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Technical Report

UMBRELLA PILE-ANCHORS

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U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

UMBRELLA PILE-ANCHORS

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Type C Final Report

by

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ABSTRACT

Two umbrella pile-anchor designs were developed for use in moorings and dolphins. One design weighs about 1400 pounds and requires a casing for placement; the other weighs about 2200 pounds and is driven directly into the ground in a locked position, then opened. Tests indicated that both designs are operational in homogeneous soils free of boulders and other large obstructions. Both have bearing capacities and resistance-to-uplift capacities in excess of 300 kips in sand bottoms. Each design offers advantages for use in specific situations depending on such factors as fabrication costs, soil characteristics and depth of water at the driving site, and equipment available for placement.

CONTENTS

page

APPENDIXES

INTRODUCTION

In some harbor installations employment of anchors and piles in a normal manner is impractical or unduly expensive. Dragging of anchors during placement of moorings or afterward may be objectional or unacceptable; space restrictions may prohibit placement of spread-type moorings where desired or needed; or the bedrock may be too deep to provide bearing support for conventional bearing or stake piles, or too shallow to permit sufficient embedment. To overcome these problems the Bureau of Yards and Docks conceived and prepared preliminary drawings of a device that could be driven into the ground and opened like an umbrella. The objective was to obtain high capacities in bearing and in resistance to uplift without the disadvantages and undesirable characteristics listed above.

The Laboratory was assigned the task of evaluating the principle and, if feasible, developing a workable umbrella pile-anchor, hereinafter called umbrella pile, capable of achieving ultimate capacities of 220 kips in bearing and 300 kips in resistance to uplift in sand when embedded at depths less than 20 feet below firm bottom. Capabilities in other soil mediums were to be evaluated later.

Two designs that meet the specified criteria were developed, one designated Mark III based on BUDOCKS' concept, and the other designated Mark IV based on an NCEL design. Each offers advantages in specific situations.

In the report that follows, the designs and their development and tests are described, including their fabrication details and placement procedures; factors affecting successful functioning of umbrella piles are examined; and the relative merits and potentials of each design are discussed.

UMBRELLA PILE DESCRIPTION

General

The umbrella piles are mechanically operated steel implements designed to be driven into the ground like a pile and opened to obtain greater capacity in bearing and in resistance to uplift than is possible with conventional piles. The Mark III design is shown in Figure 1 and the Mark IV in Figure 2; their approximate weights are 1400 and 2200 pounds respectively. Though the designs are independent developments, three basic elements common to both are a tubular frame, a runner that moves longitudinally inside the frame, and four flukes, each of which is pin-connected to the frame and to the runner. When opened outward, the flukes are supported against collapse by bracing arms and thus provide the added area to effect the desired increase in capacities. Each design also possesses a self-contained gage to indicate when the flukes are open. Differences in the two designs are evident by the accessories required for their placement, the configuration and mechanical functioning of their individual elements, and their distinct principle of operation.

Details of Mark III

The Mark III, illustrated in Figure 1, is detailed in Y & D Drawings 813663, 813664, and 813665. An 18-inch-OD steel casing and a 12-3/4-inch-OD steel follower are the two major accessories essential to its placement. Their lengths are dependent upon water depth and the desired depth of pile embedment. The follower and umbrella pile are assembled and placed inside the casing. The initial driving force is exerted against the casing, and the assembly is driven as a unit until the fluke-opening depth is reached. The casing is then extracted and thereafter the driving blows are directed against the follower, which transmits the force to the frame to activate opening of the flukes. As the pile moves downward, the soil acts against the toeplates and forces the flukes outward. This action causes ever-increasing soil pressure to act on the underside of the flukes until they are fully open. As the flukes move outward, the bracing arms force the runner upward relative to the spacer until the runner pads contact the frame base. At this position the flukes are fully open and locked.

Locking action in bearing is effected by the impingement of the runner pads and frame base preventing the flukes from opening further when the load, as in driving, is directed against the frame. Locking action against uplift is effected by two sets of conditions: (1) further opening is prevented by the contact of the runner pads against the frame base when the pull of the chain on the runner and thence on the bracing arms exerts an opening force on the flukes; (2) closure is prevented because the combined force due to the soil bearing on the frame and fluke heel area, the skin friction on the frame, and the friction of the working parts is greater than the force due to the soil bearing near the fluke tips.

The placement procedure for the Mark III is given in Appendix A.

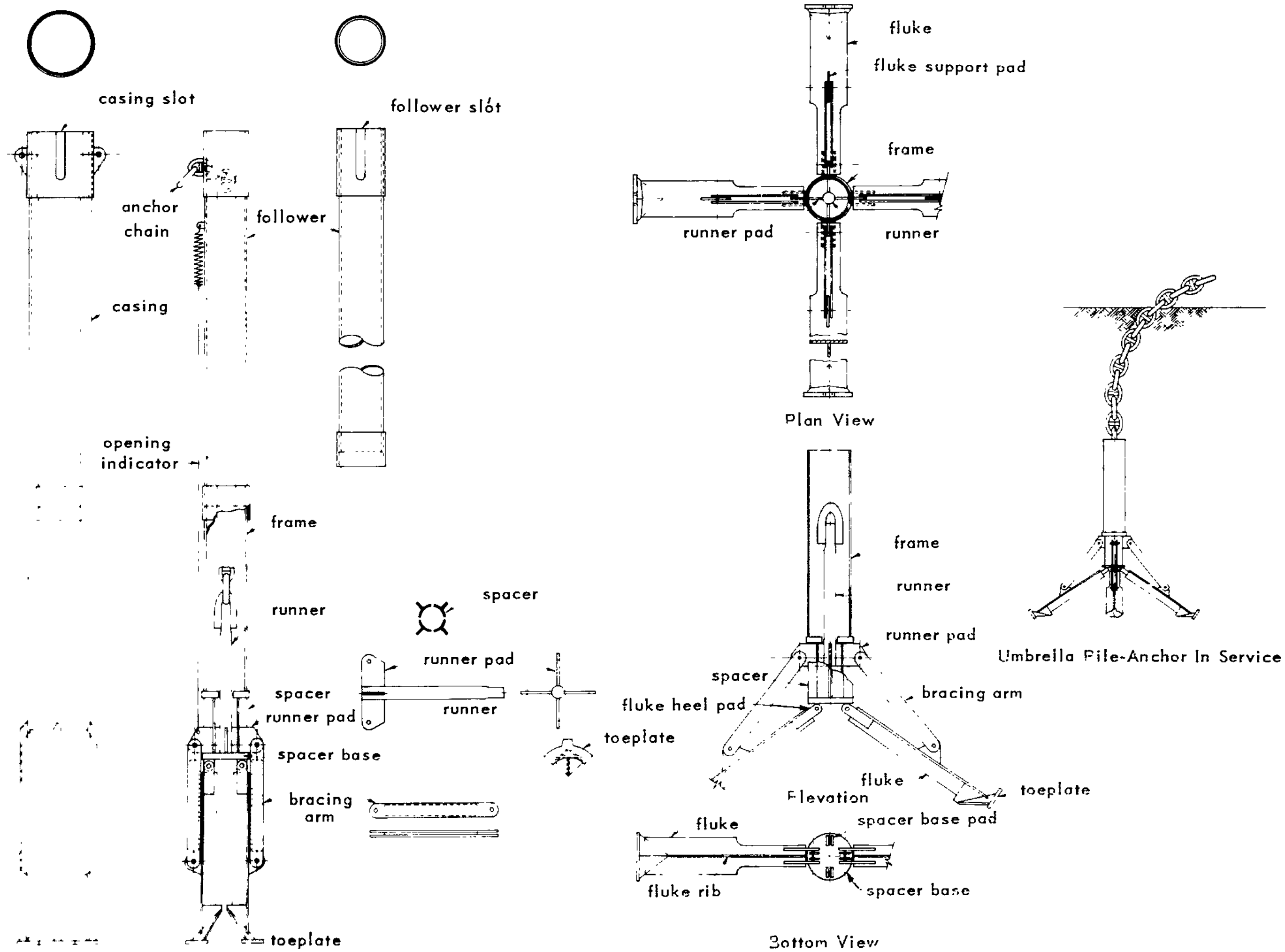


Figure 1. Mark III umbrella pile-anchor.

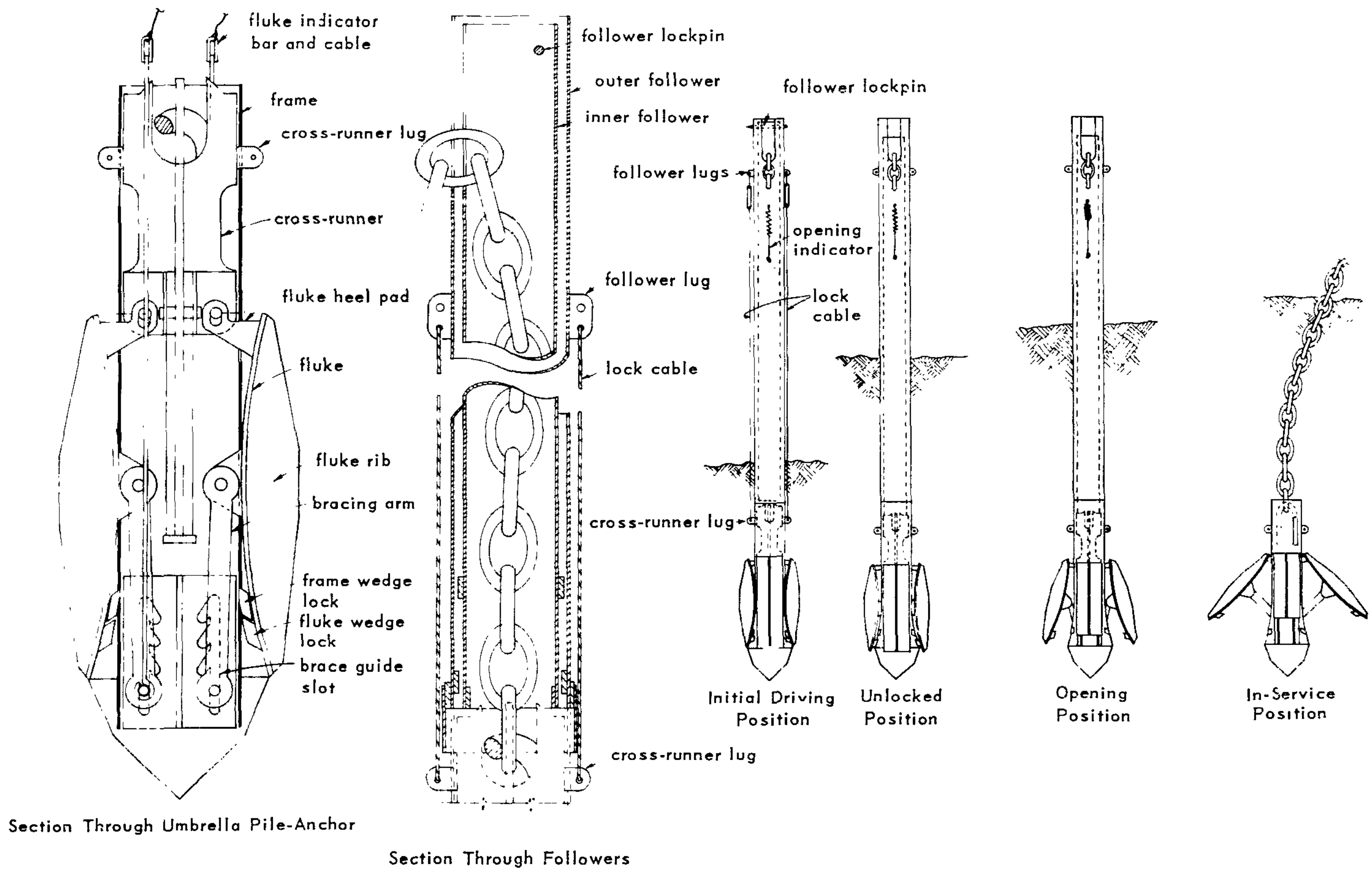


Figure 2. Mark IV umbrella pile-anchor.

Details of Mark IV

The Mark IV, illustrated in Figure 2, is detailed in Y & D Drawings 879026, 879027, 879028, 879029, and 879030. A 16-inch-OD outer follower with a 12-3/4-inch-OD inner follower are the two major accessories necessary to its placement. As with the Mark III, their lengths are dependent upon water depth and required embedment. The items are assembled with the umbrella pile attached to the lower end of the followers as shown in Figure 2. No casing is required. The pile is driven directly into the soil in the closed position by directing blows against the outer follower. The flukes are kept tightly closed by two lock cables attached to lugs on the outer follower and the cross-runner. The cables hold the cross-runner and flukes in the up position. The follower lockpin prevents the inner follower from striking the cross-runner during initial driving.

To commence the opening action at the desired depth, the lock cables are released, the follower lockpin is removed, and an adapter directs the driving force against the inner follower, moving it downward 4-1/4 inches relative to the outer follower. This movement forces the flukes downward, unlocking them and exposing their tips to soil action. The driving head of the adapter is so designed that the blows are directed against both followers after the 4-1/4-inch movement. As the pile moves downward, soil action between the flukes and frame forces the flukes outward until they are in the open position. In bearing, as in driving, the flukes are prevented from opening further by the brace guide pins bearing against the brace guide. In uplift, the flukes are prevented from closing by the brace guide pins seating in the notches of the brace guide slots.

The placement procedure for the Mark IV is given in Appendix A.

CHRONICLE OF DEVELOPMENT

Mark III

The predecessor to the Mark III (Figure 3) was a prototype of BUDOCKS' design concept for an umbrella pile-anchor. It was similar in appearance to the Mark III and its flukes functioned on the same mechanical principle, but were only about 30 percent as large. Another major difference was that, instead of driving the pile with the casing, the casing was first driven with a mandrel. When the desired depth was reached, the mandrel was withdrawn and the pile and follower were lowered through the casing until the flukes contacted the bottom of the temporary well formed by the casing. Then the casing was extracted, and from that point on the driving force was directed against the follower to activate opening of the flukes the same as for the Mark III.

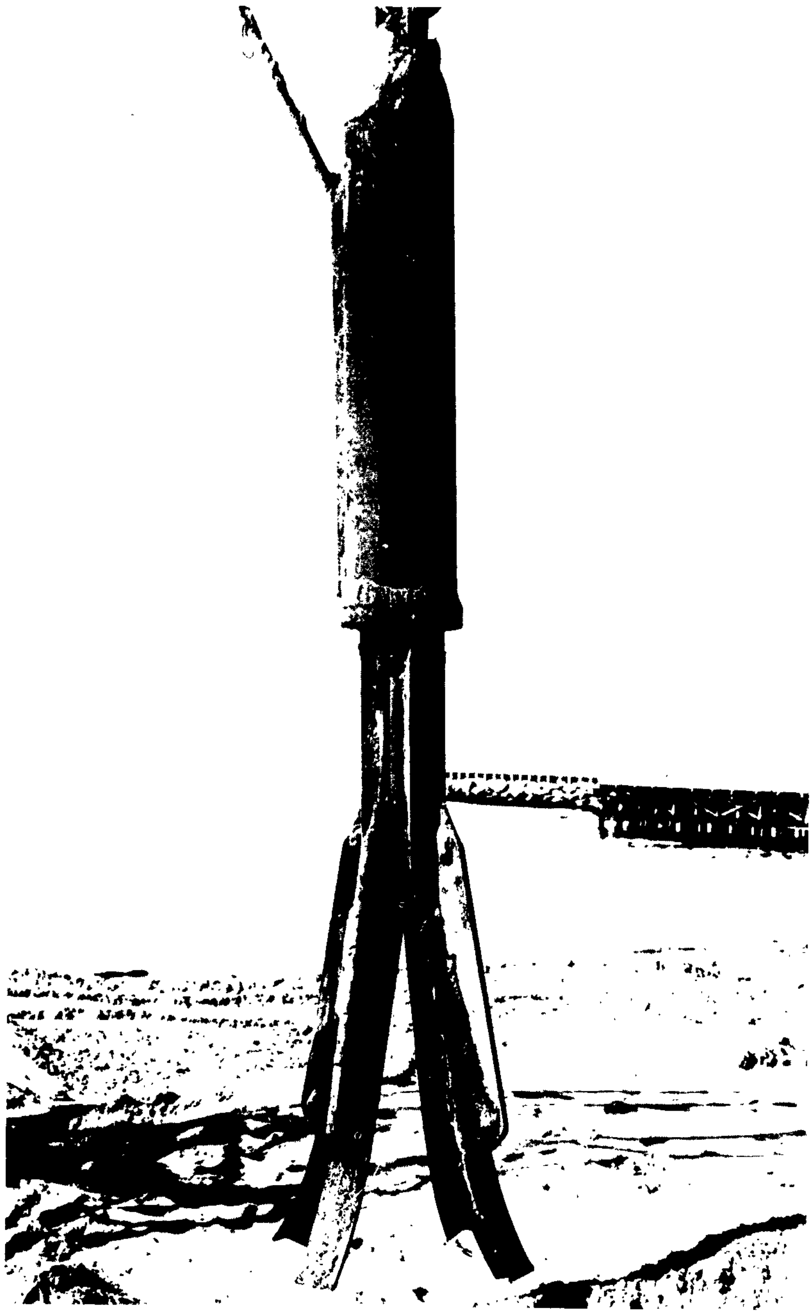


Figure 3. Predecessor to the Mark III.

During initial tests of the prototype the flukes opened outward underground and locked in position when subjected to bearing and uplift loads. Thus, it was demonstrated that development of a workable umbrella pile was feasible. The prototype's flukes were too small, however, to develop the required holding capacities at reasonable embedment depths of 18 to 20 feet below firm bottom. (Firm bottom is defined as the level to which the umbrella pile will settle under its own weight plus that of the follower(s) and hammer.) With the flukes at an embedment depth of 18 feet the prototype developed only 30 percent of the required resistance to uplift and 75 percent of the required bearing capacity.

In addition, the placement procedure was unsatisfactory for two reasons. First, when the mandrel was extracted from the casing after initial driving, soil intruded 5 to 8 feet up into the casing. This made it difficult to place the pile at the desired depth and then to extract the casing without withdrawing the pile, which tended to bind inside the casing wall. Second, the necessity of lowering the pile through the casing severely restricted the size of the flukes. Moreover, a large increase in casing diameter permitted only a slight increase in fluke size.

The Mark III was developed by revising the pro·otype design.

1. The flukes were enlarged to obtain greater holding capacity.

2. The casing was modified at its bottom end to permit insertion of the umbrella pile with larger flukes.

3. Toeplates were added to the flukes. These were shaped so that they sealed the bottom of the casing during initial driving and were positioned so that they acted to force the flukes outward during the opening operation.

4. The indicator spring and cable were devised to determine precisely when the anchor is open.

5. The fluke design was changed to lock in position at an angle of about 60 degrees from the vertical instead of 90 degrees.

The reasons for the fifth revision are explained later in the text.

Mark IV

Development of a new design to eliminate the disadvantages and restrictions imposed by the casing commenced after tests of the predecessor to the Mark III were completed. NCEL designed and fabricated a pilot model (Figure 4) that was similar in size and configuration to the later Mark IV design. It also utilized an inner and outer follower for placement, but differed from the Mark IV primarily in the shape of the individual parts and in the details of their mechanical operation. The frame was square rather than tubular and the flukes were straight rather than curved.

The pilot model failed to function because the exterior soil pressure on the flukes was greater than the generated initial opening action. This external pressure tended to keep the flukes closed. Consequently, instead of opening, the mechanism continued downward in the closed position. Two other mechanical deficiencies were noted during tests in which driving was commenced with the flukes partially open. During fluke-opening action the entire force of the hammer was directed against the fluke and bracing-arm pins as the pile was driven deeper into the ground. The excessive repeated impact forces caused cumulative damage in the pins and bracing arms, thus weakening or fracturing them. Also, the required relative movement between the inner runner and the frame for full fluke opening was too great to be practical.

Principles learned from the pilot model were applied in designing the Mark IV. The most significant improvements were:

1. The opening action was changed so that the inner follower would force the flukes straight downward, instead of outward as in the former design, exposing their tips to the surrounding soil to activate fluke opening.

2. The relationship of the individual parts was altered so that the flukes would open freely without undue stress on the pins as the entire mechanism is driven further into the ground during the opening action.

3. The relative movement between the inner and outer follower and the cross-runner and frame required for fluke unlocking and complete opening action was reduced to 4-1/2 inches.

4. The final attitude of the flukes in the open position was fixed at about 60 degrees from the vertical axis instead of 90 degrees.

Reasons for the latter change are explained later in the text. Other improvements related to refinements in construction and configuration, such as making the frame cylindrical and curving the flukes.

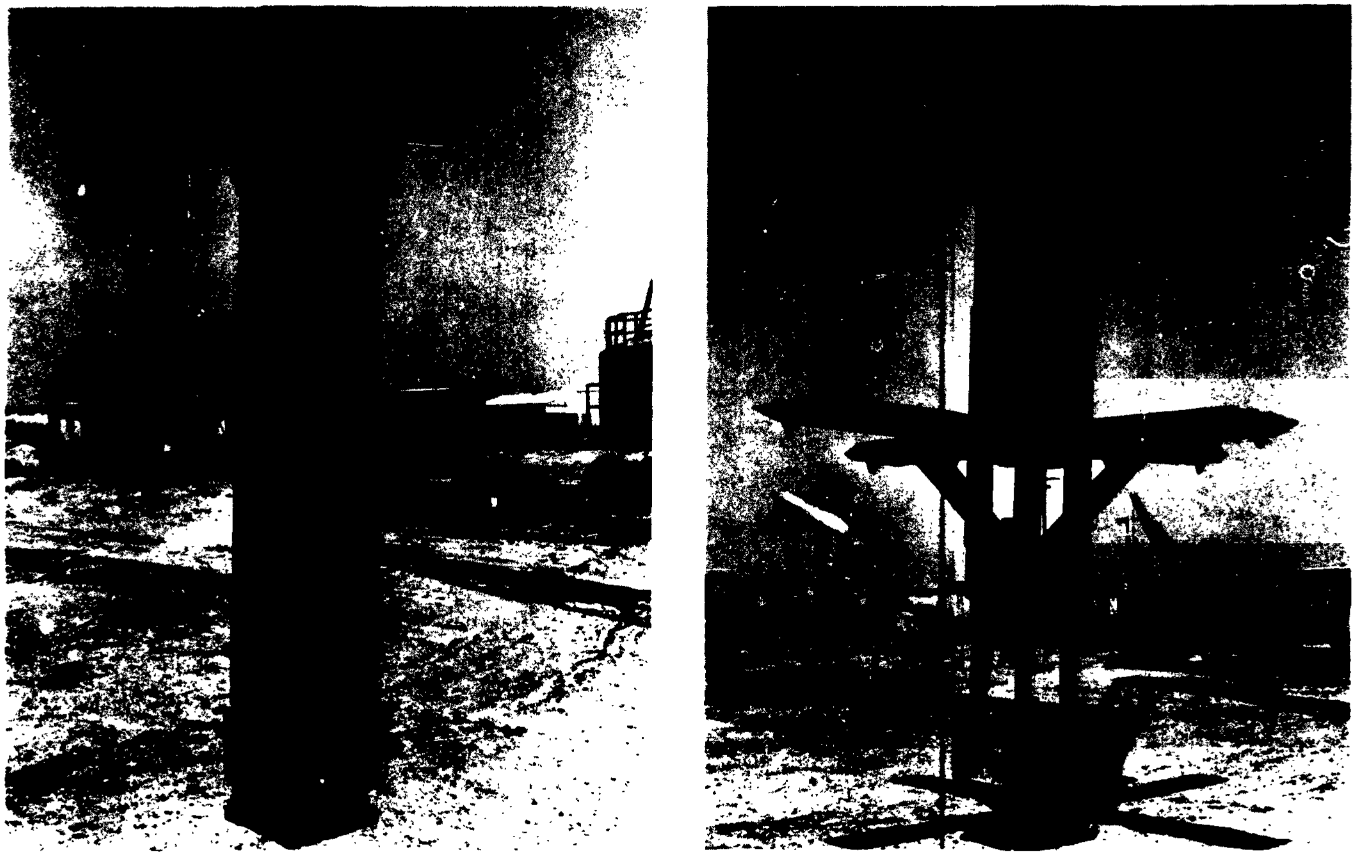


Figure 4. Predecessor to the Mark IV.

TEST PROGRAM

Tests were of two general categories. Developmental tests were necessary to perfect and evaluate the functional components of each design and the operation, handling, and placement of the entire mechanism. Uplift load tests were required to determine holding capacities. Bearing tests were not made for reasons explained in the discussion of umbrella pile capabilities. Some developmental tests provided holding-capacity data, and conversely, the load tests served to verify findings of developmental tests and to permit further refinements.

All developmental testing was done in sand at the NCEL test site. In addition, load tests were conducted in sand at NCEL and in a mud bottom (cohesive-type soil) at the San Francisco Naval Shipyard. Typical soil profiles of test-boring samples at both sites are shown in Figure 5. At NCEL the sand ranged from coarse to fine silty sand. At SFNS the bottom condition is described as blue mud interspersed with very fine gray sand; fine crushed shells were distributed uniformly throughout depth of interest.

The general test procedure at NCEL was to drive the specimen within an area 50 to 100 feet beyond the end of a 20-foot-gage railway. After placement the specimen was subjected to loads applied through a winch-pulled railcart that was attached to the umbrella pile with 180 feet of 2-3/4-inch anchor chain as shown in Figure 6. A 400,000-pound-capacity dynamometer was used to measure the magnitudes of applied loads. Vertical movement was measured by sighting on a gage that was attached to the frame and extended aboveground.

The general setup for offshore tests is illustrated in Figure 7. One offshore test utilizing pontoon barges and a YFU (Yardcraft Freight Utility) was conducted at NCEL (Figure 8) in water about 20 feet deep and in bottom sand comparable to that of the beach tests. The YFU was used as a floating base from which to drive the specimen and to maneuver the barges. After placement, the test specimen was attached to a 5 x 14-pontoon barge with 90 feet of 2-3/4-inch anchor chain. Loads were applied by a winch mounted on the 5 x 14 barge rigged to a 3 x 12 barge which was securely anchored to the beach. Vertical movement under loading was determined by sighting on a gage attached to a float that in turn was attached to the pile by cable.

The procedure for the mud-bottom tests at SFNS was similar, except that a floating-crane barge was used for driving the specimens (Figure 9). An NCEL warping tug was used for general service and for part of the pulls, as described later.

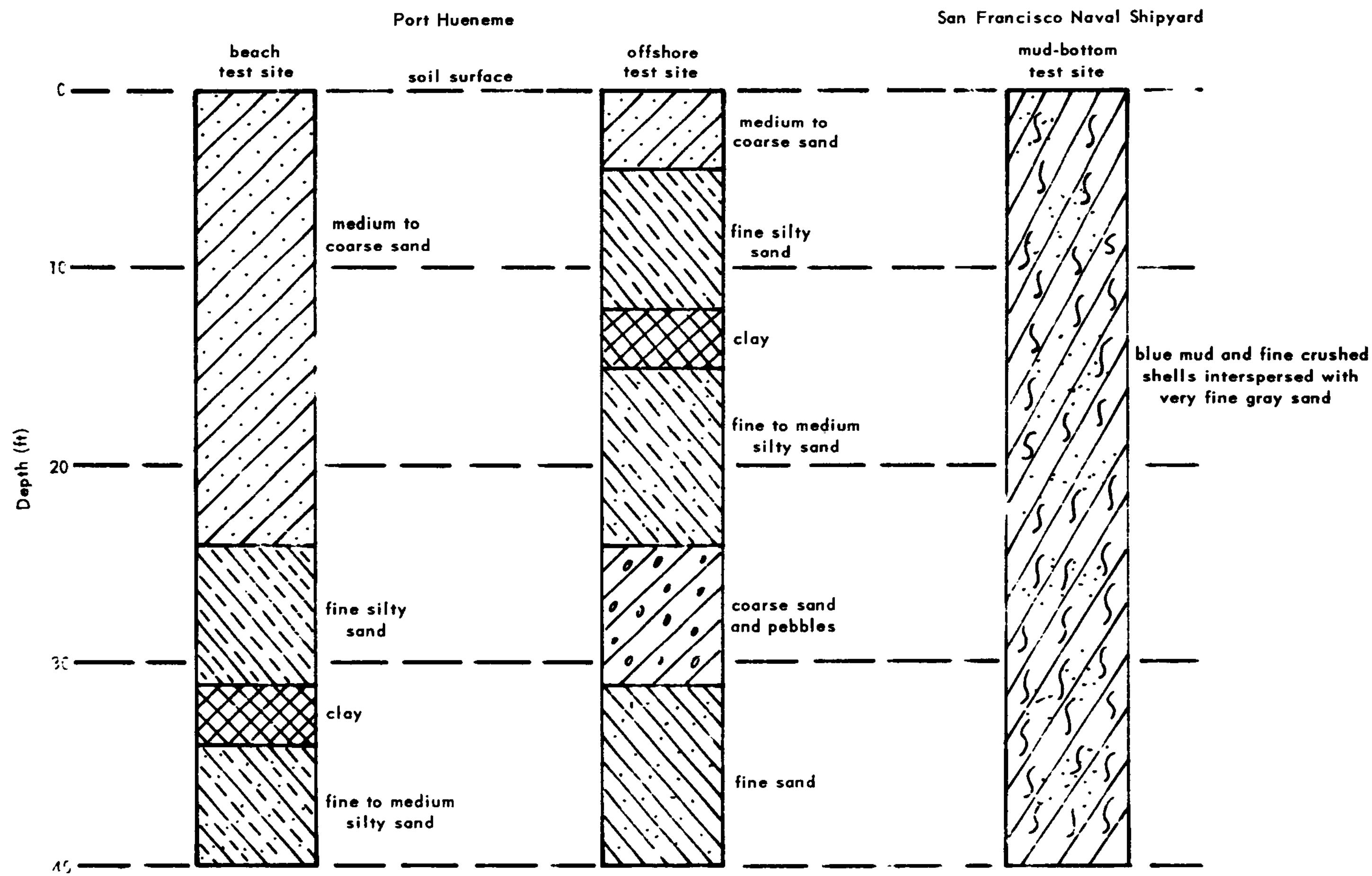
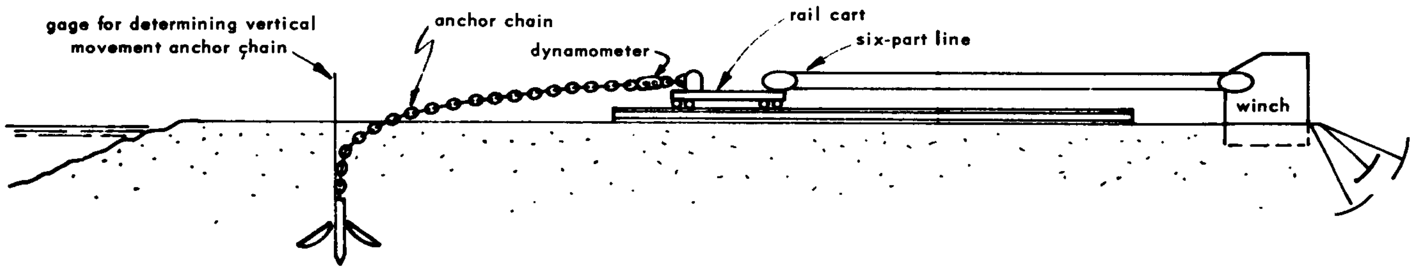


Figure 5. Typical cross sections of sand and mud test-boring samples.



(a) Schematic of loading procedure.

(b) Aerial view of loading apparatus.

Figure 6. NCEL facility for tests of umbrella piles.

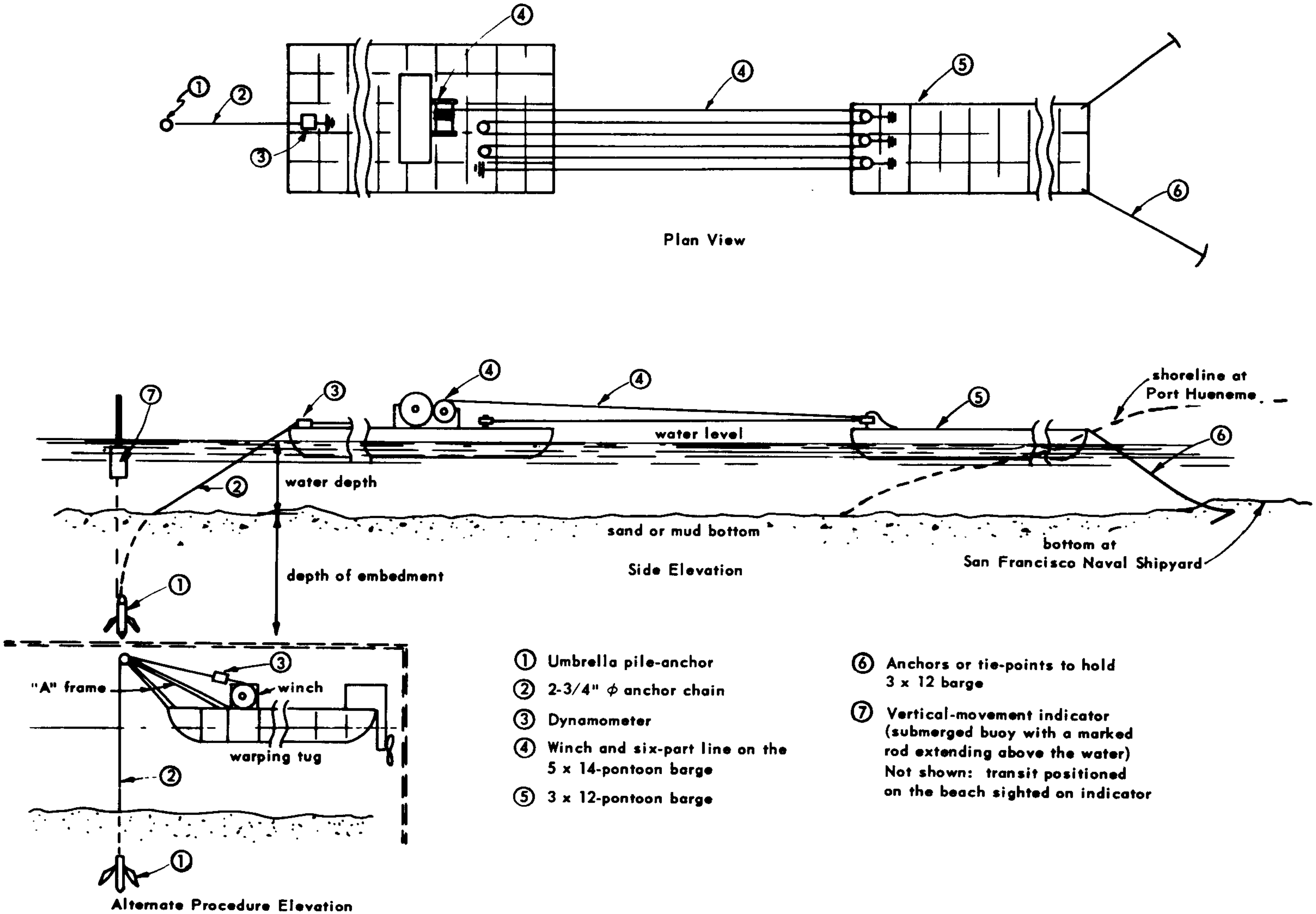


Figure 7. Apparatus used for offshore tests.

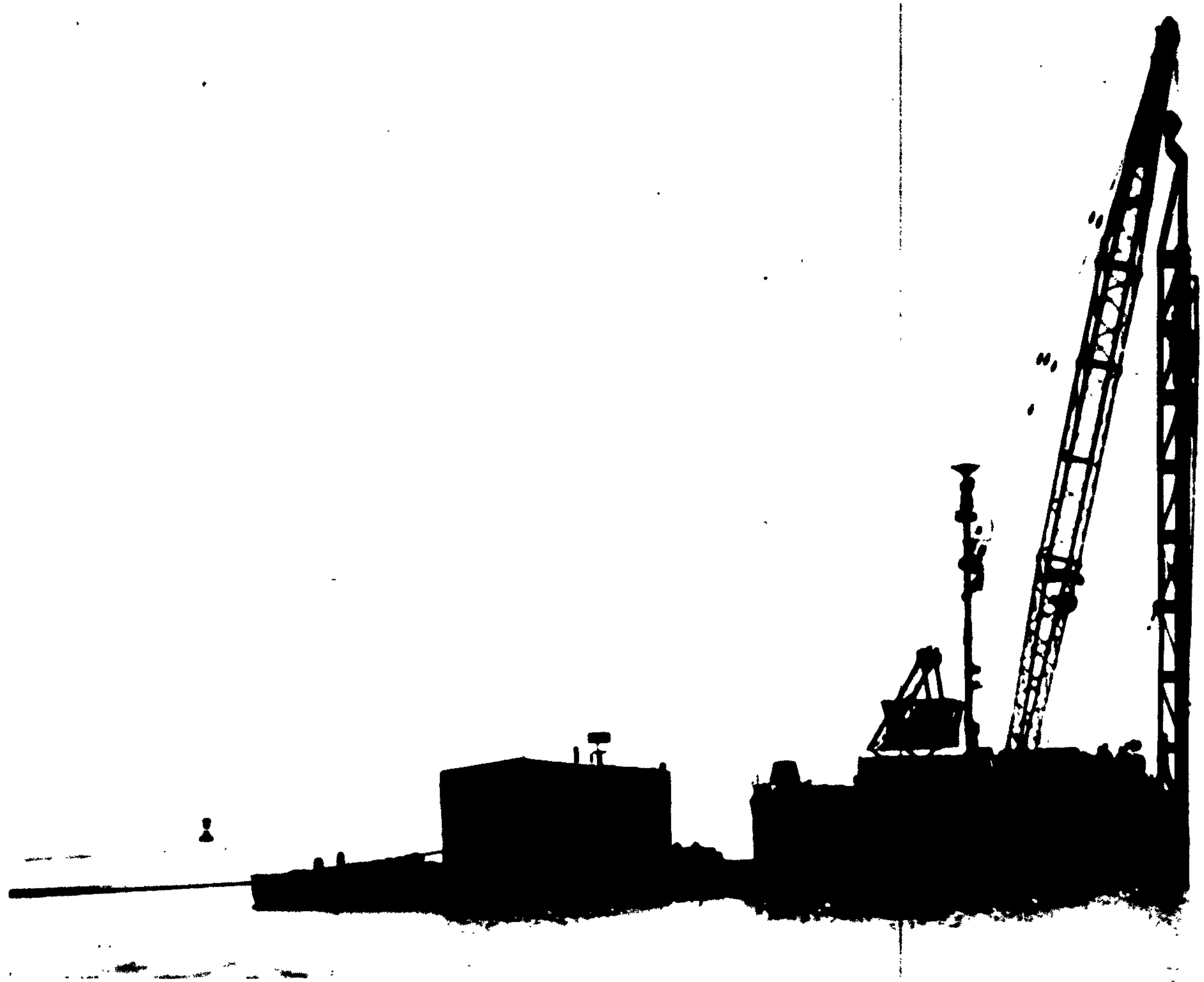


Figure 8. Driving the Mark IV offshore at Port Hueneme.

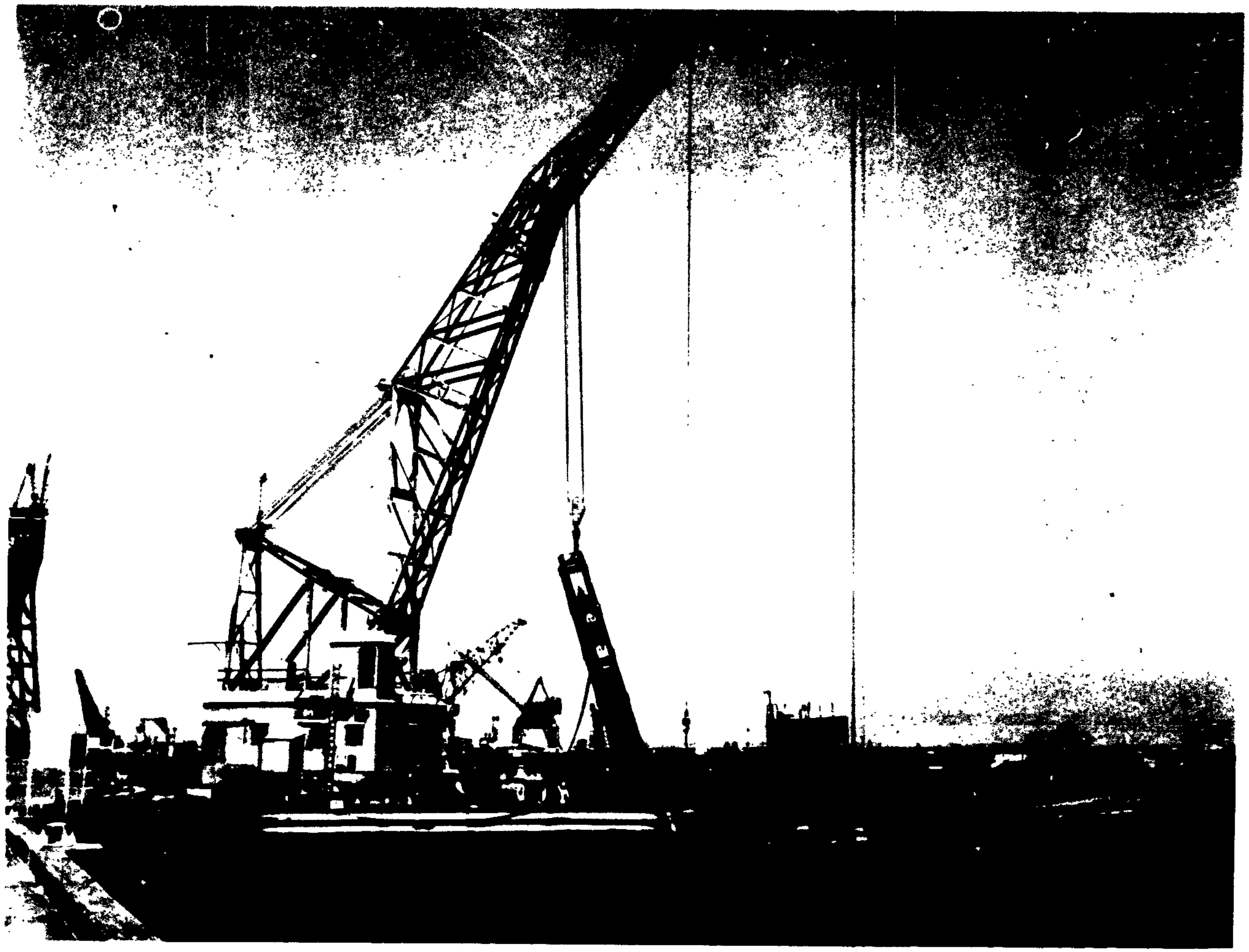


Figure 9. Preparation for driving the Mark IV at SFNS.

TESTS AND RESULTS

Mark III

After developmental testing had assured proper functioning of all parts, the Mark III was driven with a 12,000-foot-pound-capacity pile hammer for a load test in sand. (Typical driving data for the Mark III and Mark IV designs are given in Appendix B.) It was driven into the ground until the flukes were about 19 feet below firm bottom. Three successive uplift loads of 310 kips were applied; these resulted in a total vertical movement of 2-5/8 inches. The first two load applications were of short duration while the third was for 24 hours. Initial and final load readings for the sustained load were 310 and 275 kips respectively. No additional vertical movement was noted. The test results are presented in Appendix C.

There is no provision in either design for extraction. However, for test purposes the specimens were extracted by extraordinary effort. The holding power of the Mark III was so great that excavating, jetting, and applying loads in excess of 350 kips were required before it was retrieved. During extraction one of the fluke support-pad pins connecting a bracing arm to the fluke sheared at a load of about 350 kips. The Mark III otherwise was undamaged (Figure 10). The positions of the runner and the other three flukes showed that the full opening had been achieved.

Mark IV

After developmental tests indicated satisfactory operation of the Mark IV design, four load tests were conducted, two in sand at NCEL and two in mud at SFNS. One of the sand tests was at the beach site; the other, offshore in water about 20 feet deep. Both mud tests at SFNS were in water ranging from 28 to 35 feet deep.

A 15,000-foot-pound hammer was used for driving the Mark IV specimens. In the beach test, the Mark IV was driven until the flukes were about 18 feet below firm bottom. The total depth was about 20-1/2 feet. One uplift load application of 300 kips was made that resulted in a vertical movement of 3/4 inch. Comparison of data with that obtained in previous developmental tests indicated capabilities comparable to or greater than that of the Mark III, so repeated-load and sustained-load tests were not conducted.

At the conclusion of the test the Mark IV was extracted in the same manner as the Mark III. Similar extraction difficulties were encountered, but the Mark IV showed no sign of damage (Figure 11). The flukes were locked open in the intermediate position.

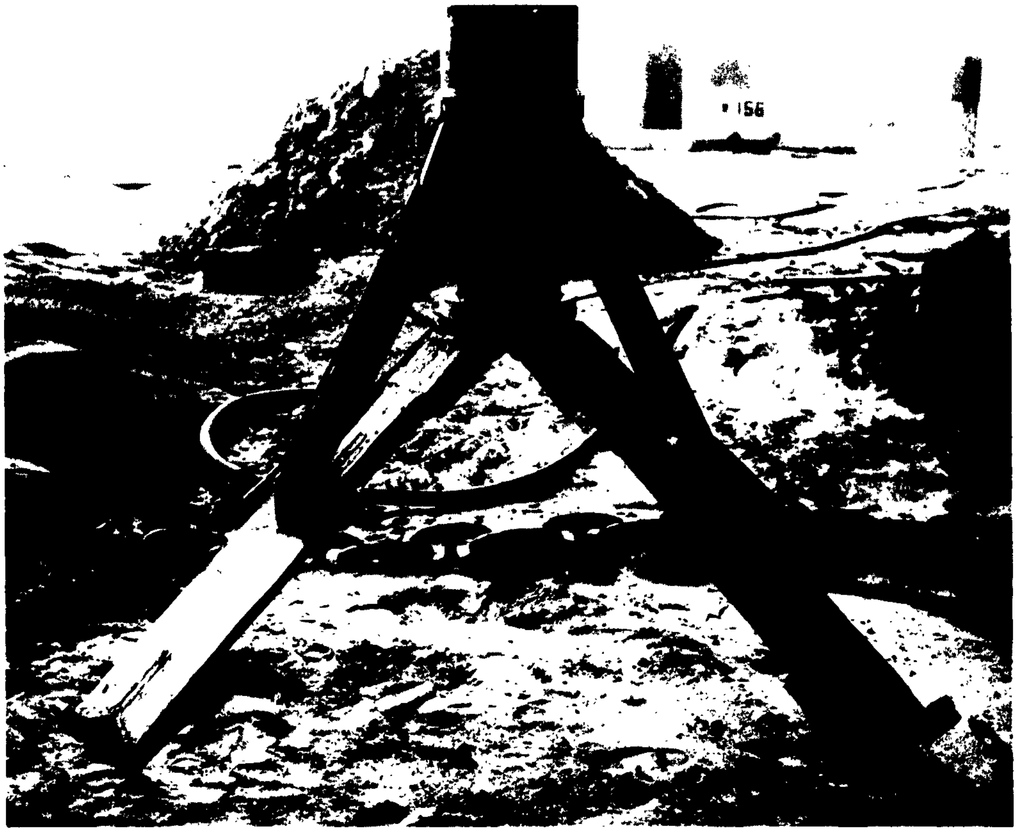


Figure 10. Mark III after test in sand.

Figure 11. Mark IV after test in sand.

High driving resistance was encountered in the offshore test, and jetting with air and water was used to facilitate placement. Driving was discontinued when the flukes were about 17 feet below firm bottom. Repeated and sustained loads were applied as shown in Appendix C. A vertical movement of 2-3/8 inches was measured on the first load application of 306 kips. Subsequent loads as high as 353 kips produced a total vertical movement of 7 inches. At the conclusion of testing, the specimen was extracted by employing the flotation force of the warping tug and by jetting. No discernible damage had occurred to the specimen. One of the flukes was locked in the lowest position, two in the intermediate position, and one in the fully open position.

Two Mark IV specimens were used in the mud-bottom tests at SFNS. Exploratory tests were made in which it was determined that the holding power could be increased and opening in mud could be facilitated by widening the tips of the flukes. Consequently, extensions were added to the flukes and later incorporated into the final Mark IV design for use in mud bottoms.

In placing the first specimen it settled 13 feet to establish the firm-bottom datum. The specimen then was driven until the flukes were about 13 feet below firm bottom. At this depth the driving limit of the equipment on hand was reached; water topped the followers. Though full fluke opening was not indicated, driving was suspended and the second specimen was placed. The second specimen settled 15 feet to firm bottom, and the opening action was commenced earlier to permit a greater fluke opening. Driving of the second specimen was also discontinued when the flukes were about 13 feet below firm bottom.

Uplift test loads were applied to each specimen in turn. At the conclusion of these load applications, direct uplift loads were applied using the flotation force of the warping tug. Both of the loading methods are graphically illustrated in Figure 7. Figure 12 shows the warping tug applying a vertical load to one Mark IV specimen. Results of these tests are given in Appendix C.

The first mud-bottom specimen achieved a maximum load of about 135 kips at 7 inches of vertical displacement. Initial movement occurred at a load of about 93 kips. When extracted, three of the flukes were in the lowest locked position and one was in the intermediate locked position. The specimen had suffered no damage.

When testing the second mud-bottom specimen, the cable used to measure vertical displacement malfunctioned and vertical movements were not obtained. Instead, loading proceeded with horizontal movements of the winch barge being recorded to determine how firm the Mark IV was holding. After allowing for initial movement of the winch barge while the anchor chain assumed its hold configuration, little additional barge creep was detected until a load of 168 kips was achieved. In a repeat test on the second specimen, uplift loads were applied with the warping tug and vertical-movement measurements were taken by sighting on the chain. A load of about 149 kips was achieved with a corresponding 4-3/4 inches of vertical movement. The data presented in Appendix C indicates more completely the performance of this specimen under continuous loading. The loading procedure described was continued until the specimen was fully extracted. No damage had occurred. Two of the flukes were fully open (Figure 13) and two were locked in the intermediate position.

DISCUSSION OF TESTS AND RESULTS

Additional comments may explain certain test results and indicate their significance. It was reported that the initial and final readings for the Mark III under a sustained 24-hour load were 310 and 275 kips respectively, with no further vertical movement noted. The drop-off in load was attributed to adjustments in position of the chain as it embedded further in the sand and to mechanical adjustments in the loading apparatus. When the Mark III specimen was being extracted after this test loading, one of the fluke support-pad pins sheared in two. This happened primarily because a large component of the extraction load was transverse to the longitudinal axis of the umbrella pile, thus causing an unequal amount of the loading to be distributed to one fluke. This condition developed because the chain attached to the top of the specimen cut into the sand during the extraction process and assumed an attitude other than vertical at the connection point. In normal application the chain will be vertical at the connection so that the load is distributed evenly to all four flukes.

The difference in the performances of the two Mark IV specimens in mud is attributed primarily to the fact that three of the flukes were open only to the lowest lock position. Holding capacities obtained with both specimens are considered good for the mud-soil condition, though even greater capacities may have resulted if the specimens in mud could have been placed deeper below firm bottom.

Unequal fluke-opening action was reported for the Mark IV in the tests. In the offshore test at Port Hueneme this may be explained by the fact that jetting was employed. In the other tests, soil conditions probably were not completely uniform throughout the travel distance. The prospect of unequal openings was anticipated and provided for in the design. The intermediate fluke position is approximately equivalent to full opening. It is considered advantageous to provide flexibility in this respect because the possibility exists of individual flukes encountering variable resistance to driving due to jetting operations, foreign objects, or unequal soil conditions.

FUNCTIONING OF UMBRELLA PILES IN SOIL

The soil constitutes an adverse environment for the functioning of umbrella piles. Failure to fully comprehend the manner of soil action as it affects various functions may lead to unworkable designs.

To appreciate the importance of and reasons for particular features of the Mark III and Mark IV designs, it is necessary to understand the character of resistance of the soil medium. The soil acts as an extremely viscous nonresilient mass that strongly resists every increment of penetration and mechanical movement by the umbrella pile. When movement is achieved by force of the hammer, the soil firmly holds the mechanism in its new location. During fluke-opening action, the soil oozes into voids and behind flukes, suspending all working parts solidly in place during each time interval between blows of the hammer. Thus, it is imperative that all working parts be configured so they function against the least line of resistance attainable and constructed so they are not damaged by impact forces during placement.

Figure 12. Uplift load being applied to Mark IV embedded in mud bottom.

Figure 13. Mark IV after test in mud bottom.

The pins, pin connections, flukes, and bracing arms are of most concern because they compose the parts that must function against extreme conditions without sustaining damage. In both designs, impact forces are not transmitted directly through the pins during the initial driving action. When fluke opening is activated the fluke heel-pad pins receive the greatest impacts, but each pin transmits the impulses only to its respective fluke. Initially, each fluke encounters comparatively minor resistance because it is moving downward endwise into the soil. Then, as the fluke opens outward, the heel portion begins to present a greater bearing area against the soil, causing more resistance to movement and greater stresses in the fluke heel-pad pin. To counteract the increased resistance, the fluke heel area was reduced as much as practical. (For cohesive-type bottoms, where resistance is not as severe, the heel area is not reduced in the Mark IV design, and its fluke tips are provided with extensions to obtain additional holding power.) Also, the final attitude of each fluke in the fully open position was fixed at about 60 degrees from the vertical axis instead of 90 degrees as in the pioneer designs because approximately 2-1/2 feet of additional penetration is required to achieve the 90-degree position. This penetration would have to be done against excessive fluke heel-bearing resistance, as illustrated in Figure 14. This resistance is proportional to the horizontal projection of the fluke area. The effective fluke area activated to resist applied loads is reduced less than 15 percent at the 60-degree position as compared to the 90-degree position.

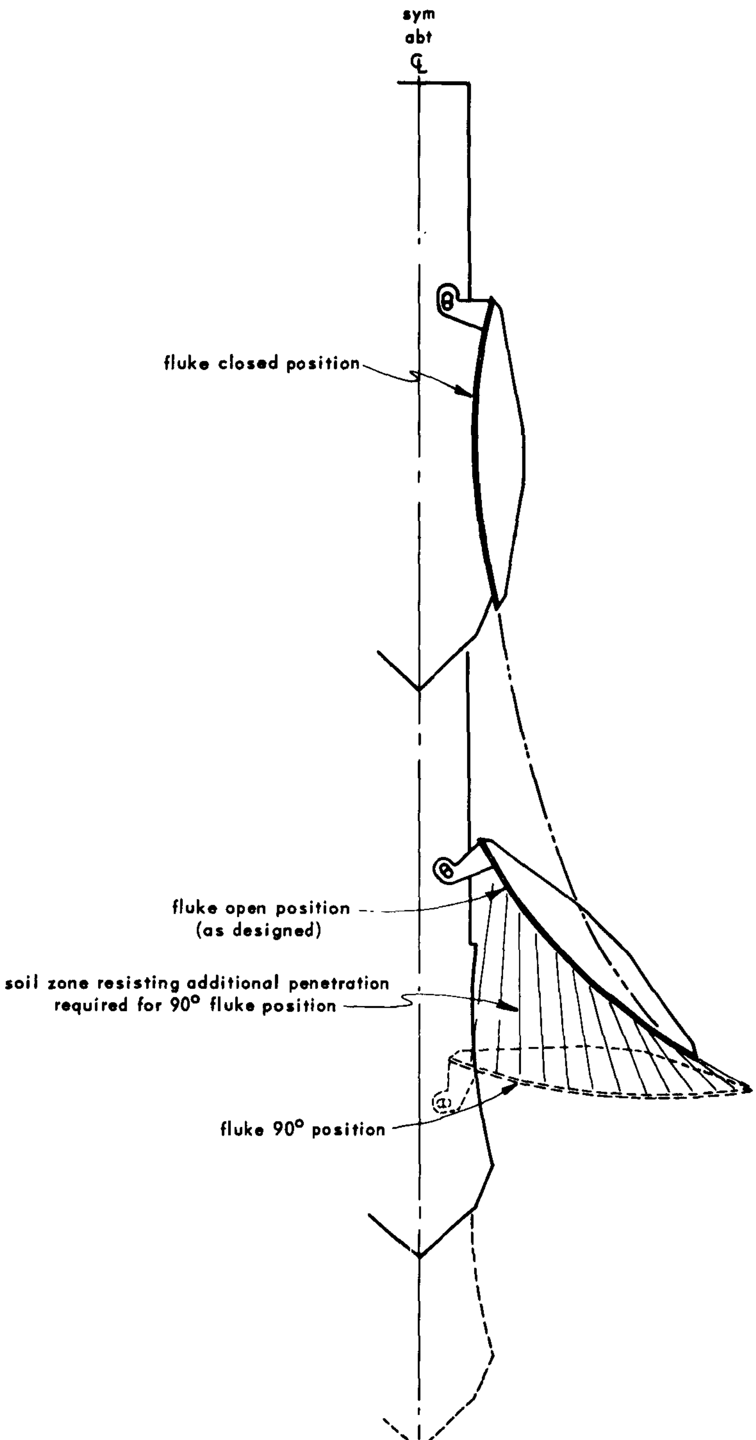


Figure 14. Sketch illustrating soil zone resisting additional penetration required for 90-degree fluke position.

The bracing arms and their pins and connections of both the Mark III and Mark IV are designed so they do not receive direct hammer impacts during placement. Examination of Figures 1 and 2 will show that the bracing arms of both designs "float" outward and upward relative to the body frame without meeting high resistance because they move edgewise through the soil.

In the Mark IV design, unlocking and activating the fluke-opening action was a difficult problem. Whereas the fluke tips of the Mark III are exposed and poised to perform their duty when the casing is removed, the fluke tips of the Mark IV have to be shielded during initial driving to prevent damage and premature opening. Once the desired opening depth was reached, the pilot model failed to function because the external soil pressure was too great to permit forcing the flukes open. The curvature of the flukes in the Mark IV design served two purposes; it permitted a quick exposure of the fluke tip for a small amount of straight downward movement in line with the hammer's force, and it presented a configuration conductive to opening action. A bonus benefit was that it allowed the fluke to follow approximately the least line of resistance throughout most of the opening action.

Once the umbrella piles are open and in service the same characteristic behavior of the soil that imposes severe hindrances to mechanical functions serves to insure that they will stay open. In the Mark III design the skin friction and the clogging action of the soil on all parts are strong factors acting to prevent closure, while in the Mark IV the soil suspends the bracing arm in position so that the bracing-arm guide pin moves into the notch of the brace guide slot when uplift loads are applied.

UMBRELLA PILE CAPABILITIES

The test program demonstrated that the Mark III and Mark IV designs are capable of functioning in sand and of developing the required holding capacity against an uplift of 300 kips when embedded at depths not more than 20 feet below firm bottom, as specified in the criteria. Bearing tests were not made since normally the maximum bearing capacity of the soil is equal to or greater than its capacity to resist uplift. Also, the designs are structurally adequate to resist required bearing and uplift loads without failure. Since the testing equipment was limited to specified ultimate capacities, the tests in sand did not establish the maximum capacities that may be attainable if either design were embedded at depths greater than 20 feet and/or in firmer soil. Should greater capacities be desired, these two factors could be investigated.

The mud-bottom tests showed that the Mark IV is capable of functioning in this medium and indicated the design's approximate holding capabilities and performance characteristics for the type of soil and the embedment depth described. The same considerations concerning effects of depth and soil properties mentioned for sand also apply for mud. The Mark III was not tested in mud because extra equipment and a new casing would be required for the water depth encountered. The additional investment was considered not necessary as the experience gained from the overall test programs indicated that the Mark III would function satisfactorily in this medium.

RELATIVE ADVANTAGES OF THE MARK III AND MARK IV DESIGNS

The Mark III and Mark IV designs each have features that offer advantages for specific situations and uses. The primary advantages of the Mark III are that it is smaller and lighter and offers less resistance to driving, both during the initial phase and while opening. Also, it is less complicated to fabricate. For moderate water depths (10 to 20 feet) no major problems should be encountered in removing the casing after initial driving. Its main disadvantage is that the placement procedure is more complicated due to the use of the casing. At greater depths of water, lifting the casing completely free of the follower would be difficult and impractical. A secondary disadvantage is that it is largely constructed of special steel alloys to withstand the high stresses imposed on its parts.

Major advantages of the Mark IV are that it may be placed directly without requiring a casing, and it is more versatile in that its flukes are more adaptable for use in different types of soil. In addition, its ultimate capacity at any depth below firm bottom in any type of soil is greater than that of the Mark III in comparable circumstances because of the larger fluke area brought to bear on the soil. Its major disadvantage is its high resistance to driving, which should be accomplished with a hammer rated at 15,000 to 20,000 foot-pounds.

Load tests of the Mark IV indicated that all four flukes may not open evenly or at the same rate. Regardless of final positions of the individual flukes, they are locked into the existing position by the bracing arms. This flexibility is not possible in the Mark III design because movement of the bracing arms is coordinated by the runner.

USES, LIMITATIONS, AND FUTURE POTENTIALS

Development of the Mark III and Mark IV provides a type of pile-anchor that can hold free-swinging or spread-type moorings in locations where limited bottom conditions prevent the use of stake piles or where space limitations, safety conditions, or other installations prohibit dragging of anchors. Savings in tackle and gear required in standard single-riser moorings can be realized. Also, the Mark III and Mark IV can be used to support pipe batter piles in "A" frame dolphins in soils that would not provide sufficient support for conventional piles. In addition to these uses, the umbrella piles possess potential advantages for use in other engineering constructions not necessarily related to harbors or moorings, such as tiedowns and supports for towers and foundations for bridge footings or as anchorages for abutments.

The Mark III and Mark IV were designed to operate in homogeneous soils. Soil partially or wholly cemented (i.e., individual soil particles bonded together simulating rocklike substance) or containing boulders or other obstructions would seriously hamper the functioning of the umbrella piles or possibly damage them beyond use.

Successful development of the two designs offers encouraging prospects for further refinements and adaptations. It is estimated that the Mark IV, with suitable followers, may be placed in considerably greater water depths than 30 feet, perhaps as deep as 100 or even 200 feet. The prospect of accomplishing deeper placements with the Mark IV appears worthy of investigation in connection with such deep-ocean problems as locating and maintaining positions of emplacements, developing driving mechanisms to operate in deep water, and developing techniques for manipulating and controlling the mechanisms. Another possible refinement for the Mark IV would be to devise a trigger device that would automatically unlock the flukes and activate their opening.

Both the Mark III and Mark IV designs are adaptable to larger or smaller scales, thus suggesting the design of a family of umbrella pile sizes that would be suitable for a wide range of requirements. The principles of operation would be the same for all sizes. Since relatively large changes in the diameter of the Mark III's casing would entail small changes in fluke size, the Mark IV appears to be more adaptable to a family of sizes.

CONCLUSIONS

1. The Mark III and Mark IV designs are workable umbrella pile-anchors suitable for use in uncemented homogeneous soils that do not contain boulders or other obstructions.

2. Each design is capable of developing required capacities of 220 kips in bearing and 300 kips in uplift when embedded in sand at depths less than 20 feet.

3. The Mark IV is capable of developing holding capacities of better than 100 kips in mud-bottom conditions comparable to those reported for SFNS.

ACKNOWLEDGMENT

The courtesy, cooperation, and assistance received from San Francisco Naval Shipyard personnel is gratefully acknowledged. Their efforts contributed in large measure to maintaining the rigid time schedule established for the mud test program, despite unforeseen difficulties.

Appendix A

PROCEDURES AND EQUIPMENT FOR PLACEMENT OF UMBRELLA PILES

PROCEDURE FOR PLACEMENT OF MARK III

1. Attach a length of chain to the connecting link of the runner. The chain must be long enough to extend through the follower by at least five links.

2. Pass the chain through the follower until the frame of the pile seats against the bell end of the follower. The flukes should be tied during this phase of handling to prevent them from opening prematurely.

3. Insert the follower and pile-anchor assembly into the casing until the fluke toeplates are seated against the bottom end of the casing. Make sure the chain slots on the casing and follower are aligned to match.

4. Put the chain into the casing and follower slots, leaving enough slack to permit the inner assembly to drop 1 to 2 feet, and lift the complete assembly into driving position by means of the casing padeyes. The toeplates should again seat against the casing when lowered into driving position on the harbor bottom or ground surface.

5. Attach a cable or other line to the chain and commence driving. The driving head should bear evenly against the casing and follower.

6. Drive to a depth about 7 feet short of the depth desired for flukes in the open position.

7. Drive on the inner follower within limits of the slack chain to free the inner assembly from the casing.

8. Lift the chain out of the follower slots and hold. Extract the casing.

9. After the casing is extracted, place the chain in its slot and commence driving on the follower. Continue until the indicator cable shows that the anchor is open.

10. Lift the chain out of the slot and hold while extracting the follower.

11. After the follower is removed, attach the chain to the mooring apparatus for placement in service.

For application as a bearing pile, steps succeeding No. 9 are:

10a. Lift the chain out of the slot and hold taut. Fill the follower and frame with concrete by means of a tremie.

11a. After the concrete has hardened, the follower becomes an integral part of the pile and the entire assemblage is placed in service for bearing or resistance to uplift.

PROCEDURE FOR PLACEMENT OF THE MARK IV

1. Attach a length of 2-3/4-inch anchor chain to the pile, making sure it is long enough to reach through the followers with several links to spare.

2. Place the chain in the follower slots and insert the follower lockpin.

3. Attach the lock cables and indicator cables.

4. Lift the assembly and position to drive.

5. Commence driving, using a hammer head that directs blows against the outer follower only.

6. Cease driving when the depth at which opening action is to commence is reached.

7. Release the locking cables and remove the follower lockpin.

8. Recommence driving, using an adapter hammer head that initially directs blows against the inner follower for 4-1/4-inches and thereafter against both followers until driving is completed.

9. Cease driving when the anchor is open. Pick up the chain, attach a cable or other line to the chain, and let the chain fall down the inner follower.

10. Extract both followers and place the pile in service by means of the chain.

Alternate Step 10 when the Mark IV is to be used as a bearing pile:

10a. Remove the inner follower, put strain on the chain, fill the outer follower with concrete by means of a tremie, and place the pile in service when the concrete has hardened.

EQUIPMENT REQUIRED FOR PLACEMENT OF MARK III AND MARK IV

Basic equipment required for lifting and driving the umbrella piles is the same as for conventional piles. Additional equipment is needed for assembling the casing and followers and removing them after driving. The following check list with appropriate comments is provided as a guide. Since conditions vary at different construction sites, specific quantities and capabilities of equipment items should be determined for each placement job.

Pile Hammer

12,000 ft-lb capacity or greater for Mark III
15,000 ft-lb capacity or greater for Mark IV

Pile Hammer Accessories

Compressor and hoses (if air hammer)
Diesel fuel (if diesel hammer)
Leads to hold hammer and piles in driving alignment
Apparatus capable of holding leads, hammer, and umbrella pile assembly; e.g., a crane, derrick, or barge

Crane

Must be capable of lifting complete assembly of casing, followers, and umbrella pile
May be used to accomplish assembly of followers and casing

Anchor Chain

Length dependent upon follower lengths

Anchor-Chain Connecting Links

Minimum of two for each umbrella pile being placed

Wire-Rope Slings

Various lengths 5/8 to 1 inch in diameter for handling and lifting assembly

Small Chain

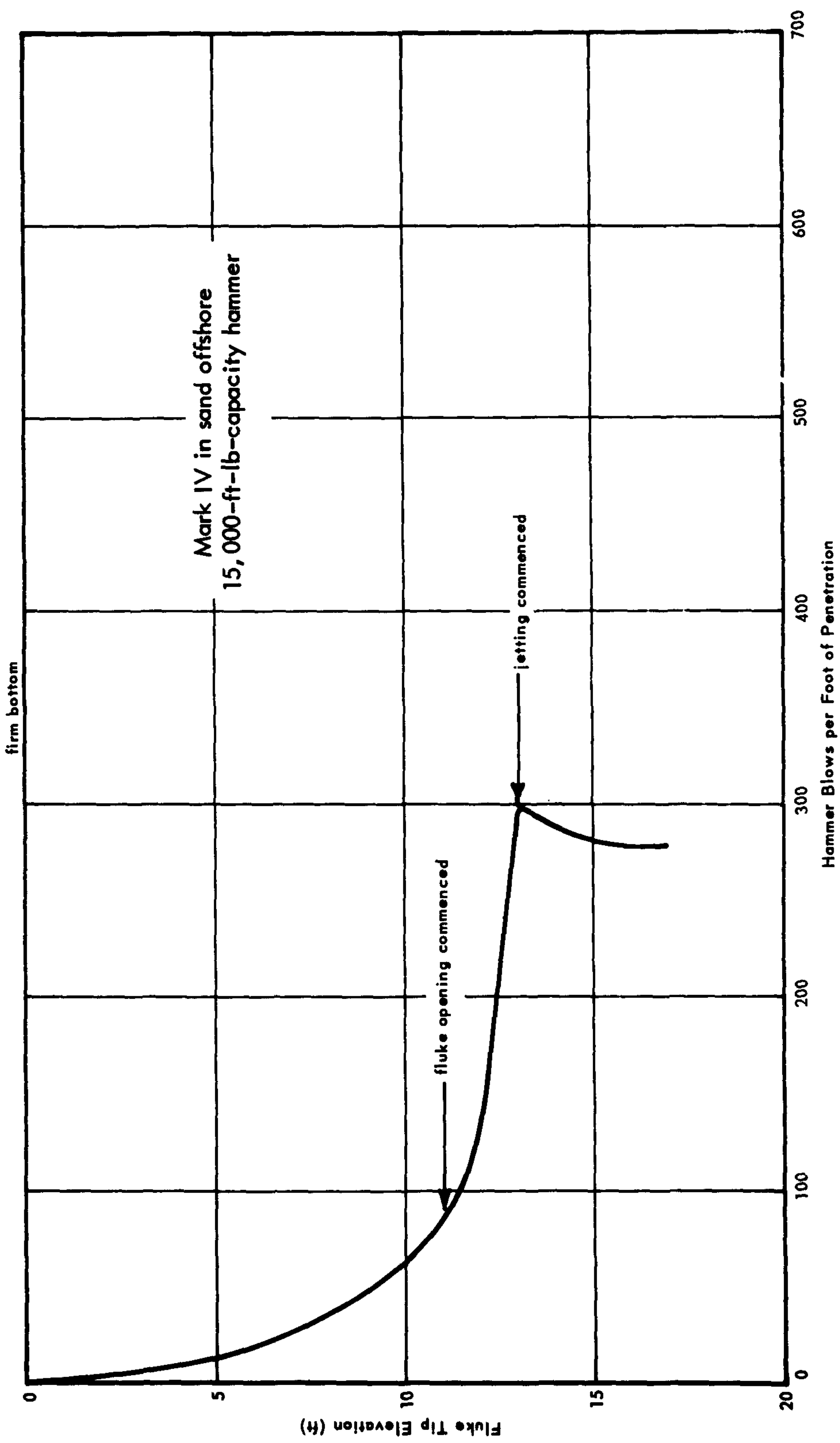
Quantity of 3/4-inch chain for holding assembly in leads

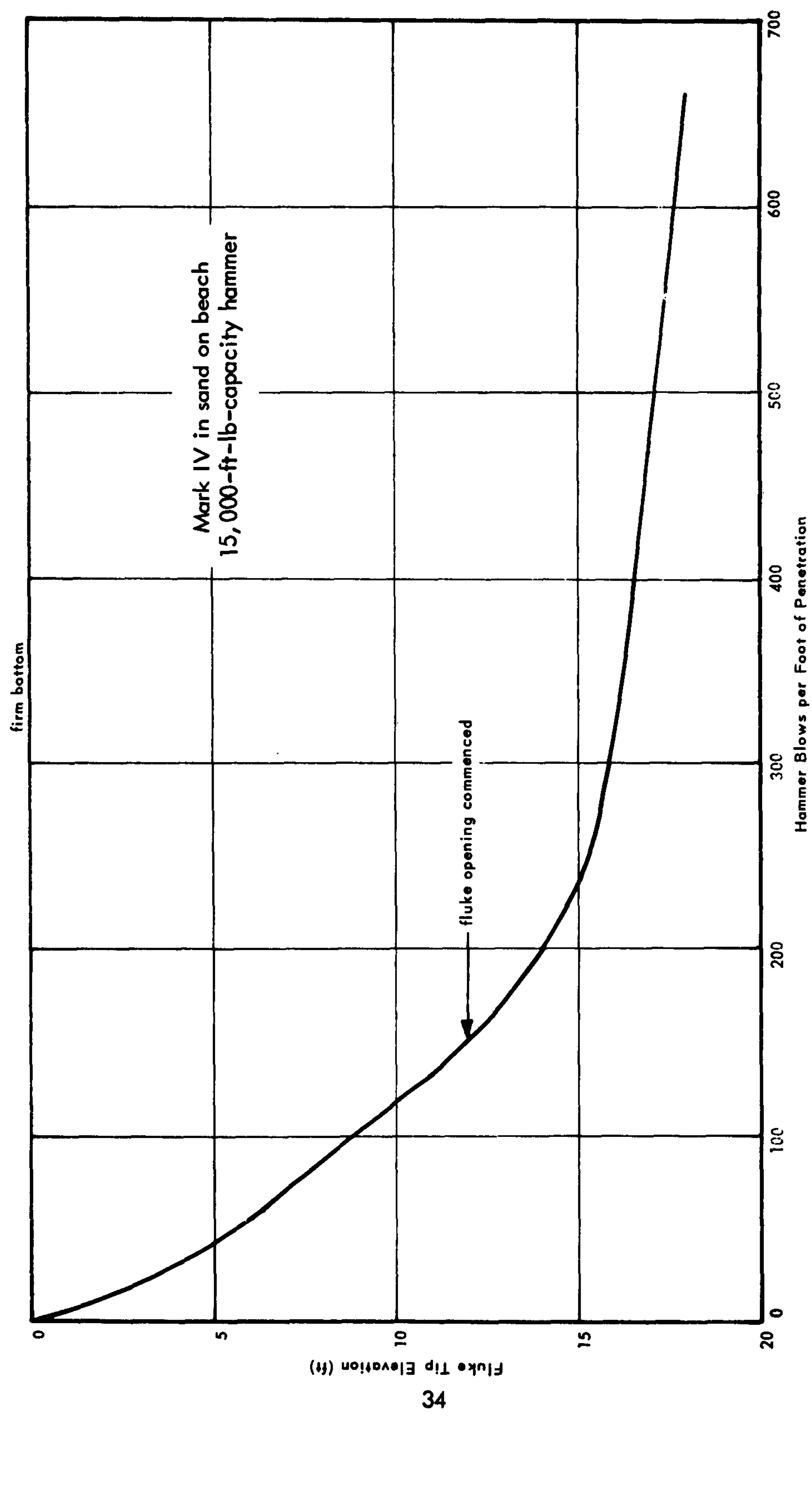
Supplementary Items for Emergency Use

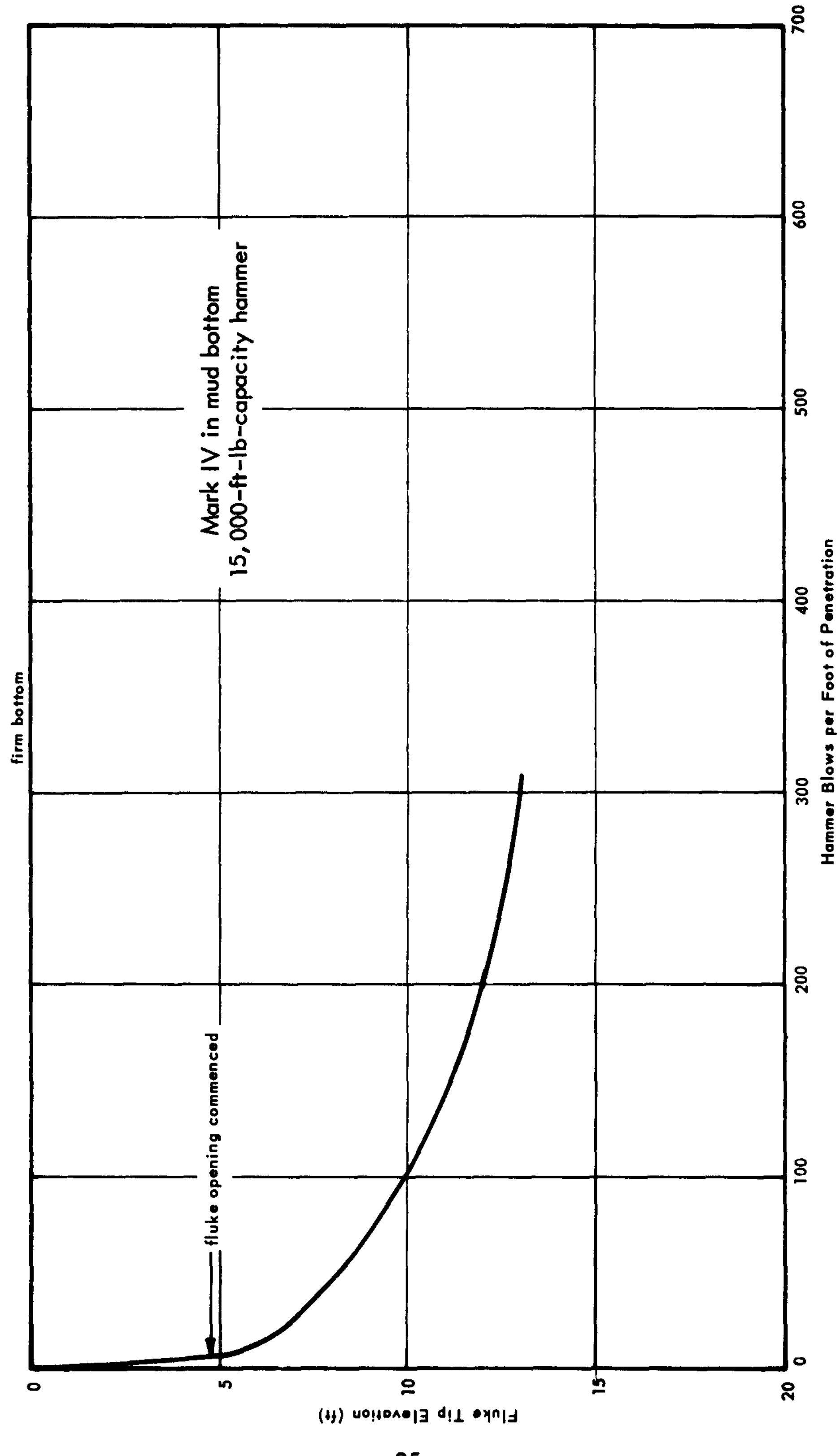
- Cutting torch
- Pump plus jetting pipe and hose for driving complete umbrella pile assembly and/or extracting casing and followers if necessary

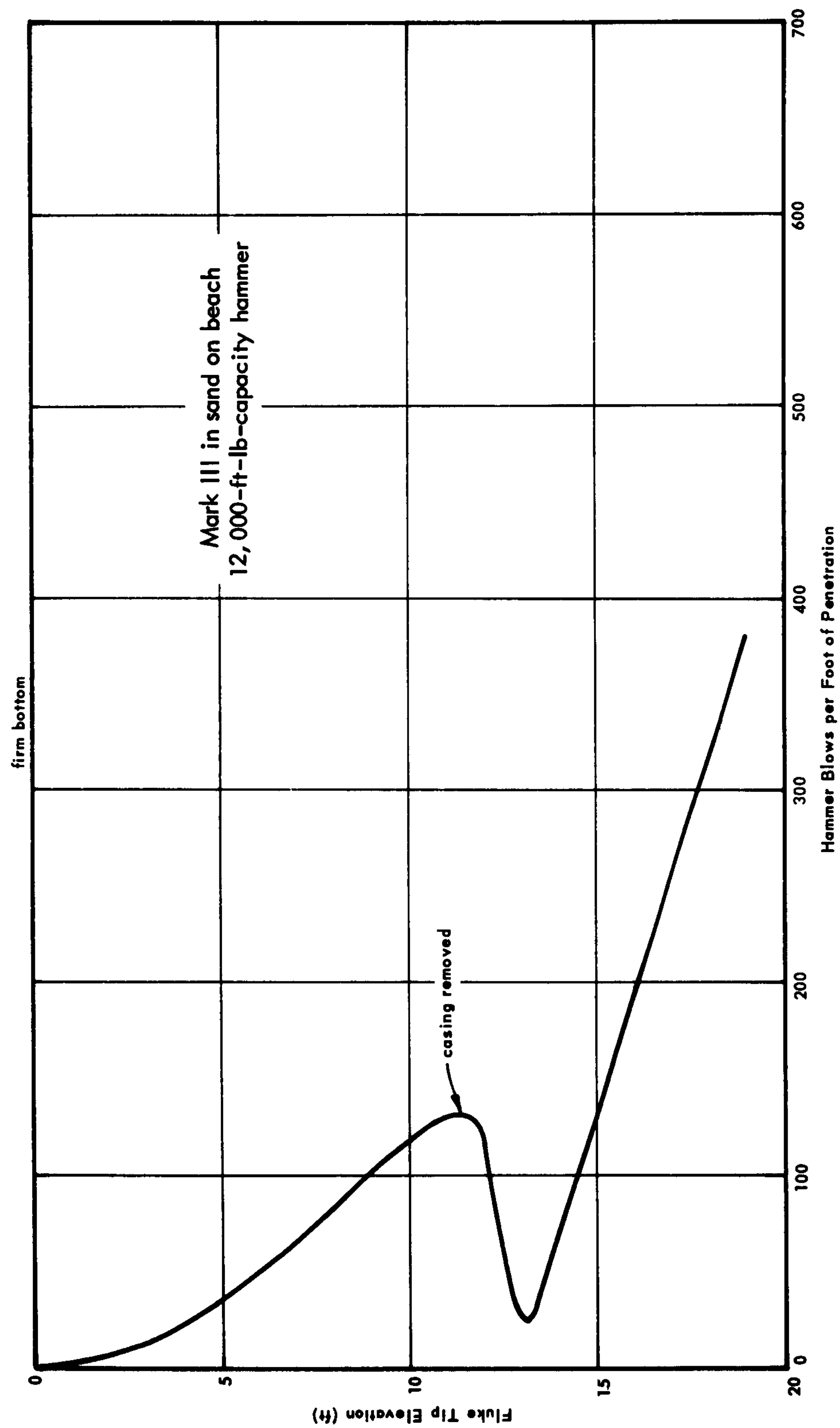
Appendix B

TYPICAL DRIVING DATA CURVES


Mark IV in sand offshore
15, 000-ft-lb-capacity hammer
firm bottom
jetting commenced
fluke opening commenced
Hammer Blows per Foot of Penetration
0
100
200
300
400
500
600
700
Fluke Tip Elevation (ft)
0
5
10
15
20


Mark IV in sand on beach
15,000-ft-lb-capacity hammer
firm bottom
fluke opening commenced
Fluke Tip Elevation (ft)
0
5
10
15
20
Hammer Blows per Foot of Penetration
0
100
200
300
400
500
600
700


Mark IV in mud bottom
15,000-ft-lb-capacity hammer
firm bottom
fluke opening commenced
Hammer Blows per Foot of Penetration
0
100
200
300
400
500
600
700
Fluke Tip Elevation (ft)
0
5
10
15
20



Mark III in sand on beach
12,000-ft-lb-capacity hammer
firm bottom
casing removed
Hammer Blows per Foot of Penetration
Fluke Tip Elevation (ft)
0
100
200
300
400
500
600
700
0
5
10
15
20

Appendix C

OUTLINE AND RESULTS OF LOAD TESTS

Test Description	Load Application Number	Load (kips)	Accum. Vert. Movement (in.)	Remarks
Mark III in sand on beach at Port Hueneme. Specimen 19 feet below firm bottom.	1	0	0	
		100	3/8	
		200	1	
		310	1-3/8	
	2	0	1-3/8	
		100	1-5/8	
		200	1-3/4	
		310	2	
	3	0	2	
		100	2-1/6	
		200	2-3/8	
		310	2-5/8	Commence 24-hr load period.
		275	2-5/8	End 24-hr load period.
Mark IV on beach at Port Hueneme. Specimen 18 feet below firm bottom.	1	0	0	No sustained-load tests made.
		140	1/16	
		200	5/16	
		300	3/4	
Mark IV offshore in sand at Port Hueneme. Specimen 17 feet below firm bottom.	1	0	0	
		39	1/8	
		70	1/4	
		168	3/4	
		198	7/8	
		242	1-5/8	
		290	2	
		306	2-3/8	Commence 40-min load period.
		300	2-3/4	End 40-min load period.
	2	0	2-3/4	
		306	2-3/4	Commence 24-hr load period.
		133[a]	3-1/8	End 24-hr load period.
	3	0	3-1/8	
		236	3-1/4	
		300	3-1/2	
		325	4	
		345	4-7/8 5-1/4	Commence 7-min load period. End 7-min load period.
	4	0	5-1/4	
		307	6	
		353	6-1/2	Commence 40-min load period.
		319	7	End 40-min load period.

Test Description	Load Application Number	Load (kips)	Accum. Vert. Movement (in.)	Remarks
Mark IV in mud bottom at SFNS. 1st specimen 13 feet below firm bottom.	1[b]	0	0	
		115	1/16	Commence 30-min load period.
			1-1/2	End 30-min load period.
		122	2-3/4	Commence 30-min load period.
			3-3/4	End 30-min load period.
	2[b]	0	3-3/4	
		110	3-3/4	Commence 30-min load period.
			3-3/4	End 30-min load period.
		130	3-3/4	Commence 30-min load period.
			7	End 30-min load period.
		120	7	Commence 30-min load period.
			9	End 30-min load period.
	3	120 to 135		Extraction load using warping tug. See Fig. 7. Time 2 hr 5 min to extract from 9 in. to surface.
Mark IV in mud bottom at SFNS. 2nd specimen 13 feet below firm bottom.	1	168		Measuring device not functioning. Negligible barge movement noted prior to 168-kip load. When barge began to creep measurably, switched to alternate loading arrangement, Fig. 7.
	2[b]	0	0	
		91	1/2	Commence 15-min load period.
			1/2	End 15-min load period.
		107	1	Commence 15-min load period.
			1	End 15-min load period.
		120	2	Commence 15-min load period.
			2	End 15-min load period.
		130	2-3/4	Commence 15-min load period.
			3	End 15-min load period.
		134	3-3/4	Commence 15-min load period.
			4	End 15-min load period.
		149	4-3/8	Commence 15-min load period.
			4-3/4	End 15-min load period.
	3[b]	0	4-3/4	
		124	6	Commence 1-hr load period.
			7	End 1-hr load period.
		139	8-1/2	Commence 1-hr load period.
			9	End 1-hr load period.
		143	10-3/4	Commence 30-min load period.
			11	End 30-min load period.
		152	15	Specimen started creeping steadily. Extraction complete after 1 hr 30 min.

a/ Drop-off in load is due to varying tide levels. Maximum load during load period is estimated at 320 kips.

b/ Loads varied as much as 5 kips either side of loads listed for time period due to tide, wave, and wind conditions.

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