installed on elevated piers.

453. The necessity of driving DeLong spuds should be investigated thoroughly. If it is found to be a valid requirement, driving equipment should be evaluated and classified in the military's material list. The position of the bottom diaphragm in the caisson should be evaluated to reduce the driving stress, if possible.

454. The practicality of modifying DeLong "B" barges for transport aboard the Seabee barge ship should be investigated. The lateral stability of the barge under horizontal loading should be determined.

455. A small spud barge should be designed that will satisfy the requirements of a construction module and a flat-deck cargo or construction barge. It should be deployable on a barge ship.

456. Surfacing requirements should be determined for each

container handling vehicle considered for use at military ports prior to procurement in order to evaluate the effects of vehicle characteristics on engineering construction effort relative to surfacing requirements.

457. A comprehensive traffic study should be made of the various types of container handling vehicles during actual operation in storage areas. Data resulting from such a study would provide information for determining vehicle operational patterns as a function of vehicle characteristics. This information could be used as a basis for developing methods for design of various areas according to variation in anticipated traffic density. This would be input for development of storage yard layouts that would provide the necessary area for efficient operation. The study should also consider variation in container size and weight so that equivalent operation factors might be determined for use in evaluation of vehicles relative to surfacing requirements.

458. Appropriate portions of this report should be incorporated into the Army training literature program.

LITERATURE CITED

1. Headquarters, Department of the Army, "Construction in the Theater of Operations," Technical Manual TM 5-302, Dec 1969, U. S. Government Printing Office, Washington, D. C.
2. Joint Logistics Review Board, "Logistic Support in the Vietnam Era; A Summary Assessment with Major Findings and Recommendations," Vol I, 1969-1970, Washington, D. C.
3. Johnson, J. M., "The Trend in Tanker Construction and Its Effects on Military Logistics," 1965, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio.
4. U. S. Joint Chiefs of Staff, "Joint Logistics and Personnel Policy and Guidance," Publication 3, 18 Apr 1969, U. S. Government Printing Office, Washington, D. C.
5. Headquarters, Department of the Army, "Base Development," Field Manual FM 31-82, Jun 1971, U. S. Government Printing Office, Washington, D. C.
6. __________, "Care, Handling, Preservation and Destruction of Ammunition," Technical Manual TM 9-1300-206, 12 Nov 1964, U. S. Government Printing Office, Washington, D. C.
7. Quinn, A. DeF., Design and Construction of Ports and Marine Structures, 2d ed., McGraw-Hill, New York, 1972.
8. Naval Facilities Engineering Command, "Waterfront Operational Facilities," NAVFAC DM-25, Oct 1971, Washington, D. C.
9. Headquarters, Department of the Army, "Image Interpretation Handbook," Technical Manual TM 30-245, Dec 1967, U. S. Government Printing Office, Washington, D. C.
10. Jeffers, K. B., "Hydrographic Manual," Publication 20-2, 1960, U. S. Department of Commerce, Coast and Geodetic Survey, Washington, D. C.
11. Headquarters, Department of the Army, "Elements of Surveying," Technical Manual TM 5-232, 1964, U. S. Government Printing Office, Washington, D. C.
12. __________, "Special Surveys," Technical Manual TM 5-235, Sep 1964, U. S. Government Printing Office, Washington, D. C.
13. Department of the Navy, Oceanographic Office, "Instruction Manual for Obtaining Oceanographic Data," Publication No. 607, 1968, U. S. Government Printing Office, Washington, D. C.
14. Headquarters, Department of the Army, "The Effects of Nuclear Weapons," Pamphlet 39-3, Feb 1964 (rev ed.), U. S. Government Printing Office, Washington, D. C.

15. American Association of State Highway Officials, Standard Specifications for Highway Bridges, 10th ed., 1969, Washington, D. C.

16. Headquarters, Department of the Army, "Military Fixed Bridges," Technical Manual TM 5-312, 1 Dec 1968, U. S. Government Printing Office, Washington, D. C.

17. American Concrete Institute, "Building Code Requirements for Reinforced Concrete (ACI 318-63)," ACI Standard 318-63, Jun 1963, Detroit, Mich.

18. __________, "Building Code Requirements for Reinforced Concrete (ACI 318-71)," ACI Standard 318-71, 1971, Detroit, Mich.

19. Bohannan, B., "FPL Timber Bridge Deck Research," U. S. Forest Products Laboratory, Madison, Wisc.

20. American Institute of Timber Construction, "Standard Specifications for Structural Glued Laminated Timber," AITC 117-71, Englewood, Colo.

21. __________, Timber Construction Manual, 1st ed., Wiley, New York, 1966.

22. Headquarters, Department of the Army, "Bailey Bridge," Technical Manual TM 5-277, 25 Aug 1966, U. S. Government Printing Office, Washington, D. C.

23. Wilson, E. L., "SAP (A General Structural Analysis Program)," Report No. USCESM 70-20, Sep 1970, University of California, Structural Engineering Laboratory, Berkeley, Calif.

24. Texas A&M University, "Pile Analysis Wave Equation Computer Program Utilization Manual," Research Report 33-11, Study 2-5-62-33, College Station, Tex.

25. Headquarters, Department of the Army, "Self-elevating Barge," Technical Bulletin TB 5-360-1, 15 Jul 1968, U. S. Government Printing Office, Washington, D. C.

26. Towne, R. C., "Mooring Systems for an Expeditionary Logistic Facility," R 712, Feb 1971, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.

27. Lee, T. T., "A Study of Effective Fender System for Piers and Wharves," R 312, Mar 1965, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.

28. Lord Manufacturing Co., "Marine Dock Fenders," Technical References LB-474 and LB-476, Erie, Pa.

29. Schmid, W. E., Elms, D. G., and Carioti, B. M., "Analysis and Design of Dolphins," Apr 1963, Department of Civil Engineering, Princeton University, Princeton, N. J.

30. Rula, A. A. and Nuttall, C. J., Jr., "An Analysis of Ground Mobility Models (ANAMOB)," Technical Report M-71-4, Jul 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

31. Ladd, D. M. and Ulery, H. H., Jr., "Aircraft Ground-Flotation Investigation; Part I, Basic Report," Technical Documentary Report AFFDL-TDR-66-43, Aug 1967, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio; also published as Technical Report No. 3-737, Aug 1967, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

32. Hammitt, G. M. II, "Thickness Requirements for Unsurfaced Roads and Airfields; Bare Base Support," Technical Report S-70-5, Jul 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

33. Brown, D. N. et al., "Relative Surfacing Requirements for Container-Handling Vehicles," Miscellaneous Paper S-72-34, Nov 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

34. Ulery, H. H., Jr., and Wolf, D. P., "Thickness Requirements for Soils Beneath Landing Mats; Bare Base Support," Miscellaneous Paper S-71-3, Jan 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

35. U. S. Department of Defense, "Test Methods for Pavement Subgrade, Subbase, and Base-Course Materials," Military Standard MIL-STD-621A, Dec 1964, U. S. Government Printing Office, Washington, D. C.

36. Ahlvin, R. G. et al., "Multiple-Wheel Heavy Gear Load Tests; Basic Report," Technical Report S-71-17 (in 5 vols), Vol I, Nov 1971, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

37. Brown, D. N. and Thompson, O. O., "Lateral Distribution of Aircraft Traffic," (in preparation), U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

38. Burns, C. D. and Fenwick, W. B., "Development of CBR Design Curves for Runways to be Surfaced with M8A1 (Formerly T10) Steel Landing Mat," Miscellaneous Paper No. 4-817, May 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

39. Headquarters, Department of the Army, Tables of Organization and Equipment TOE 5-166T, Mar 1970, U. S. Government Printing Office, Washington, D. C.

40. ________, Tables of Organization and Equipment TOE 5-167T, Mar 1970, U. S. Government Printing Office, Washington, D. C.

SELECTED BIBLIOGRAPHY*

Technical Reports

American Society for Testing and Materials, "Sampling of Soil and Rock," Special Technical Publication 483, Feb 1971, Philadelphia, Pa.

_________, "Underwater Soil Sampling, Testing, and Construction Control," Special Technical Publication 501, Mar 1972, Philadelphia, Pa.

Boyer, W. C., "Concerning Containers in the Port of Baltimore," Aug 1971, Department of Transportation, State of Maryland, Baltimore, Md.

_________, "A Layman's View of Ships in World Trade," Aug 1971, Department of Transportation, State of Maryland, Baltimore, Md.

Defense Intelligence Agency, "Guide to the Production of DIA Port Studies," Manual 57-2, Jun 1965, Washington, D. C.

Department of the Navy, Oceanographic Office, "Instruction Manual for Obtaining Oceanographic Data," Publication No. 607, 1968, U. S. Government Printing Office, Washington, D. C.

Equipment Mecaniquer & Hydrauliques (EMH), "Rigid Arm Mooring for 63,000 DWT Tanker," Paris, France.

Hersent, G. E. M., "Port Autonome de Bordeaux, Le Verdon Oil Terminal (France)," Location Plan, Mar 1968.

_________, "Port Autonome de Bordeaux, Le Verdon Oil Terminal (France)," 2d Stage, Location Plan, 1969.

Hironaka, M. and Hoffman, W., "Site Surveying for Ocean Floor Construction," Technical Report R 691, Aug 1970, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Jeffers, K. B., "Hydrographic Manual," Publication 20-2, 1960, U. S. Department of Commerce, Coast and Geodetic Survey, Washington, D. C.

Johnson, J. M., "The Trend in Tanker Construction and Its Effect on Military Logistics," 1965, Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio.

Lee, T. T., "A Study of Effective Fender System for Navy Piers and Wharves," R 312, Mar 1965, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Leendertse, J. J., "Design Criteria for Camels or Floating Fenders," Technical Report R 174, Jan 1961, U. S. Naval Civil Engineering Laboratory, Port Hueneme, Calif.

---

* Classified reports relevant to this study have been published. Interested and qualified requesters can obtain a listing of these reports by contacting the Technical Information Center, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi 39180.

Meisburger, E. P. and Duane, D. B., "Geomorphology and Sediments of the Inner Continental Shelf, Palm Beach to Cape Kennedy, Florida," Technical Memorandum 34, Feb 1971, Coastal Engineering Research Center, Washington, D. C.

_________, "Geomorphology and Sediments of the Nearshore Continental Shelf, Miami to Palm Beach, Florida," Technical Memorandum 29, Nov 1969. Coastal Engineering Research Center, Washington, D. C.

McClelland, B., "Foundation Investigations for Offshore Drilling Structures in the Gulf of Mexico," presented at New Orleans Convention, American Society of Civil Engineers, Mar 1952.

Pace, C. E. et al., "Surface Waves Resulting from Explosions in Deep Water; Effect of Charge Depth of Submergence on Wave Height and Energy Coupling," Technical Report No. 1-647 (DASA 1482-4), Report 4, Jan 1969, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Pace, C. E., Whalin, R. W., and Strange, J. N., "Surface Waves Resulting from Explosions in Deep Water; Propagation Characteristics," Technical Report No. 1-647 (DASA 1482-3), Report 3, Apr 1968, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Pinkston, J. M., Jr., "Surface Waves Resulting from Explosions in Deep Water; Summary of Experimental Procedures and Results of Tests at Lake Ouachita, Arkansas," Technical Report No. 1-647 (DASA 1482-2), Report 2, Apr 1966, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

_________, "Surface Waves Resulting from Explosions in Deep Water; Summary of Experimental Procedures and Results of Tests at WES Underwater Explosion Test Site," Technical Report No. 1-647 (DASA 1482-1), Report 1, Jul 1964, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Richards, A. F., ed., Marine Geotechnique, University of Illinois Press, Urbana, Ill., 1967.

Rubner, D. P., "Tanker Mooring Site Survey Equipment," Report 2014, Sep 1971, U. S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Va.

Saucier, R. T., "Acoustic Subbottom Profiling Systems, A State-of-the-Art Survey," Technical Report S-70-1, Apr 1970, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Schmid, W. E., Elms, D. G., and Carioti, B. M., "Analysis and Design of Dolphins," Apr 1963, Department of Civil Engineering, Princeton University, Princeton, N. J.

Towne, R. C., "Mooring Systems for an Expeditionary Logistic Facility," R 712, Feb 1971, Naval Civil Engineering Laboratory, Port Hueneme, Calif.

Technical Reports (Continued)

Tudor, W. J., "Uplift Pressures Under a Pier Deck from Water Waves," Technical Note N668, Dec 1964, U. S. Naval Civil Engineer Laboratory, Port Hueneme, Calif.

U. S. Army Coastal Engineer Research Center, CE, "Shore Protection, Planning and Design," Technical Report No. 4, 3d ed., 1966, U. S. Government Printing Office, Washington, D. C.

U. S. Army Engineer Waterways Experiment Station, CE, "State-of-the-Art of Marine Soil Mechanics and Foundation Engineering," Technical Report S-72-11, Aug 1972, Vicksburg, Miss.

Wilson, E. L., "SAP (A General Structural Analysis Program)," Report No. UCSESM 70-20, Sep 1970, University of California, Structural Engineering Laboratory, Berkeley, Calif.

Military Publications

Historical

Dod, K. C., *United States Army in World War II, The Technical Services; The Corps of Engineers: The War Against Japan,* U. S. Government Printing Office, Washington, D. C., 1966.

"Final Report of the Chief Engineer, European Theater of Operations," 1942-1945.

Joint Logistics Review Board, "Logistic Support in the Vietnam Era; A Review of Logistic Support in the Vietnam Era," Vol II, 1969-1970, Washington, D. C.

__________, "Logistic Support in the Vietnam Era; A Summary Assessment with Major Findings and Recommendations," Vol I, 1969-1970, Washington, D. C.

__________, "Logistic Support in the Vietnam Era; Construction," 1969-1970, Washington, D. C.

Office, Chief of Engineers, General Headquarters, Army Forces, Pacific, "Engineers of the Southwest Pacific, 1941-1945; Airfield and Base Development," Vol VI, 1951, U. S. Government Printing Office, Washington, D. C.

__________, "Engineers of the Southwest Pacific, 1941-1945; Amphibian Engineer Operations," Vol IV, 1959, U. S. Government Printing Office, Washington, D. C.

__________, "Engineers of the Southwest Pacific, 1941-1945; Critique," Vol VIII, 1951, U. S. Government Printing Office, Washington, D. C.

Military Publications (Continued)

Historical (Continued)

Office, Chief of Engineers, General Headquarters, Army Forces, Pacific, "Engineers of the Southwest Pacific, 1941-1945; Engineer Supply," Vol VII, 1949, U. S. Government Printing Office, Washington, D. C.

Naval

Department of the Navy, Bureau of Yards and Docks, "Weight Handling Equipment and Service Craft," NAVDOCKS Design Manual 38, Feb 1962, Washington, D. C.

Naval Facilities Engineering Command, "Civil Engineering," NAVFAC DM-5, Sep 1970, Washington, D. C.

_________, "Harbor and Coastal Facilities," NAVFAC DM-26, Washington, D. C.

_________, "Pontoon Gear Handbook Navy Lightered (N.L.) Equipment P-Series," NAVFAC P-401, Washington, D. C.

_________, "Soil Mechanics, Foundations, and Earth Structures," NAVFAC DM-7, Washington, D. C.

_________, "Structural Engineering," Sep 1970, NAVFAC DM-2, Washington, D. C.

_________, "Waterfront Operational Facilities," NAVFAC DM-25, Oct 1971, Washington, D. C.

U. S. Army Field Manuals and Technical Manuals

Headquarters, Department of the Army, "Ammunition Service in the Theater of Operations," Field Manual FM 9-6, Aug 1971, U. S. Government Printing Office, Washington, D. C.

_________, "Bailey Bridge," Technical Manual TM 5-277, 25 Aug 1966, U. S. Government Printing Office, Washington, D. C.

_________, "Base Development," Field Manual FM 31-82, Jun 1971, U. S. Government Printing Office, Washington, D. C.

_________, "Bills of Materials and Equipment of the Engineer Functional Components System," Technical Manual TM 5-303, Sep 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Carpentry and Building Construction," Technical Manual TM 5-460, U. S. Government Printing Office, Washington, D. C.

_________, "Combat Service Support," Field Manual FM 100-10, Oct 1968, U. S. Government Printing Office, Washington, D. C.

_________, "Construction in the Theater of Operations," Technical

Military Publications (Continued)

U. S. Army Field Manuals and Technical Manuals (Continued)

Manual TM 5-302, Dec 1969, U. S. Government Printing Office, Washington, D. C.

Headquarters, Department of the Army, "Construction Management," Technical Manual TM 5-333, Feb 1972, U. S. Government Printing Office, Washington, D. C.

__________, "Construction Surveying," Technical Manual TM 5-233, Oct 1968, U. S. Government Printing Office, Washington, D. C.

__________, "Control of Soils in Military Construction," Technical Manual TM 5-541, Sep 1954, U. S. Government Printing Office, Washington, D. C.

__________, "Doctrine for Amphibious Operations," Field Manual FM 31-11, Aug 1967, U. S. Government Printing Office, Washington, D. C.

__________, "Elements of Surveying," Technical Manual TM 5-232, Jun 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Amphibious Units," Field Manual FM 5-144, Nov 1966, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Cellular Teams," Field Manual FM 5-33, Jul 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Construction and Construction-Support Units," Field Manual FM 5-162, Dec 1968, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Functional Components System Staff Tables of Installations, Facilities, and Equipages," Technical Manual TM 5-301, Oct 1970, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Troop Organizations and Operations," Field Manual FM 5-1, Jul 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Engineers' Reference and Logistical Data," Field Manual FM 5-35, Feb 1960, U. S. Government Printing Office, Washington, D. C.

__________, "Foreign Maps," Technical Manual TM 5-248, Oct 1963, U. S. Government Printing Office, Washington, D. C.

__________, "Marine Equipment Characteristics and Data," Technical Manual TM 55-550, Feb 1968, U. S. Government Printing Office, Washington, D. C.

__________, "Materials Testing," Technical Manual TM 5-530, Feb 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Military Fixed Bridges," Technical Manual TM 5-312, Dec 1968, U. S. Government Printing Office, Washington, D. C.

Military Publications (Continued)

U. S. Army Field Manuals and Technical Manuals (Continued)

Headquarters, Department of the Army, "Military Floating Bridge Equipment," Technical Manual TM 5-210, Aug 1970, U. S. Government Printing Office, Washington, D. C.

_________, "Military Petroleum Pipeline Systems," Technical Manual TM 5-343, Feb 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Planners and Estimator's Handbook," Technical Manual TM 5-333-1, Nov 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations," Technical Manual TM 5-330, Sep 1968, U. S. Government Printing Office, Washington, D. C.

_________, "Physical Security," Field Manual FM 19-30, Feb 1965, U. S. Government Printing Office, Washington, D. C.

_________, "Pile Construction," Technical Manual TM 5-258, Jun 1963, U. S. Government Printing Office, Washington, D. C.

_________, "Port Construction and Rehabilitation," Technical Manual TM 5-360, Sep 1964, U. S. Government Printing Office, Washington, D. C.

_________, "Railroad Construction," Technical Manual TM 5-370, Sep 1970, U. S. Government Printing Office, Washington, D. C.

_________, "Rigging," Technical Manual 5-725, Oct 1968, U. S. Government Printing Office, Washington, D. C.

_________, "Route Reconnaissance Classification," Field Manual FM 5-36, Jan 1970, U. S. Government Printing Office, Washington, D. C.

_________, "Special Surveys," Technical Manual TM 5-235, Sep 1964, U. S. Government Printing Office, Washington, D. C.

_________, "Staff Officers' Field Manual; Organizational, Technical, and Logistical Data," Field Manual FM 101-10-1, Jul 1971, U. S. Government Printing Office, Washington, D. C.

_________, "Staff Officers' Field Manual; Staff Organization and Procedure," Field Manual FM 101-5, Jun 1968, U. S. Government Printing Office, Washington, D. C.

_________, "Terrain Intelligence," Field Manual FM 30-10, Oct 1967, U. S. Government Printing Office, Washington, D. C.

_________, "The Area Support Command TASTA-70," Field Manual FM 54-6-1, May 1967, U. S. Government Printing Office, Washington, D. C.

_________, "The Logistical Command," Field Manual FM 54-1, Jul 1962, U. S. Government Printing Office, Washington, D. C.

_________, "Transportation Reference Data," Field Manual FM 55-15, Feb 1968, U. S. Government Printing Office, Washington, D. C.

Military Publications (Continued)

U. S. Army Field Manuals and Technical Manuals (Continued)

Headquarters, Department of the Army, "Transportation Terminal Operations," Field Manual FM 55-55-1, Mar 1967, U. S. Government Printing Office, Washington, D. C.

_________, "Utilization of Engineer Construction Equipment; Lifting, Loading, and Hauling Equipment," Technical Manual 5-331B, Vol B, May 1968, U. S. Government Printing Office, Washington, D. C.

Headquarters, Departments of the Air Force and the Army, "Well Drilling Operations," Air Force Manual AFM 85-23, Technical Manual TM 5-297, Sep 1965, U. S. Government Printing Office, Washington, D. C.

Engineering Pamphlets

Office, Chief of Engineers, "Construction Inspector's Guide; Architectural and Structural Features in Building Construction," EP 415-1-252, Jun 1965, U. S. Government Printing Office, Washington, D. C.

_________, "Construction Inspector's Guide; Dams, Levees, Pile Driving and Related Items," EP 415-1-264, Oct 1970, U. S. Government Printing Office, Washington, D. C.

_________, "Construction Inspector's Guide; General Information, Safety, Site Preparation, Paving, Railroads," EP 415-1-261, Jun 1964, U. S. Government Printing Office, Washington, D. C.

_________, "Construction Inspector's Guide; Mechanical and Electrical Features of Building Construction," EP 415-1-263, Aug 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Floating Plant List," EP 1125-2-1, Feb 1970, U. S. Government Printing Office, Washington, D. C.

Catalogs

American Wood Preservers Institute, "Pile Foundations: Know-How," Washington, D. C.

Associated Pile and Fitting Corp., "Pile Accessories," Clifton, N. J.

Bethlehem Steel Corp., "Steel Sheet Piling," CAT 2620, Bethlehem Steel Corp.

_________, "Typical Installations of Bethlehem Steel Sheet Piling," Booklet 1959-B, Bethlehem, Pa.

Goodyear Tire and Rubber Co., "Marine Fenders," Akron, Ohio.

Lord Manufacturing Co., "Marine Dock Fenders," Technical Reference LB-474, Erie, Pa.

Catalogs (Continued)

Lord Manufacturing Co., "Marine Dock Fenders," Technical Reference LB-475, Erie, Pa.

McKiernan-Terry Corp., "Pile Driving Equipment," CAT 680600, Dover, N. J.

Uniroyal Plastic Products, "Marine Fendering Systems," Mishawaka, Ind.

United States Steel Corp., "U. S. S. Steel H-Piles," 1962, Pittsburgh, Pa.

__________, "U. S. S. Steel Sheet Piling," Pittsburgh, Pa.

__________, "U. S. S. Steel Sheet Piling Design Manual," 1970, Pittsburgh, Pa.

Vulcan Iron Works, Inc., "Pile Driving, Pile Extracting Machinery," West Palm Beach, Fla.

Civilian Texts

General

American Society of Civil Engineers, "Analytical Treatment of Problems of Berthing and Mooring Ships," 1971, NATO Advanced Study Institute, New York, N. Y.

__________, "Report on Small Craft Harbors," No. 50, 1969, New York, N. Y.

Finlay, P., ed., Jane's Freight Containers, McGraw-Hill, New York, 1971-1972.

Proceedings, Fifth International Harbour Congress, 2-8 Jun 1968, Antwerp, Belgium.

Docks, Wharves, and Piers

American Association of Port Authorities, Port Design and Construction, 1st ed., Washington, D. C., 1964.

American Society of Civil Engineers, Civil Engineering in the Oceans II, New York, 1970.

Cornick, H. F., Dock and Harbour Engineering, Vols 1-4, 1958-1962, Griffin, London, 1962.

Du-Plat-Taylor, F. M., The Design, Construction and Maintenance of Docks, Wharves and Piers, 3d ed, Eyre and Spottiswoode, London, 1949.

Institution of Civil Engineers, The Civil Engineer in War; Docks and Harbours, Vol 2, Clowes and Sons, London.

Docks, Wharves, and Piers (Continued)

National Ports Council, Port Structures, Vols 1 and 2, Westminister Drawing Office, London, 1969.

Notes on the Design of Harbor Structures, 3d ed., Fay, Spofford, Thorndike, Boston, 1941.

Quinn, A. DeF., Design and Construction of Ports and Marine Structures, 2d ed., McGraw-Hill, New York, 1972.

Handbooks of Engineering

Abbett, R. A., American Civil Engineering Practice, Wiley, New York, 1956.

American Institute of Steel Construction, Inc., Manual of Steel Construction, 7th ed., New York, 1970.

Fuller, D., Organizing, Planning, and Scheduling for Engineering Operations, Industrial Education Institute, Boston, 1962.

Merritt, F. S., Standard Handbook for Civil Engineers, McGraw-Hill, New York, 1968.

Seelye, E. E., Data Book for Civil Engineers; Design, Vol 1, 3d ed., Wiley, New York, 1960.

__________, Data Book for Civil Engineers; Specifications and Costs, Vol 2, Wiley, New York, 1946.

Stubbs, F. W., Handbook of Heavy Construction, 1st ed., McGraw-Hill, New York, 1959.

Piles and Foundations

Blessey, W. E., "The Case for High Capacity Long Steel Piles," Sep 1969, American Iron and Steele Institute, New York, N. Y.

Carson, A. B., Foundation Construction, McGraw-Hill, New York, 1965.

Chellis, R. D., Pile Foundations, 2d ed., McGraw-Hill, New York, 1961.

Jumikis, A. R., Foundation Engineering, Intext Educational Publishers, San Francisco, 1971.

Seelye, E. E., Foundations; Design and Practice, Wiley, New York, 1956.

Shepard, F. P., Submarine Geology, 2d ed., Harper and Row, New York, 1963.

Concrete

American Concrete Institute, "Building Code Requirements for Reinforced Concrete (ACI 318-63)," ACI Standard 318-63, Jun 1963, Detroit, Mich.

Concrete (Continued)

American Concrete Institute, "Manual of Standard Practice for Detailing Reinforced Concrete Structures (ACI 315-65)," ACI Standard 315-65, 1965, Detroit, Mich.

Barker, J. A., *Reinforced Concrete Detailing,* Oxford, New York, 1967.

Peurifoy, R. L., *Formwork for Concrete Structures,* McGraw-Hill, New York, 1964.

Urquhart, L. C., O'Rouke, C. E., and Winter, G., *Design of Concrete Structures,* 6th ed., McGraw-Hill, New York, 1958.

Dredging

Cooper, H. R., *Practical Dredging,* Brown, Son, and Ferguson, Ltd., Great Britian, 1958.

Huston, J., *Hydraulic Dredging; Theoretical and Applied,* Cornell Maritime Press, Cambridge, Md., 1970.

Water Wave Propagation

Hasegawa, K. and Sono, K., "Waves Produced by Sudden Depression of the Bottom in the Immediate Neighborhood of a Point," *Bulletin, Central Meteorological Observatory of Japan,* Tokyo, Vol 2, 1915.

Havelock, T. H., "The Propagation of Waves in Dispersive Media," *Proceedings, Royal Society, London,* ixxxi, 1908.

Ichiye, T., "On the Theory of Tsunami," *Oceanographical Magazine,* Central Meteorological Observatory of Japan, Vol 2, No. 3, Sep 1950, pp 83-100.

Kajiura, K., "The Leading Wave of a Tsunami," *Bulletin, Earthquake Research Institute,* University of Tokyo, Vol 41, Part 3, Sep 1963.

Kinsman, B., *Wind Waves, Their Generation and Propagation on the Ocean Surface,* Prentice-Hall, Englewood Cliffs, N. J., 1965.

Kranzer, H. C. and Keller, J. B., "Water Waves Produced by Explosions," Report IMM-NYU-222, Sep 1955, New York Institute of Mathematical Sciences, New York; also published in *Journal of Applied Physics,* Vol 30, No. 3, Mar 1959, pp 398-407.

Leech, T. D. J., "The Final Report of Project 'Seal'," Dec 1950, Department of Scientific and Industrial Research, Wellington, New Zealand.

LeMehaute, B., Whalin, R. W., and Webb, L. M., "Contributions to the Mono Lake Experiments; Predictions of the Water Waves and Run-Up Generated by TNT Explosions in Mono Lake," NESCO Report S-256-2, Vol 1, Oct 1965, National Engineering Science Company, Pasadena, Calif.

Water Wave Propagation (Continued)

Marine Advisors, Inc., "A Statistical Survey of Ocean Wave Characteristics in Southern California Waters," Jan 1961, La Jolla, Calif.

National Marine Consultants, "Wave Statistics for Seven Deep Water Stations Along the California Coast," Dec 1960, Santa Barbara, Calif.

Prins, J. E., "Characteristics of Waves Generated by a Local Surface Disturbance," Series 99, Issue 1, Aug 1956, Wave Research Laboratory, University of California, Berkeley, Calif.

Sono, K., "On the Waves Caused by a Sudden Deformation of a Finite Portion of the Bottom of Sea of Uniform Depth," Geophysical Magazine, Vol 10, 1936.

Van Dorn, W. G., "Explosion-Generated Waves in Water of Variable Depth," Journal of Marine Research, Sears Foundation for Marine Research, New Haven, Conn., Vol 22, No. 2, 15 May 1964, pp 123-141.

__________, "Some Characteristics of Surface Gravity Waves in the Sea Produced by Nuclear Explosions," Journal of Geophysical Research, American Geophysical Union, Washington, D. C., Vol 66, No. 11, Nov 1961, pp 3845-3862.

Whalin, R. W., "Contributions to the Mono Lake Experiments; The Linear Theory of Water Waves Generated by Explosions," NESCO Report S-256-2, Vol 2, Oct 1965, National Engineering Science Company, Pasadena, Calif.

__________, "Water Waves Produced by Impulsive Energy Sources; Part 5, Propagation," NMC-ONR-62, Sep 1963, National Marine Consultants, Anaheim, Calif.

__________, "Water Waves Produced by Underwater Explosions: Propagation Theory for Regions Near the Explosion," Journal of Geophysical Research, American Geophysical Union, Washington, D. C., Vol 70, No. 22, 15 Nov 1965, pp 5541-5549.

Wiegel, R. L., Oceanographical Engineering, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1964.

APPENDIX A: LIST FOR BOOK SET

Civilian Texts

Docks, Wharves, and Piers

American Association of Port Authorities, Port Design and Construction, 1st ed., Washington, D. C., 1964.

Cornick, H. F., Dock and Harbour Engineering, Vols 1-4, 1958-1962, Griffin, London, 1962.

Notes on the Design of Harbor Structures, 3d ed., Fay, Spofford, Thorndike, Boston, 1941.

National Ports Council, Port Structures, Vols 1 and 2, Westminister Drawing Office, London, 1969.

Quinn, A. DeF., Design and Construction of Ports and Marine Structures, 2d ed., McGraw-Hill, New York, 1972.

Handbooks of Engineering

American Institute of Steel Construction, Inc., Manual of Steel Construction, 7th ed., New York, 1970.

Merritt, F. S., Standard Handbook for Civil Engineers, McGraw-Hill, New York, 1968.

Stubbs, F. W., Handbook of Heavy Construction, 1st ed., McGraw-Hill, New York, 1959.

Piles and Foundations

Chellis, R. D., Pile Foundations, 2d ed., McGraw-Hill, New York, 1961.

Seelye, E. E., Foundations; Design and Practice, Wiley, New York, 1956.

Shepard, F. P., Submarine Geology, 2d ed., Harper and Row, New York, 1963.

Concrete

American Concrete Institute, "Building Code Requirements for Reinforced Concrete (ACI 318-63)," ACI Standard 318-63, Jun 1963, Detroit, Mich.

Peurifoy, R. L., Formwork for Concrete Structures, McGraw-Hill, New York, 1964.

Urguhart, L. C., O'Rouke, C. E., and Winter, G., Design of Concrete Structures, 6th ed., McGraw-Hill, New York, 1958.

Civilian Texts (Continued)

Dredging

Cooper, H. R., Practical Dredging, Brown, Son, and Ferguson, Ltd., Great Britian, 1958.

Huston, J., Hydraulic Dredging; Theoretical and Applied, Cornell Maritime Press, Cambridge, Md., 1970.

U. S. Navy Design Manuals

Naval Facilities Engineering Command, "Structural Engineering," Sep 1970, NAVFAC DM-2, Washington, D. C.

__________, "Civil Engineering," NAVFAC DM-5, Sep 1970, Washington, D. C.

__________, "Waterfront Operational Facilities," NAVFAC DM-25, Oct 1971, Washington, D. C.

__________, "Harbor and Coastal Facilities," NAVFAC DM-26, Washington, D. C.

Department of the Navy, Bureau of Yards and Docks, "Weight Handling Equipment and Service Craft," NAVDOCKS Design Manual 38, Feb 1962, Washington, D. C.

Naval Facilities Engineering Command, "Pontoon Gear Handbook Navy Lightered (N.L.) Equipment P-Series," NAVFAC P-401, Washington, D. C.

U. S. Army Field Manuals and Technical Manuals

Headquarters, Department of the Army, "Engineer Troop Organizations and Operations," Field Manual FM 5-1, Jul 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Cellular Teams," Field Manual FM 5-33, Jul 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Route Reconnaissance Classification," Field Manual FM 5-36, Jan 1970, U. S. Government Printing Office, Washington, D. C.

__________, "Engineers' Reference and Logistical Data," Field Manual FM 5-35, Feb 1960, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Amphibious Units," Field Manual FM 5-144, Nov 1966, U. S. Government Printing Office, Washington, D. C.

__________, "Engineer Construction and Construction-Support Units," Field Manual FM 5-162, Dec 1968, U. S. Government Printing Office, Washington, D. C.

U. S. Army Field Manuals and Technical Manuals (Continued)

Headquarters, Department of the Army, "Ammunition Service in the Theater of Operations," Field Manual FM 9-6, Aug 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Physical Security," Field Manual FM 19-30, Feb 1965, U. S. Government Printing Office, Washington, D. C.

__________, "Terrain Intelligence," Field Manual FM 30-10, Oct 1967, U. S. Government Printing Office, Washington, D. C.

__________, "Doctrine for Amphibious Operations," Field Manual FM 31-11, Aug 1967, U. S. Government Printing Office, Washington, D. C.

__________, "Base Development," Field Manual FM 31-82, Jun 1971, U. S. Government Printing Office, Washington, D. C.

__________, "The Logistical Command," Field Manual FM 54-1, Jul 1962, U. S. Government Printing Office, Washington, D. C.

__________, "The Area Support Command TASTA-70," Field Manual FM 54-6-1, May 1967, U. S. Government Printing Office, Washington, D. C.

__________, "Transportation Terminal Operations," Field Manual FM 55-55-1, Mar 1967, U. S. Government Printing Office, Washington, D. C.

__________, "Combat Service Support," Field Manual FM 100-10, Oct 1968, U. S. Government Printing Office, Washington, D. C.

__________, "Staff Officers' Field Manual; Organizational, Technical, and Logistical Data," Field Manual FM 101-10-1, Jul 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Staff Officers' Field Manual; Staff Organization and Procedure," Field Manual FM 101-5, Jun 1968, U. S. Government Printing Office, Washington, D. C.

__________, "Military Floating Bridge Equipment," Technical Manual TM 5-210, Aug 1970, U. S. Government Printing Office, Washington, D. C.

__________, "Elements of Surveying," Technical Manual TM 5-232, Jun 1971, U. S. Government Printing Office, Washington, D. C.

__________, "Construction Surveying," Technical Manual TM 5-233, Oct 1968, U. S. Government Printing Office, Washington, D. C.

__________, "Special Surveys," Technical Manual TM 5-235, Sep 1964, U. S. Government Printing Office, Washington, D. C.

__________, "Foreign Maps," Technical Manual TM 5-248, Oct 1963, U. S. Government Printing Office, Washington, D. C.

__________, "Pile Construction," Technical Manual TM 5-258, Jun 1963, U. S. Government Printing Office, Washington, D. C.

__________, "Bailey Bridge," Technical Manual TM 5-277, 25 Aug 1966, U. S. Government Printing Office, Washington, D. C.

U. S. Army Field Manuals and Technical Manuals (Continued)

Headquarters, Departments of the Air Force and the Army, "Well Drilling Operations," Air Force Manual AFM 85-23, Technical Manual TM 5-297, Sep 1965, U. S. Government Printing Office, Washington, D. C.

Headquarters, Department of the Army, "Engineer Functional Components System Staff Tables of Installations, Facilities, and Equipages," Technical Manual TM 5-301, Oct 1970, U. S. Government Printing Office, Washington, D. C.

_________, "Construction in the Theater of Operations," Technical Manual TM 5-302, Dec 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Bills of Materials and Equipment of the Engineer Functional Components System," Technical Manual TM 5-303, Sep 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Military Fixed Bridges," Technical Manual TM 5-312, Dec 1968, U. S. Government Printing Office, Washington, D. C.

_________, "Planning and Design of Roads, Airbases, and Heliports in the Theater of Operations," Technical Manual TM 5-330, Sep 1968, U. S. Government Printing Office, Washington, D. C.

_________, "Utilization of Engineer Construction Equipment; Lifting, Loading, and Hauling Equipment," Technical Manual 5-331B, Vol B, May 1968, U. S. Government Printing Office, Washington, D. C.

_________, "Construction Management," Technical Manual TM 5-333, Feb 1972, U. S. Government Printing Office, Washington, D. C.

_________, "Planners and Estimator's Handbook," Technical Manual TM 5-333-1, Nov 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Military Petroleum Pipeline Systems," Technical Manual TM 5-343, Feb 1969, U. S. Government Printing Office, Washington, D. C.

_________, "Port Construction and Rehabilitation," Technical Manual TM 5-360, Sep 1964, U. S. Government Printing Office, Washington, D. C.

_________, "Railroad Construction," Technical Manual TM 5-370, Sep 1970, U. S. Government Printing Office, Washington, D. C.

_________, "Carpentry and Building Construction," Technical Manual TM 5-460, U. S. Government Printing Office, Washington, D. C.

_________, "Materials Testing," Technical Manual TM 5-530, Feb 1971, U. S. Government Printing Office, Washington, D. C.

_________, "Control of Soils in Military Construction," Technical Manual TM 5-541, Sep 1954, U. S. Government Printing Office, Washington, D. C.

_________, "Rigging," Technical Manual 5-725, Oct 1968, U. S. Government Printing Office, Washington, D. C.

U. S. Army Field Manuals and Technical Manuals (Continued)

Headquarters, Department of the Army, "Care, Handling, Preservation, and Destruction of Ammunition," Technical Manual TM 9-1300-206, Nov 1964, U. S. Government Printing Office, Washington, D. C.

__________, "Marine Equipment Characteristics and Data," Technical Manual TM 55-550, Feb 1968, U. S. Government Printing Office, Washington, D. C.

U. S. Army Engineering Pamphlets

Office, Chief of Engineers, "Construction Inspector's Guide; General Information, Safety, Site Preparation, Paving, Railroads," EP 415-1-261, Jun 1964, U. S. Government Printing Office, Washington, D. C.

__________, "Construction Inspector's Guide; Mechanical and Electrical Features of Building Construction," EP 415-1-263, Aug 1969, U. S. Government Printing Office, Washington, D. C.

__________, "Construction Inspector's Guide; Dams, Levees, Pile Driving and Related Items," EP 415-1-264, Oct 1970, U. S. Government Printing Office, Washington, D. C.

__________, "Floating Plant List," EP 1125-2-1, Feb 1970, U. S. Government Printing Office, Washington, D. C.

APPENDIX B

SELECTING LEAD TYPES AND CALCULATING CRANE LOADS

(From McKiernan-Terry Corp. Catalog 680600)

SWINGING LEAD –

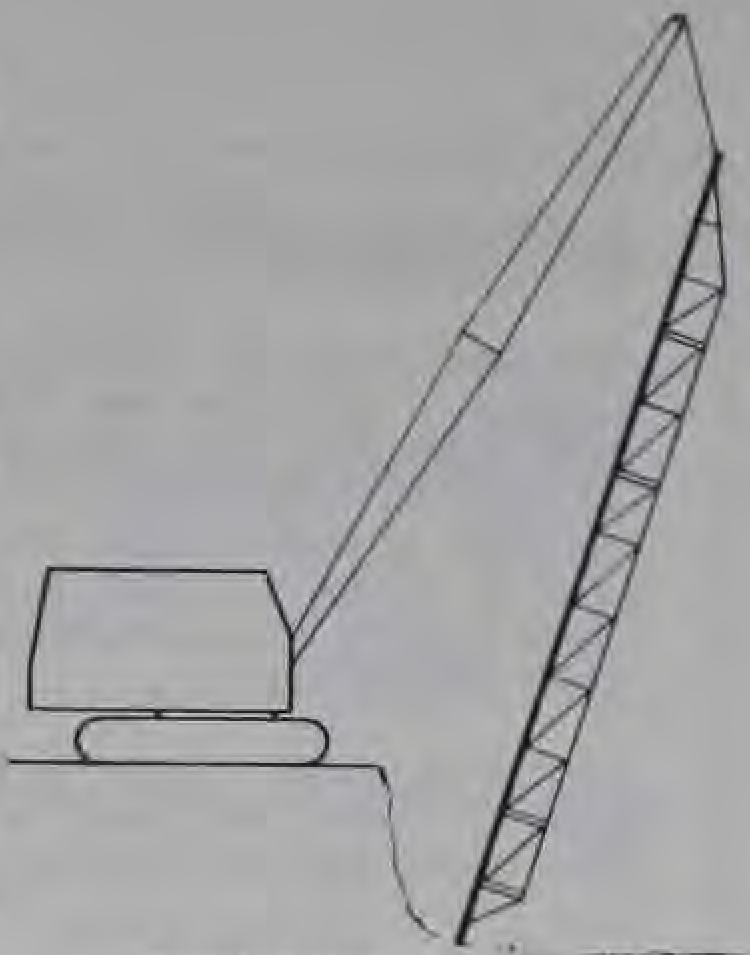
This Lead is hung from a Crane Boom with a single line. In use, this Lead is spotted on the ground at the Pile location, generally with Stabbing Points attached, and held Plumb or at the desired Batter with the supporting Crane Line. Short swinging Leads are often used to assist in driving Steel Sheet Piling.

ADVANTAGES:

- Lightest, simplest and least expensive.
- With Stabbing Points secured in ground this Lead is free to rotate sufficiently to align Hammer with Pile without precise alignment of Crane with Pile.
- Because these Leads are generally 15 - 20 ft. shorter than Boom, Crane can reach out farther, assuming the Crane capacity is sufficient.
- Can drive in a hole or ditch or over the edge of an excavation.
- For long Lead and Boom requirements, the Lead weight can be supported on the ground while the Pile is lifted into place without excessively increasing the working load.

DISADVANTAGES:

- Requires 3-Drum Crane (1 for Lead, 1 for Hammer, 1 for Pile) or 2-Drum Crane with Lead hung on Sling from Boom Point.
- Because of Crane Line Suspension, precise positioning of Lead with Pile Head is difficult and slow.
- Difficult to control twisting of Lead if Stabbing Points are not secured to ground.
- It is more difficult to position Crane with these Leads than with any other. You must rely on balance while C.G. continues to move.



SWINGING LEADS

UNDERHUNG LEAD –

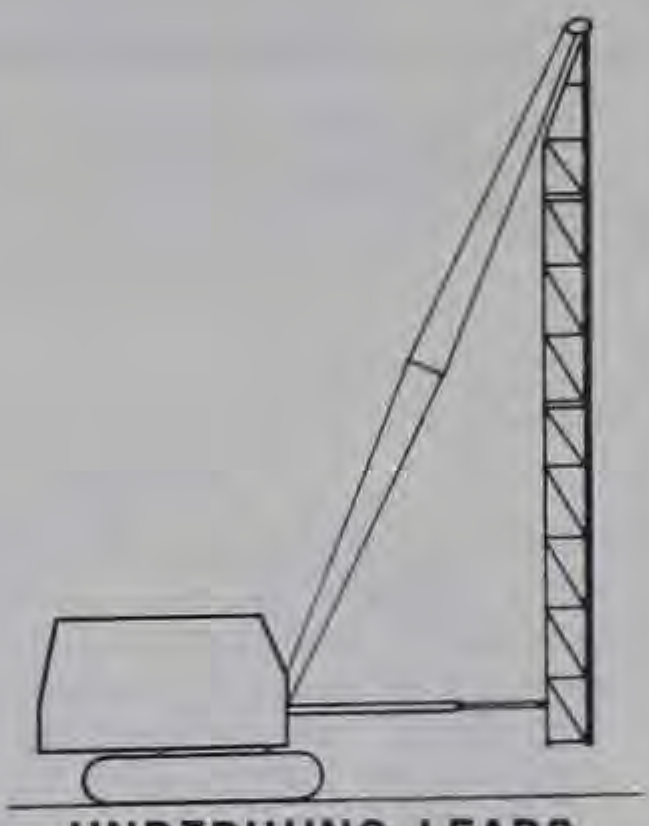
This Lead is pinned to the Boom Point and connected to the Crane Cab by either a Rigid Bottom Brace for vertical driving or a Manually or Hydraulically Adjustable Bottom Brace for Fore and Aft driving.

ADVANTAGES:

- Lighter and generally less expensive than extended type Lead.
- Requires only 2-Drum Crane.
- Accuracy in locating Lead in Vertical or Fore and Aft Batter positions.
- Rigid control of Lead during positioning operation .
- Reduces rigging time in setting up and breaking down.
- Utilizes Sheave Head in Crane Boom.

DISADVANTAGES:

- Cannot be used for Side to Side Batter Driving.
- Length of Pile limited by Boom length since this type of Lead cannot be extended above the Boom Point.
- When long Leads dictate the use of a long Boom, the working radius which results may be excessive for the capacity of the Crane.
- Does not allow the use of a Boom shorter than the Lead.



UNDERHUNG LEADS

EXTENDED 4-WAY LEAD –

This Lead attaches to the Boom Point with a swivel connection to allow Batter in all directions when used with a Parallelogram Bottom Brace. Extension of Lead over the Boom Point must not exceed ⅓ of total Lead length or up to 25 ft. maximum. Proper selection of components will provide a Lead which can be accurately positioned hydraulically or manually and which can be remotely controlled (Hydraulic Phase only).

ADVANTAGES:

- Requires only 2-Drum Crane.
- Accuracy in locating Lead in Vertical Position and all Batter Positions.
- Rigid control of Lead during positioning operation.
- Compound Batter angles can be set and accurately maintained.
- Allows use of short Boom with resulting increase in capacity.
- Boom can be lowered and Leads folded under (for short-haul over the road and railroad travel) when Crane of adequate capacity is used. (This depends on the length of Lead and Boom and the configuration of the Crane.)

DISADVANTAGES:

- Heaviest and most expensive of the three basid Lead types.
- More troublesome to assemble.

EXTENDED, 4-WAY LEADS

Calculating Crane Load

To calculate the Crane Load in Fore and Aft Batter Operation proceed as follows:

After selecting the Lead elements and Hammer necessary to satisfy the Pile length and the Batter requirements, layout Lead and Crane with appropriate Boom. (See figures A & B) Measure from center of gravity of Leads and Hammer to center of rotation to establish d_1, d_2, d_3, etc. (Center of gravity of Lead and Hammer assumed to be in middle of length.)

Take sum of moments of Lead section , Bottom Brace and Hammer with respect to center of Crane rotation using the following formula:

(See figures A & B)

$$D = \frac{w_1 d_1 + w_2 d_2 + w_3 d_3 + w_4 d_4 \text{ etc.}}{W}$$

W = Sum of w_1, w_2, w_3, etc.
w_1 = Hammer Wt.
w_2 = Bottom Brace Wt.
w_3 = Boom Connections (if used)
w_4 = Top Lead Section with Sheave Head
D = Equivalent Load Radius

Using equivalent load radius (D) and total weight (W) refer to Crane Manufacturer's Lifting Capacity Chart.

(See the following example)

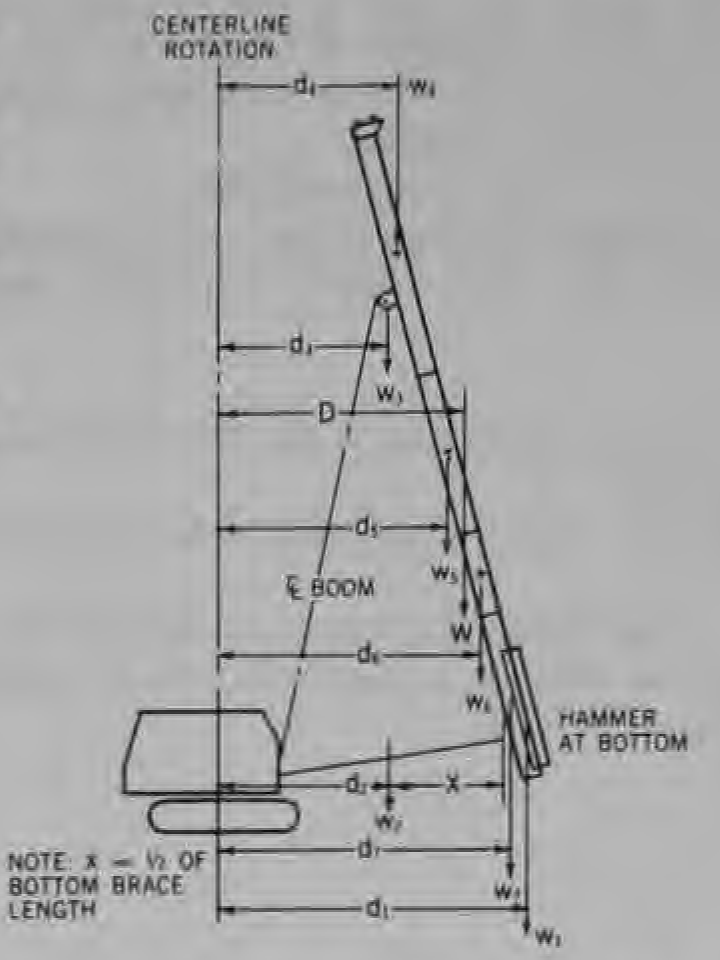


FIGURE A — FORE BATTER

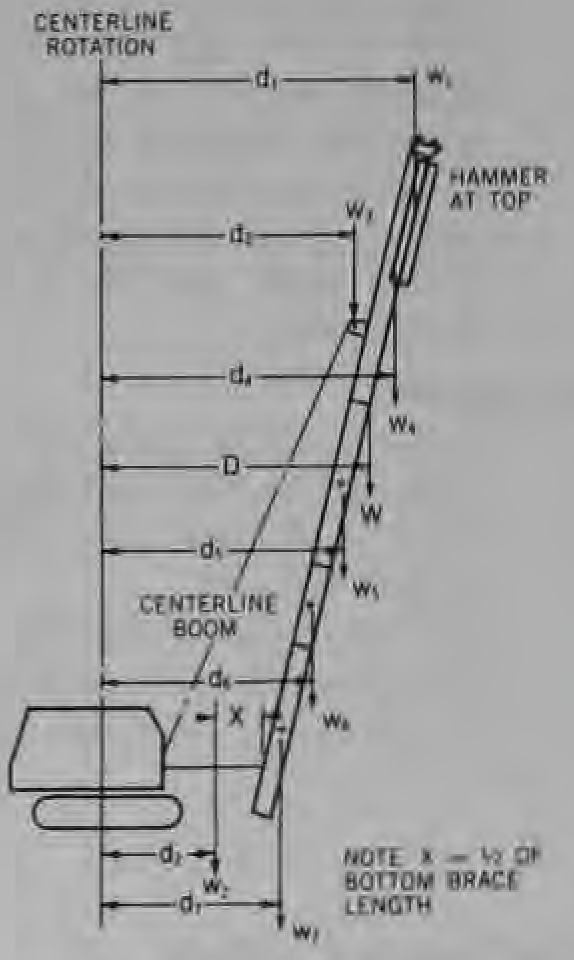


FIGURE B — AFT BATTER

TYPICAL EXAMPLE

In the following example, we shall calculate the Crane Load using a 70 ft. extended Lead on a 3:1 Fore Batter and a MKT DE-30 Pile Hammer. We shall consider using a Manitowoc Model 3000 B Crane with a 50 ft. Boom. The Lead will consist of a 30 ft. Slide Section with Sheave Head, (1) 20 ft. Intermediate Section, (1) 20 ft. Intermediate Section with Bottom Brace Connection and Bottom Brace 62-074. (See figure C)

$$D = \frac{w_1 d_1 + w_2 d_2 + w_3 d_3 + w_4 d_4 + w_5 d_5 + w_6 d_6}{W}$$

$$D = \frac{(9075 \times 32.7) + (3128 \times 18.5) + (995 \times 16) + (3513 \times 17) + (1544 \times 24.7) + (1712 \times 30.8)}{9075 + 3128 + 995 + 3513 + 1544 + 1712}$$

$$D = \frac{296{,}750 + 57{,}870 + 15{,}920 + 59{,}720 + 38{,}140 + 52{,}730}{19{,}967} = \frac{521{,}130}{19{,}967} = 26.1 \text{ ft.}$$

Our result shows the Load to be 19,967# at an equivalent Load radius of 26.1 ft. In checking the Lifting Capacity Chart of the Manitowoc Model 3000 B Crane, we find the capacity at 28 ft. radius and 50 ft. Boom to be 29,700#. This indicates a safe operating condition.

In these calculations and examples the weight of the Pile and its effect on the equivalent Load radius has been omitted. Generally, in a Pile Driving operation the Pile is threaded under the Hammer when the Leads are vertical, thus is not reflected in the Batter calculations. When the Pile Batter is set, one end of the Pile rests on the ground and the Hammer is resting on top of it. This reduces the equivalent working Load on the Crane to less than shown in the above examples.

NOTE: If the Pile is threaded into Leads before Batter is set then the Pile weight must be considered in these calculations.

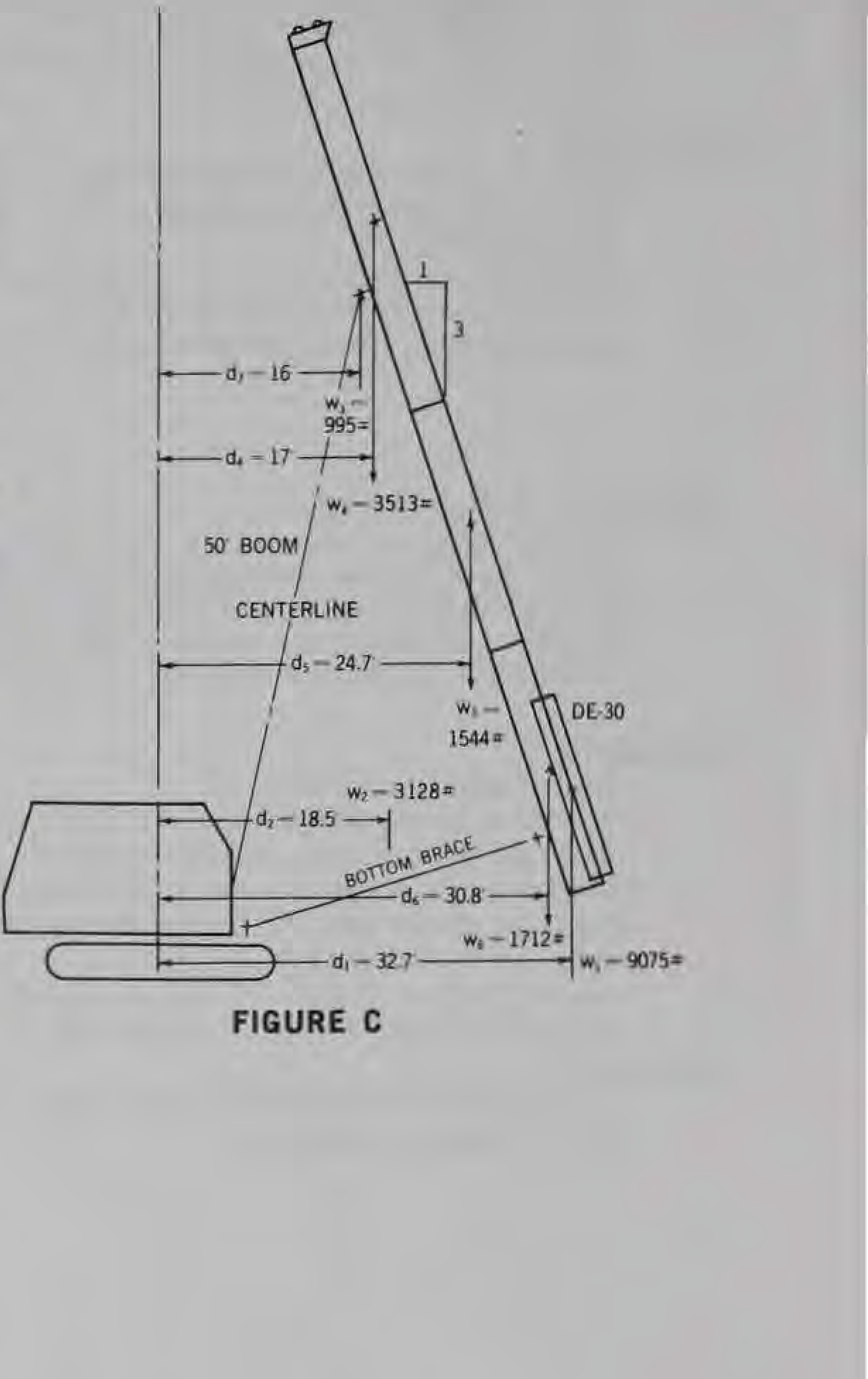


FIGURE C

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)*
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
PORT CONSTRUCTION IN THE THEATER OF OPERATIONS

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

5. AUTHOR(S) *(First name, middle initial, last name)*
Alton A. Clark   Donald N. Brown   Robert W. Whalin
Richard J. Lacavich   William K. Dornbush   Frank B. Cox

6. REPORT DATE
June 1973

7a. TOTAL NO. OF PAGES
299

7b. NO. OF REFS
197

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. 4A664717D895

c. Task 22

d. Work Unit 012

9a. ORIGINATOR'S REPORT NUMBER(S)
Technical Report H-73-9

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Office, Chief of Engineers, U. S. Army
Washington, D. C.

13. ABSTRACT

Recent developments in marine shipping will have a profound effect on military port construction. The use of large container vessels and super tankers already requires that commercial marine terminals be extensively modified in order to operate efficiently, and the Army must be capable of constructing facilities that are compatible with the new developments. This report furnishes basic reference information for use in selecting sites for military ports and port facilities, fulfilling the requirements of container facilities, and solving engineering problems that new developments will place on the military engineer. It involves only present state-of-the-art techniques and equipment that permit the off-loading of all types of commercial and military cargo vessels at the earliest practical time after a site has been tactically secured. The effects of new shipping developments and the modifications that they will require in base development plans are described. A comprehensive section is included on the collection of terrain intelligence data that cover topographical, hydrographical, and cultural aspects of the proposed port location and sources and techniques to acquire necessary data for sound engineering decisions. Design considerations for structures are discussed with emphasis placed on container facilities. One of the critical design factors is the type of equipment that will use the facility. An evaluation was performed of the Army's existing DeLong barges to determine if they could be efficiently utilized as container facilities, and, if so, to determine the engineering problems that would develop. The design considerations and problems involved in the selection of fenders are also discussed herein. Flexible pavement curves, M8A1 landing mat requirements, and vehicle cone indexes for sample container handling equipment operating on unsurfaced soils are developed herein. The criteria for operation of aircraft on unsurfaced areas were used for medium- and high-strength soils, and the criteria for the design of military roads and airfields were employed in the analysis of M8A1 landing mat and flexible pavements. Surface area requirements for container facilities are also discussed. The capabilities and uses of different types of dredges and new developments in transportability to the theater of operations are also discussed. Cranes, pile driving equipment, and construction barges are discussed regarding their use in constructing port facilities. Results of the study indicate that recent developments in marine shipping will significantly change the requirements for port facilities within the theater of operations.

DD FORM 1 NOV 65 **1473** REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cargo ships						
Container ships						
DeLong piers						
Dredges						
Marine terminals						
Marine transportation						
Military facilities						
Ports						
Terrain intelligence						
Unsurfaced soils						