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TECHNICAL MEMORANDUM

title: EMBEDMENT ANCHOR SITING, INSTALLATION, AND HOLDING CAPACITY VERIFICATION

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CONTENTS

ABSTRACT

Several concepts for the verification of embedment anchors are described. The concepts verify different phases of the anchor fluke embedment and keying. The verification technique used will vary with the specific application and environment. Moderately loaded anchor flukes in a seafloor known to be homogeneous can be verified to a satisfactory degree by indirectly measuring the fluke penetration using a 12 kHz pinger attached to the anchor line near the seafloor. In seafloors of suspected heterogeneity, a 3.5 kHz pinger similarly attached would be necessary to indicate the layer thicknesses to enable satisfactory prediction of holding capacities. Critical, heavily loaded anchor flukes, especially when in heterogeneous seafloors, will require proofloading to design load for satisfactory verification and may require, in some cases, installation and pull-out of a test anchor.

INTRODUCTION

Purpose

The Naval Facilities Engineering Command is sponsoring an effort aimed at improving the reliability of holding capacity predictions for direct embedment anchors. This memorandum culminates the first phase of that effort by describing the better concepts for holding capacity verification and by describing the equipment and techniques development necessary to reach operational status.

Background

Direct embedment anchors are driven near vertically into the seafloor sediments, and less commonly into seafloor rocks, by an external driving force. The force may derive from a launcher burning a propellant or from a vibratory or impulse pile-driver-type device. The fluke driven into the seafloor usually rotates or expands so as to present an enlarged bearing area to the direction of travel.

Direct embedment anchors are beginning to find use with the operational Navy. Eighteen 100-kip propellant driven anchors were installed for two tanker moorings at Diego Garcia. Two 20-kip and two 10-kip anchors were installed in coral at Midway Island in support of a cable repair project. More anchor uses of this nature are scheduled and still more are being considered.

Holding capacity predictions for direct embedment anchors are believed reliable given a representative quantitative picture of the subseafloor. In some seafloor environments, such a representative quantitative picture of the subseafloor is difficult to obtain at each anchor position, and the ultimate holding capacity of the flukes is not certain. This was the case at Diego Garcia where the embedment anchors were installed in a coralline lagoon with occasional hard coral areas with coralline debris between, and most likely, with large subsurface voids. To verify the Diego Garcia anchors, each was proofloaded to its design-holding capacity, and its depth of embedment was indirectly measured by measuring the length of the anchor line remaining above the seafloor and comparing this exposed length to the known total length of the line. Three sand anchor flukes were installed at Coronado, California as part of an amphibious exercise. The first fluke was installed over shallowly buried hard rock, was badly damaged in striking the rock, and pulled out at less than the design load. The remaining flukes, installed in deep sand, performed satisfactorily. The Coronado experience points up the need to detect and identify subseafloor reflectors in the proposed path of an embedment anchor fluke. At Coronado, the existence of the covered rock was known by the user, but the vessel was mistakenly placed over the rock. Given the prior information, a quick survey would have prevented the fluke damage and premature pullout through a slight change in location.

APPROACH

This effort is intended to improve the reliability of holding capacity predictions for direct embedment anchors by improving our knowledge of where the fluke is (embedment depth) and what the fluke is in (soil type, strength, and sensitivity). To accomplish this objective, techniques for measuring the depth of embedment of a fluke, for identifying and measuring the thickness of sediment and rock strata, and for directly measuring the fluke performance under load were identified, evaluated, and compared to each other. As a result of this qualitative comparison of techniques, more than half were eliminated from further consideration and the remainder were arranged as a function of mission and site requirements. CEL has been concentrating recently on the development of propellant-actuated direct embedment anchors. While the concepts described herein are applicable to other types of direct embedment anchors, this report is slanted toward the propellant actuated anchor. This report culminates with recommendations for developing a sufficient verification capability for Navy needs for direct embedment anchors.

EVALUATION OF VERIFICATION TECHNIQUES

Table 1 is a list of techniques usable for verifying some or all aspects of direct embedment anchor holding capacity. The following section describes the rationale behind each technique, lists the special requirements for execution, and then notes the advantages and disadvantages of adopting that technique.

Measure Ultimate Load Capacity of Test Anchor

Rationale. An extremely good technique for verifying the predicted performance of embedment anchors is to install a test anchor* identical to the service anchor** and load this test anchor to failure. Then, provided all parameters are held constant, other embedment anchors could be expected to behave similarly. Some of the more important parameters that would require near duplication are the fluke weight, size, configuration and penetration velocity, and of course, the soil density, strength, and sensitivity profile.

Table 1. Techniques for Verifying the Holding Capacity of Installed Direct Embedment Anchors

A. Measure ultimate load capacity of test anchor.

B. Develop load versus displacement curve due to working load.

C. Observe performance of service anchor subjected to proof-load.

D. Measure embedment at full-keyed position.

E. Measure penetration of fluke.

F. Measure launch vehicle orientation at time of firing.

G. Observe that the fluke has been launched.

H. Examine seafloor and subseafloor at planned anchor location.

This technique for embedment anchor verification corresponds to the use of pile load tests for pile selection and design in terrestrial engineering. Pile driving and load tests are frequently used in

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*''Test anchor'' denotes only those anchors intended for destructive testing.

**''Service anchor'' denotes those anchors installed for some purpose other than destructive testing.

terrestrial engineering as an aid to technical/economic decision making regarding pile type selection when large numbers of piles are involved. However, test piles are rarely driven when only a small number (highly variable, say 50) of piles are involved because it is normally cheaper to overdesign the service piles and omit the test piles. Thus, normally test piles are not utilized to verify only a few service piles; and, if a parallel were to be drawn, then test anchors would not be used to verify only a few service anchors. However, the parallel is not complete because the cost of test piles, relative to the pile foundation cost, is much higher than the cost of test anchors, relative to the service anchor cost. Because test anchors are relatively inexpensive, as compared to test piles, the use of test anchors to verify only a few service anchors is justified.

A variation of the full-scale test anchor approach is to use a small anchor and rely upon the improving capability to analyze the behavior of objects extracted from the seafloor. This is not as desirable as a full scale test, but it does offer some obvious advantages such as reduced ship handling capabilities and lower overall cost, including ship cost and expendable hardware cost. In lower reliability situations, this procedure is viable; however, for purposes of this report the remaining discussion will concern the full scale test.

Requirements. The use of test anchors for the verification of direct embedment anchors will impose certain requirements in addition to those of service anchor installation alone as follows:

1. A capability to apply sufficient load to/pull out the anchor fluke is required. For a minimal 20-kip anchor, the loading capability required could range up to 50 kips (220,000 N). A weak link or some other form of separation means would be installed between the anchor fluke and main load line to prevent possible line loss and expand the probabilities of finding suitable vessels.

2. Performance of an anchor pullout test would consume valuable time out of the available weather window. Minimum expected time is five hours.

3. Performance of pullout tests would require extra propellant, detonators, arming devices, and expendable hardware.

4. In order for pullout tests to effectively describe the performance of service embedment anchors in seafloor areas of high variability, the seafloor material profile would have to be determined to be the same at test anchor and service anchor locations or the anchors would have to be positioned quite near each other to ensure that little profile difference exists.

Advantages. The pullout test or ultimate load capacity test is very attractive because it does provide a direct measure of anchor ultimate load resistance. Thus, the engineer can be reasonably sure of the factor of safety under the design short-term loading, and he has somewhat greater confidence in predictions of long-term holding capacity than he would have without the ultimate load test. The suitability of the procedure would depend to a great degree upon areal variability of the seafloor. In an ocean basin with areally uniform soil properties, this procedure could be used without sophisticated surveying gear with a high degree of confidence.

Disadvantages. The disadvantages of using pullout tests for verification have been touched upon earlier. First, ships capable of applying and measuring the required anchor pullout loads are not easy to come by. Then the time required to perform the test may not be available within the projected weather window. (An implantment would not normally be designed that could not tolerate a test lasting a few hours, but it is conceivable.) Handling and storage facilities for the necessary load line may not be available. Lastly, and probably most significant, the test anchor must be embedded in a soil profile very similar to that in which the service anchor is to be placed in order for the test results to be applicable. Thus, sophisticated equipment is required either (1) to locate a similar looking seafloor soil profile, or (2) to place the test anchor sufficiently close to the service anchor site (probably quite easy in many deep-sea environments, but difficult and time consuming in some critical locations).

The first approach for utilizing test anchors, that involving location of similar subseafloor profiles by acoustic means, appears to involve the lesser cost. Further, the first approach appears to be a more reliable technique for verifying anchor pullout load. The first technique is more reliable because a 3.5 kHz pinger is used to locate an acoustically similar seafloor profile and the engineer assumes that the engineering properties profile is similar – a relatively reasonable assumption. In the second technique a 12 kHz positioning system is used to position the test anchor over a location assumed to have a seafloor profile similar to that in which the service anchor will be installed. Here the seafloor topography and limited available data on the subseafloor, from cores and from previous deep penetration acoustic surveys, are used to guide the decision as to seafloor profile similarity – an assumption which can be very much in error. Thus, the siting of service anchors, so as to ensure performance equivalent to that of a test anchor, appears best accomplished by looking for a similar seafloor soil profile with a 3.5 kHz pinger-receiver system.

Develop Load Versus Displacement Curve Due to Working Load

Rationale. A conceptual technique for evaluating a direct embedment anchor was to load the anchor in increments and measure fluke displacement to develop a load-displacement, P-Δ, curve for the anchor fluke. The basis for this concept lies with terrestrial pile load testing where changes in the P-Δ curve identify skin friction and point bearing load resistance components of the pile and identify the load at which overall plastic deformation of the supporting soil begins to occur. The holding capacity of anchor flukes, it is felt, could be identified by comparing the P-Δ curve of the structure anchor to the previously developed ''handbook'' type curve for a similar soil, say for a Globigerina ooze. The shapes and slopes of the P-Δ curves would identify the expected ultimate short-term and long-term holding capacities and the recommended design holding capacity. Unfortunately, subsequent developments demonstrated the concept to be unworkable.

The idea of developing a P-Δ curve indicative of soil strength mobilization is not workable because field and laboratory tests indicate that the anchor fluke does not reach its full-keyed position until nearly the full ultimate load has been applied. Significant displacement is required to accomplish fluke rotation from the vertical, on edge, position to the horizontal, load bearing, position; displacement to reach full keying averages twice the fluke length. Such large displacements during keying will mask the small displacement components arising from soil strength mobilization. Further, development of a P-Δ curve after keying the fluke and presumably loading the fluke to ultimate is not desirable because structure flukes should not be subjected to ultimate loads. Field testing has shown that the holding capacity of embedded plate anchors drops off significantly after reaching ultimate load presumably due to soil remolding and due to the fluke moving upward into weaker soil strata. Thus, structure anchors should not be proofloaded to near the ultimate load because this action serves to decrease their holding capacity.

In summary, direct embedment anchors to be used in a structure should not be loaded to near their ultimate or pullout load. On the other hand, unless such anchors are loaded to near their ultimate load, the P-Δ curve developed is likely not to be indicative of the anchor holding capacity. Thus, the concept of using the P-Δ relationship to describe direct embedment anchor holding capacity is not viable.

Observe Performance of Structure Anchor Subjected to Proofload

<u>Rationale.</u> Although the concept of developing and using a P-Δ relationship for verification is not viable, observation of structure anchor performance under load can provide valuable information. For instance, if the design load is applied to the launched service anchor and the anchor does hold over the short-term, then embedment of the fluke, the initiation of proper keying, and the adequacy of the anchor to hold the design short-term load are all verified. No direct determination is made of long-term performance.

Safe use of this anchor verification technique requires that the proofload applied be at least equal to the maximum load expected from the structure. More commonly, the proofload is 25 to 100% greater than the design maximum load to provide a safety factor of sorts. This technique was used at Diego Garcia for verification of the direct embedment anchors for the tanker moorings.

<u>Requirements.</u> The proofloading of a structure anchor requires the equipment, hardware, and time necessary to conduct the test. The necessary equipment may be hard to obtain and the time available for the operation may be too limited to permit the inclusion of proofload

tests. With some structure designs, for instance those structures which are entirely submerged, special accommodation must be made to provide load lines running up to the sea surface. Appropriate selection of fluke size and propellent weight will depend on establishing the sediment type, density, and strength profile at the point of anchor installation.

Advantages. Proofloading of structure anchors offers capabilities to anchor verification not available through other concepts, capabilities which are extremely valuable. Because of these capabilities, the proofloading technique for verification will always be employed in problem situations where reliable prediction of holding capacity is impossible. Some of the advantages of proofloading are:

1. Verification of holding capacity in extremely heterogeneous environments, as offered by coralline environments, is achieved. Here holding capacity, and even the optimum fluke design, may change significantly with only a few feet change in location.

2. A direct test of load resisting capability is achieved. The following techniques to be discussed in this report make engineering predictions of holding capacity; while these predictions may be quite reliable in some seafloor environments, they cannot be so in all environments until an adequate case history data bank is compiled. Thus, direct verification that a given anchor will resist a given load in a given environment will be a distinct advantage for some time to come.

3. Lastly, proofloading does not require the expenditure of hardware, propellant, and time as for a test anchor.

Disadvantages. Conducting a proofloading does require a ship or other platform with capability to apply and measure the line load. Properly controlling and accurately measuring the line load are the more difficult tasks at sea. Because the proofloading is applied to a structure anchor, it is relatively inexpensive in ship time requiring perhaps one hour per anchor – normally not a significant disadvantage.

Measure Embedment at Full-Keyed Position

Rationale. At an early stage of this study, measurement of fluke embedment at its full-keyed position was suggested as a reasonable concept for verifying proper fluke launching and embedment. This concept, which does require loading of the fluke in order to rotate it into its keyed position, was intended to suffice in those instances where a proper load measuring system was not available or could not be rigged. A measure of fluke embedment, coupled with a profile of the sediment engineering properties from a core sample or penetrometer record, would provide, it is felt, the next best information in lieu of obtaining actual load test data.

Unfortunately, loading until the fluke reaches the full-keyed position is not desirable. Keying is not completed until the anchor pullout load is closely approached, thus it would be quite easy to exceed the ultimate load and initiate pullout while keying the fluke. Should pullout be initiated, then the subsequent load capacity is reduced by some substantial factor. Thus, it is not desirable to load an anchor fluke until it reaches the full keyed position because pullout may be initiated in the process reducing the anchor holding capacity.

Measure Penetration of Fluke

Rationale. A concept for embedment anchor verification which has developed into a very attractive one is that of simply measuring the fluke penetration, comparing this data with the predicted penetration based on the soil engineering properties profile, correcting that profile if necessary, and then confirming the predicted fluke holding capacity or altering the predicted holding capacity as necessary. The measurement of fluke penetration has been accomplished by attaching a ''downward looking'' 12 kHz pinger to the fluke line about 15 m above the launch vehicle. Such equipment is readily available, compatible with usual shipboard Precision Depth Recording equipment, and provides a reliable measure of distance from the pinger to the seafloor to ±0.2 m. Knowing the assembled line length between the pinger and the fluke, the depth of the fluke beneath the seafloor can be readily determined. When the depth of fluke penetration is known, then the soil property profile and the predicted anchor holding capacity can be assessed. For some noncritical installations, penetration depth alone is a good indication of holding capacity, even without prior predictive comparison. A general a priori knowledge of the seafloor (e.g., sand, clay, etc.) would be sufficient.

Requirements. As with all other indirect holding capacity verification techniques, to obtain useful information from the penetration measurement, some idea of soil property profile must be available. Generally, a sediment core of reasonable quality is required, with supporting penetrometer tests providing information on site variability. Shipboard equipment capable of receiving and appropriately representing the 12 kHz data is necessary. Ship time required is minimal: actual data taking time is negligible; travel of the pinger in returning to the sea surface and recovery of the pinger would consume the measurable time. A pinger could be fitted with a hydrostatic shutoff switch set to deactivate/activate at a reasonable distance off the seafloor. During its return to the surface after shutoff it would not interfere with a second installation. The pingers could be recovered when convenient.

Advantages. The verification of embedment anchors via simply measuring the depth of penetration is very attractive because it requires a short interval of ship time (for pinger recovery) and because no heavy line loading equipment and no specialized load measuring equipment are required. Further, this concept is amenable to development into a subbottom profiling system for close examination of the spot immediately beneath a fluke about to be launched. Such a 3.5 kHz system will be described further in a later section.

Disadvantages. Of course simple measurement of the fluke penetration really verifies only the prediction of penetration depth. Estimates of fluke travel to reach the partially keyed position due to the design load, and estimates of the safety factor available at that design load, remain the subject of engineering judgment. Concern has been expressed over the trueness of the fluke trajectory in the sediment; that is, maybe the fluke will deviate radically from vertical during penetration and its true penetration elevation might be considerably above that determined by this verification technique. Although a nonvertical trajectory is possible, laboratory and field test data indicate the potential for serious error is low, assuming the launch vehicle is near vertical at launch.

Measure Launch Vehicle Orientation at Time of Firing

Rationale. Concern about the trueness of the fluke trajectory naturally led to concern about the orientation of the launch-vehicle and fluke at firing. Measurement of the orientation by a tilt indicator mounted on the launch vehicle is possible. Even more attractive is the inclusion of a vertical attitude sensor in the firing train to permit firing only when the launch vehicle is vertical. However, the potential of the launcher to be partially toppled over at the time of firing, particularly if the lowering rate is kept less than 100-150 m/min, is very slim as compared to other difficulties that could occur such as encountering subseafloor obstacles to fluke penetration. Since this is considered an avoidable problem, it is appropriate to concentrate available funding on proven unsolved problems.

Further, it should be stated that if a launch orientation and fluke depth of penetration should be suspect, application of a proofload, where possible coupled with the previously described acoustic system to measure indirectly the length of line buried in the seafloor, would be sufficient to verify the fluke embedment or prove it unsatisfactory.

Observe That the Fluke Has Been Launched

Rationale. In some construction sequences it may prove time consuming or unduly complicated to apply a light load to the anchor line to verify that the fluke has been properly launched and has penetrated a sufficient distance into the seafloor. In these instances, it would be of value to know that the launcher had fired and had done so approximately at the time of bottom contact. No special equipment is required for this task: a 12 kHz pinger mounted 15 m above the launcher can be effectively used to indicate the time of bottom contact and the receiving hydrophone can be monitored to detect the firing. In water depths less than 1,000 to 1,500 m, anchor firing can be detected audibly.

A more significant problem concerning launcher firing is that of identifying the cause and thus the seriousness of an anchor misfire – i.e., that condition in which the firing sequence has been initiated but not completed. However, this problem of identifying the cause of anchor misfire is beyond the scope of this report.

Examine Seafloor and Subseafloor at Planned Anchor Location

Rationale. Direct embedment anchor installation efforts have encountered one very difficult to cope with installation hazard – that of undetected rock beneath a thin (0 to 10 m) sediment cover. The thickness of sediment cover, and the underlying rock topography, can differ considerably over short horizontal distances in the ocean ridge and rise provinces, on the continental and insular shelves and on seamounts. In one instance of note, a direct embedment anchor was fired into a sand seafloor and struck an undetected shallowly buried rock mass. The badly mangled fluke pulled out at a fraction of its design capacity. In similar circumstances, it would be possible to take a good quality core, perform 3 or 4 penetrometer tests, embed a test anchor and pull it out, all within a fairly small area, and then to strike rock and damage the service anchor fluke. There is no need to entertain such risk. Acoustic subbottom sounding equipment is now available which can detect the existence of shallowly buried rock and give a reliable measure of the thickness of sediment cover.

The technique to be used in this verification concept would be an extension of that technique developed to indirectly measure the depth of fluke embedment using a 12 kHz pinger. Reliable examination of the subseafloor would require a 3.5 kHz pinger to provide sufficient acoustic penetration. Before embedment anchor system touchdown, the 3.5 kHz subseafloor sounding system would be used to check for an acoustic reflector that could represent a rock surface. If a suspected rock surface was detected within reach of the fluke, then the sea-surface platform would be maneuvered to move the anchor system until it was over a suitable, safe anchoring location. In addition to detecting possible rock outcrops, the 3.5 kHz system is expected to permit correlation of sediment layers with core sample and penetrometer data in stratified seafloors. It will alert the cognizant engineer to an unusual situation and cause additional measures, such as prooftesting, to be taken; thus, improving anchor reliability.

Requirements. Examination of the subseafloor at the proposed point of anchor implantment to the accuracy necessary requires a 3.5 kHz pinger as a pulsed sound source mounted about 15 m above the launcher. A few such pingers have been fabricated, and a second generation model has been designed by industry. Appropriate hydrophones and sensitive recording equipment are available. Pinger recovery techniques are developed and were used on CEL's SEACON II in 1,000 m of water.

In practice, core samples and penetrometer records taken in the immediate area with accompanying 3.5 kHz subseafloor sounding records will be required to establish the correlation between reflectors and sediment layers of differing engineering properties.

Advantages. The immediate advantage of assembling a subseafloor acoustic sounding system for use with the embedment anchor system will be to eliminate the possibility of only partially embedding flukes or of damaging those flukes where near seafloor surface rock exists. Such partial embedment or fluke damage would likely result in premature pull-out of a mooring leg. The acoustic sounding system would require very little additional ship time when used, yet would save the time that might potentially be lost should the fluke strike rock. Further, the 3.5 kHz pinger system will also provide the capability to indirectly measure the depth of fluke embedment (assuming a near-vertical fluke trajectory). Hope is expressed by some that it may even prove possible in some environments to ''see'' the embedded fluke and directly measure the depth of embedment.

Disadvantages. The main disadvantage to using this technique for verification is that anchor holding capacity is not directly verified. This technique verifies that the subseafloor beneath the anchor system looks acoustically similar to that of a core or penetrometer location nearby. Thus, it verifies only the assumed profile of sediment engineering properties with depth and the fluke embedment.

SELECTION OF OPTIMUM VERIFICATION CONCEPTS

Criteria for Selection

Initial plans were to select the optimum verification concept based on a cost projection of each concept on a yearly operational basis. This plan was not carried through to fruition because (A) there is no firm idea of the numbers of respective anchor types to be used in deep versus shallow water environments per year and because, (B) more importantly, the ''optimum'' concept was determined to vary with mission and environment. Thus, no one optimum concept exists.

For a very costly or very sensitive structure, either (1) the anchor would be designed with a large factor of safety to preclude failure or, (2) the exact anchor holding capacity would be verified and modifications made until the service anchor was determined safe. If option (1) is being used, then a probable approach to construction would be to:

(a) Verify that the sediment engineering profile used to predict the fluke penetration and holding capacity does very probably exist at the structure anchor location. The fluke ultimate holding capacity would incorporate a factor of safety of 3 to 5.

(b) Verify that the fluke has penetrated to the sediment depth predicted.

Adherence to these two steps, and application of the high safety factors, should ensure reliable, long-lasting anchor performance.

However, large structures will likely require higher design and ultimate holding capacities. The higher required ultimate holding capacities may not be obtained with the existing launcher system. Unless a great demand develops for launchers larger than the present 20 kip deep water system and the 100 kip shallow water system, it is likely that engineers will be called on to raise the allowable loading on the anchors by decreasing the factor of safety being used, rather than by building larger launchers capable of driving bigger flukes deeper. Thus, for large, costly or sensitive structures, it is now necessary, and will be necessary for some time, to verify the exact anchor holding capacity (option (2) above). By obtaining a direct indication of anchor holding capacity, some of the uncertainties of engineering judgment are removed, and the factor of safety being used can be reduced with confidence. Using option (2), a probable approach to construction would be to:

(a) Verify that there are no obstacles to full fluke penetration at the launch location

(b) Verify that the fluke has penetrated to the sediment depth predicted

(c) Apply and maintain for some short period a proofload, preferably equal to or greater than the design holding capacity, to partially verify the anchorage. The long-term holding capacity would be verified analytically based on the engineering properties of cores taken nearby.

Thus, there are two options for the verification of direct embedment anchors for large, costly or sensitive structures:

(1) If high factors of safety are workable, i.e., the anchor system can attain sufficiently high ultimate load capacities, then simply design to utilize this high safety factor, and verify only that proper fluke installation into the anticipated sediment formation has occurred

(2) If high factors of safety are not obtainable, then the emplaced anchor fluke must be prooftested

Smaller, less costly or less sensitive structures can be approached differently. For such structures, it will not be necessary to mobilize the ultimate capacity possible with the anchor system and the factors of safety to be used can be lowered to 1.5 to 2. Only rarely will a proof-test of an embedded fluke be necessary. Indirect verification of anchor holding capacity predictions will in most cases prove sufficient. A probable approach to construction would be to:

(a) Verify that the sediment engineering profile used to predict the fluke penetration and holding capacity does very probably exist at the structure anchor location

(b) Verify that the fluke has penetrated to the sediment depth predicted

Selection of Verification Concepts

Noncritical Installations in Homogeneous Areas. For noncritical installations in areas of lateral continuity, the necessary verification consists of establishing the depth of penetration of the direct embedment anchor fluke. This measurement is best accomplished indirectly by using a pinger attached to the mooring line about 15 m above the launcher. The pinger would provide a measure of distance to the seafloor from which the fluke embedment could be obtained. Either a 12 kHz or a 3.5 kHz system can be used for this purpose. The 3.5 kHz system is the more versatile because it can be used to fill other needs noted below.

In predicting the ultimate holding capacity, some estimate of fluke travel during keying is necessary to permit estimating the fluke embedment at ultimate load and selecting the appropriate soil engineering properties from the profile. In lieu of more exacting full scale test data, travel distance during fluke keying can be assumed to be three times the fluke length in soft clays and two times the fluke length in sands. Data on keying distance in clay are limited. Additional tests in deep ocean clays are scheduled with an improved soft clay fluke. Final recommendations on keying distance will be adjusted accordingly.

Noncritical Installations in Nonhomogeneous Areas. For noncritical installations in areas of heterogeneous sediment distribution, especially those with thinly covered or outcropping seafloor rock, the necessary verification consists of (1) determining that the subseafloor acoustic profile is equivalent to that profile on which the anchor design is based and (2) establishing the depth of penetration of the direct embedment anchor fluke. The depth of penetration would be measured as described above. Development of the subseafloor acoustic profile would require a 3.5 kHz pinger attached to the mooring line to examine the local seafloor with sufficient resolution.

Critical Installations. For critical installations, the above verification techniques will not be sufficient. In addition to verifying the acceptableness of the subseafloor profile and the depth of penetration of the fluke, the anchor holding capacity prediction must be verified, at least the short-term capacity. This requires a proofloading of the service anchor. Equipment to accomplish such proofloadings is available.

Conclusions. Verification of direct embedment anchors for all types of structures in all environments imposes differing equipment requirements.

1. In the simplest case, a 12 kHz seafloor sounding system with near-bottom pinger is required to verify the depth of fluke embedment. Such equipment is available, and it is frequently used for similar measurements. Alternatively, a 3.5 kHz system can be used to accomplish the same objective.

2. In a more complicated environment, a 3.5 kHz subseafloor sounding system with near-bottom pinger is required to verify the subseafloor acoustic profile and to verify the depth of fluke embedment. Prototype 3.5 kHz equipment has been built, but not thoroughly tested nor evaluated.

3. In all environments with critical installations, a 3.5 kHz subseafloor sounding system will be required supplemented by shipboard equipment for applying, measuring, and maintaining for short durations the required proofloadings. No new developments in loading equipment and techniques and in load measuring equipment are necessary.

RECOMMENDATIONS

To acquire the necessary capability to verify the assumed subseafloor acoustic profile, a 3.5 kHz pinger and signal receiving equipment should be purchased, tested, and evaluated.

Equipment Characteristics

1. The 3.5 kHz pinger must meet the following minimum specifications:

   a. Water depth capability of 6,000 m

   b. Signal level sufficient to produce interpretable reflected signal from rock surface beneath 10 m of sand cover and 15 m of clay cover

   c. Pinger operating life of 8 hours at 4°C

   d. Remote signal shut-off via acoustic command or via some physical action of the mooring line

2. The 3.5 kHz hydrophone must be capable of being hung about 50 m beneath the ship to minimize interference due to hull noise.

3. The data processing and display equipment must permit measurement of pinger distance above the seafloor to ±0.2 m.

Test and Evaluation Program

The 3.5 kHz subseafloor sounding system should be tested and evaluated where possible in conjunction with installation of direct embedment anchor systems. The testing program should seek to vary significant environmental parameters, specifically the water depth, sediment types, and thickness of sediment cover over rock. The performance evaluation of the system should seek to identify the following:

1. The accuracy of the distance measurement of the pinger above the seafloor.

2. The maximum acoustic penetration in probable sediment types. The nature and material of the reflecting strata will be a significant variable.

3. The influence on subseafloor data quality of the launcher and fluke or of a corer hanging beneath the pinger. Determine spacing requirements between the pinger and launcher in terms of potential damage to the pinger due to launcher firing.

4. The potential for acoustically ‘‘seeing’’ the embedded fluke with a 3.5 kHz system.

Since each installation has a different degree of criticality, required anchor reliability will vary with each situation. As a follow on to this original effort, it is recommended that the verification procedures recommended for various situations be outlined and put in manual form for use by anchor installers.

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