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OCEAN FACILITIES ENGINEERING CRITERIA AND METHODS PROGRAM

PHASE Ia – SUPPLEMENTARY REPORT NO. 1-S

PROGRAM RECOMMENDATIONS FOR AREA OF TECHNOLOGY:

ANCHOR SYSTEMS

BY: R. J. Taylor, D. G. True, and H. J. Lee

DECEMBER 1974

CIVIL ENGINEERING LABORATORY
NAVAL CONSTRUCTION BATTALION CENTER
PORT HUENEME, CALIFORNIA 93043

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

3. DISTRIBUTION AVAILABILITY OF RI
Approved for public release; distribution is unlimited

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

4. PERFORMING ORGANIZATION REPORT NUMBER

5. MONITORING ORGANIZATION REPORT
FPO 7402

6a. NAME OF PERFORM. ORG. 6b. OFFICE SYM
Civil Engineering Lab.
Naval Construction
Battalion Center

7a. NAME OF MONITORING ORGANIZATIC
Ocean Engineering
& Construction
Project Office
CHESNAVFACENGCOM

6c. ADDRESS (City, State, and Zip Code)
Port Hueneme, CA

7b. ADDRESS (City, State, and Zip
BLDG. 212, Washington Navy Yard
Washington, D.C. 20374-2121

8a. NAME OF FUNDING ORG. 8b. OFFICE SYM

9. PROCUREMENT INSTRUMENT INDENT #

8c. ADDRESS (City, State & Zip)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT #	PROJECT #	TASK #	WORK UNI ACCESS #

11. TITLE (Including Security Classification)
Anchor Systems

12. PERSONAL AUTHOR(S)
R.J. Taylor, D.G. True, & H.J. Lee

13a. TYPE OF REPORT 13b. TIME COVERED FROM TO

14. DATE OF REP. (YYMMDD) 74-12

15. PAGE 2 vo

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if nec
Anchors

19. ABSTRACT (Continue on reverse if necessary & identify by block number)
Anchor systems for fixed ocean facilities are described. A comprehensive breakdown of anchor technology is given in terms of all possible classes and subclasses of equipment and parameters, each class and subclass being described by relatively terse verbal statements, sometimes including →(Con'

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
UNCLASS/UNLIMITED X SAME AS RPT. DTIC

21. ABSTRACT SECURITY CLASSIFICATI
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
Jacqueline B. Riley

22b. TELEPHONE
202-433-3881

22c. OFFICE SYMB

DD FORM 1473, 84MAR

SECURITY CLASSIFICATION OF THIS PAC

BLOCK 19 (Con't)

numerical information. The report is ~~not an engineering~~ manual, ~~but rather~~ a tutorial exposition for managers and program planners in ocean engineering and construction. A specific objective of this report is presentation of minimal background information to be used in establishment of methods and criteria for the Navy's ocean facilities engineering efforts.

The report includes a discussion of the impact of anchor technology on other areas of technology within the field of ocean facilities engineering, and, also, the impact of other technologies on anchor systems.

Accession For	
NTIS GRA&I	☒
DTIC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
A-1	

QUALITY INSPECTED 3

UNANNOUNCED

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OCEAN FACILITIES ENGINEERING CRITERIA AND METHODS PROGRAM,
Phase Ia, Supplementary Report No. 1-S

PROGRAM RECOMMENDATIONS FOR AREA OF TECHNOLOGY: Anchor Systems

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December 1974

Prepared for
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Chesapeake Division
Naval Facilities Engineering Command

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ABSTRACT

This report is a collection of Point Papers which discuss anchor-system technology areas which are deficient in established criteria and methods for optimal execution of projects in ocean engineering and construction. Recommendations are made in each Point Paper which specify the actions to be pursued in establishing the needed criteria and methods. The recommended actions include compilation of existing data on all types of anchors used in ocean construction and the development of standard analytical methods for predicting the performance of anchors.

CONTENTS

INTRODUCTION

As required by the instructions (Reference 1) for Phase I, Part 1, of the Criteria and Methods (C/M) Program (managed by Chesapeake Division, NAVFAC) a set of Point Papers has been written for each assigned area of technology (AAT) within the field of ocean facilities engineering. Originally the C/M Program was titled Ocean Engineering and Construction Standards and Criteria (S/C) Program. Point Papers were written before the title was changed, and therefore discuss S/C areas within the AAT rather than C/M areas. This report presents the Point Papers for the AAT, Anchor Systems (Reference 2).

The purpose of the C/M Program is establishment of methods and criteria applicable to the needs of ocean engineering and construction. The Point Papers discuss deficiencies in the AAT's and make recommendations essential to achieving the aims of the C/M Program. The term, standards, used in the Point Papers, should be interpreted as methods and procedures which are cost effective, easily documented, and acceptable to the ocean construction engineer.

Each Point Paper is divided into the following sections:

1. Definition of S/C area: scope and content of the AAT area where S/C are needed.
2. Applicability: importance of the defined S/C area with respect to the NAVFAC mission.
3. Needs for S/C: explanation of why S/C are needed in certain AAT areas.
4. Impact of RDT&E: description of on-going or recent RDT&E having an effect on the defined S/C area.
5. Recommendations: course of action to be pursued in establishing S/C.

POINT PAPER

ANCHOR CHARACTERISTICS

1.0 DEFINITION OF S/C AREA

Included in this S/C area are the physical, mechanical, and chemical, etc., characteristics of anchors, except for "Composition" which is included in the AAT "Ocean Engineering Materials" and "Acoustic Energy Emission" which is discussed as a separate S/C area under this AAT.

2.0 APPLICABILITY

Information on the physical characteristics of anchors is used by designers and operations personnel to design and install FOF's. A comprehensive compilation of the physical characteristics of anchors would simplify design effort, provide the designer with the full range of known anchors from which to select those needed for his specific application, and thus provides a better design.

3.0 NEEDS FOR STANDARDS AND CRITERIA

3.1 Physical Data

Data on all existing anchors that are suitable for use in ocean engineering and construction of fixed ocean facilities need to be accumulated, cataloged, and placed in a data bank so as to be readily available in a systematic manner for the use of design and operations personnel.

4.0 IMPACT OF RDT&E

Adequate information is already available. There is no known RDT&E that significantly impacts this S/C area.

5.0 RECOMMENDATIONS

It is recommended that the needed data bank cited in paragraph 3.1 be established by accumulating existing documents such as DOT handbooks, technical reports and manuals, manufacturers' catalogs and standard Navy drawings.

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POINT PAPER

ACOUSTIC ENERGY EMISSION

1.0 DEFINITION OF S/C AREA

Acoustic energy is imparted to seawater during the firing of a propellant-launched penetrating anchor. The energy can be characterized in terms of its signature, that is, its pressure level at a known distance from the source, and its frequency-based power spectral density.

2.0 APPLICABILITY

The time of arrival of firing-induced sound at triangulating monitor stations can be used to determine the installed position of the anchor.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following standards and criteria are needed in this area:

3.1 Standard Characterization Methods

Hardware testing and data format standards are required for the evaluation of each newly developed anchor, so that descriptions of the anchor's characteristics can be transmitted in a readily recognizable and usable form.

3.2 Standard Installation Monitoring Methods

Installation monitoring procedures and equipment must be standardized to provide installers with a simply executed program for confirmation of the proper firing and positioning accuracy of this type of anchor.

4.0 IMPACT OF RDT&E

The following programs have impact on developing standards and criteria in the area of acoustic energy emission:

4.1 Anchor Installation for Expedient Moorings

SCOPE - One aspect of this program deals directly with determining the acoustic signature of a propellant-launched penetrating anchor and developing a method to utilize acoustic monitoring data to verify the anchor's proper firing and positioning accuracy.

IMPACT - The results of this work should provide a model for the characterization of other propellant-launched anchors and for the formulation of monitoring methods.

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Work Unit Summary, YF53.535.004.01.006

5.0 RECOMMENDATIONS

It is recommended that:

5.1 Standard methods be developed for measuring and reporting the acoustic emissions of anchors.

5.2 The acoustic emission characteristics - the "signatures" - should be determined and recorded for existing anchors, and for new (future) anchors as they are developed.

(The results of the program described in paragraph 4.1 will serve as a basis for the Recommendations 5.1 and 5.2.)

5.3 Whenever practicable firings of propellant-activated anchors should be monitored and the results recorded, using the standard method developed in Recommendation 5.1 to build up the data bank file of known information.

5.3 When sufficient data is accumulated under Recommendations 5.2 and 5.3 the methods developed under Recommendation 5.1 should be reviewed and revised as necessary to develop a validated method that could then be used as a basis for an Interim Standard.

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POINT PAPER

ABRASION OF ANCHOR SYSTEM GROUND TACKLE

1.0 DEFINITION OF S/C AREA

The standards and criteria area for abrasion includes the wear/failure of the connection line and joining gear caused by the dynamic movement of the components in the anchor system. This movement may be induced by waves, wind, current, or tide forces on the moor structure, mooring buoy, or connection line.

2.0 APPLICABILITY

The following items discuss the importance of abrasion and the need for standards and criteria for this area in terms of applicability to the NAVFAC mission and impact on mission requirements.

2.1 Design Life

Abrasion of mooring systems connective apparatus can result in premature loss or disablement of the moored FOF.

2.2 Significant Replacement Time and Cost

Mooring systems connection line failures caused by abrasion now result in significant replacement time and costs. One example of the problem is a Navy tanker mooring at an exposed beach in which the ground tackle connection line fails in the dip area because of the abrasion. This requires a continuing inspection and replacement of the connection line.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following types of standards and criteria are needed in this area.

3.1 Component Positioning Data

The input of the component types which fail and the positions of the components in the connective system that are most susceptible to failure.

3.2 Abrasion Data

Data are required relating the physical forces and the abrasion type failures.

3.3 Line Pre-tension Data

Data is needed relative to the effect of line pre-tension on connective gear abrasion.

3.4 Design Criteria

Criteria is needed to select the proper types and locations of connection gear to ensure long life.

4.0 IMPACT OF RDT&E

No programs are known that can be identified as having an impact on development of standards and criteria for the area of anchor system ground tackle abrasion. An RDT&E program will provide the NAVFAC design/field engineer with data and procedures for decreasing field maintenance costs on anchor systems and improve the system reliability.

5.0 RECOMMENDATIONS

5.1 It is recommended that Interim criteria be developed utilizing to the fullest extent possible data from past and existing installations. The Interim criteria would include recommended practice and suggested components which could, at some future time, be established as standards. It is not anticipated that a distinct R&D effort will be required; as more information becomes available to satisfy the needs identified in paragraphs 3.2, 3.3, and 3.4 the Interim criteria would be updated.

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POINT PAPER

INSTALLATION TIME OF ANCHOR SYSTEMS

1.0 DEFINITION OF S/C AREA

This standards and criteria area involves the determination of the time required on ship to prepare an anchor system for deployment, the time the system remains on surface, if applicable, the total transit time to the seafloor and installation time while on the seafloor. Installation of conventional anchorage is not included in this standards and criteria area because their time depends heavily upon too many environmental and operational uncertainties.

2.0 APPLICABILITY

The following items discuss the importance of accurate information concerning installation time and the need for standards and criteria in this area.

2.1 Determinable Final Position

Anchor systems in the water column are subjected to current forces. Knowledge of the exact descent velocity of free fall or auto-moored systems is needed if accurately known final positions are required.

2.2 Environmental Effects

Total time for anchor installation which includes on-ship preparation, on-surface and in-water-column time is only part of total mooring installation time but it must be determined to ascertain potential effects of weather and system detectability.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following types of standards and criteria are needed in this area:

3.1 Installation Time Data

The on-ship assembly, on-surface and surface-to-seafloor transit times are needed in order to establish an operational guide for installation of anchor systems.

3.2 Standard Measurement Procedures

Standard procedures to measure descent velocity are needed.

3.3 Standard Assembly Procedures

Standard anchor system assembly procedures are needed.

4.0 IMPACT OF RDT&E

The following programs are identified as having an impact on developing standards and criteria for anchor installation time.

4.1 Anchors For Mooring Navy Equipment

SCOPE - One task currently being conducted is the test and evaluation of the CEL Deep Water Anchor.

IMPACT - The program provides data on the on-ship assembly time and the in-water (transit time to the seafloor of a control lowered anchor).

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PUBLICATIONS

CEL TN-1282, "Propellant-Actuated Deep Water Anchor: Interim Report," Port Hueneme, CA, by R. J. Taylor and R. M. Beard, August 1973.

4.2 Flight Accuracy Study

SCOPE - A study to reduce the sensitivity of Glide-Out-Anchors to cross currents and to reduce the steepness of its average glide angle.

IMPACT - This program has provided data concerning the glide descent velocity of model glide out anchors. This data should be pertinent to larger anchors.

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PUBLICATIONS

CEL CR 73.013 "Flight Accuracy Study of Glide-Out Anchor," Honeywell, Seattle, Washington, February 1973.

5.0 RECOMMENDATIONS

It is recommended that the considerable existing data be gathered and used to develop (1) interim standard procedures for assembling an anchor system on board ship and (2) interim standard procedures to measure descent velocity. Existing data on on-ship assembly, on-surface and surface-to-seafloor transit times should be tabulated and evaluated to provide input data for "Anchor Deployment" (as described in the Hardware/Equipment TBS paragraph 2.1) and criteria while pertinent on-going and future programs be monitored for additional data.

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POINT PAPER

HYDRODYNAMICS OF ANCHORS DURING INSTALLATION

1.0 DEFINITION OF S/C AREA

The standards and criteria area involves the hydrodynamic behavior of systems while either on or below the sea surface that are control lowered, free fall dropped to the seafloor, or auto-moored. The hydrodynamic characteristics, methods to define and control anchor route to the seafloor, anchor final position on the seafloor, and cable line tension which result from free fall are included.

2.0 APPLICABILITY

The following items discuss the importance of defining the hydrodynamic behavior of anchor systems and the need for standards and criteria for this area in terms of applicability to the NAVFAC mission and impact on mission requirements.

2.1 Systems allowed to remain on the sea surface even for short periods of time must be properly designed to withstand normal wind and wave forces.

2.2 An anchor system, whose final position on the seafloor, after being free fall dropped or auto-moored, cannot be accurately predetermined, could not be used for most critical installations.

2.3 Free fall either by anchor-first or anchor-last technique can impose high line tensions which are difficult to accurately assess.

2.4 An auto-mooring package utilizing an internal cable bale could behave erratically without active or passive control mechanisms to minimize the effects of the rapdily deployed cable.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following criteria are needed in this area.

3.1 Criteria are needed to guide the engineer in planning deployment techniques which most nearly satisfy his system requirements and limitations. In order to establish such criteria the following information is known or can be generated within the state of the art but is not documented at present: data concerning the surface and subsurface behavior of anchor systems; methods to suppress unwanted motions while on surface and during transit to the seafloor; analysis techniques to determine the magnitude of these motions; and techniques to determine line tensions during free fall deployment.

4.0 IMPACT OF RDT&E

The following RDT&E program has impact on developing criteria on the hydrodynamic behavior of anchor systems.

4.1 Anchor Installation for Expedient Moorings

SCOPE - One task related to this program is currently being conducted and concerns devising a means to free fall drop the CEL Deep Water Anchor.

IMPACT - This program should provide data on the surface and subsurface behavior of a free fall anchor with a self-contained cable system. It is anticipated that data generated from this effort will be useful in determining standards and criteria for hydrodynamic behavior of anchor systems.

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CEL Technical Note "Deep Water Anchor Expedient Mooring System," Port Hueneme, California (to be published).

5.0 RECOMMENDATIONS

It is recommended that considerable amount of existing data be collected and analyzed and used as a basis to develop standard analysis techniques to predict the motions of anchor systems and the line tension while the anchor systems are deployed on the surface and during transit to the seafloor. These analysis and prediction techniques can likely be developed from state-of-the-art knowledge in hydrodynamics; the results should be published as interim criteria.

POINT PAPER

MULTIPLE ANCHOR PROPERTIES

1.0 DEFINITION OF S/C AREA

The standards and criteria area involves configuration, spacing, interaction and resulting efficiency of multiple anchor systems and the criteria needed for their proper design.

2.0 APPLICABILITY

The following items discuss the importance of the determination of multiple anchor properties and the need for standards and criteria for this area in terms of applicability to the NAVFAC mission and impact on mission requirements.

2.1 Lack of Information

In many deep ocean moors, anchors are used in series, parallel, etc., because of system limitations or simply because of hardware unavailability. There is little or no information available on how to design this type of system or what to expect once emplaced.

2.2 Anchor Interaction

Anchors placed too close together can interact, resulting in reduced efficiency.

2.3 Anchor Combinations

Proper performance of an anchor can be impeded when combined with another anchor type. For example, complete burial of a standard anchor connected to a deadweight anchor will be prevented if the length of ground tackle between the anchors is too short.

2.4 Anchor Set Distance

Standard anchors joined at a common point through which unidirectional load is applied, must be properly spaced during deployment to adeqately account for set distance to ensure that the final anchorage configuration is most efficient.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following types of standards and criteria are needed in this area.

3.1 Design Criteria

Criteria are needed with which to determine the proper configuration, spacing, interaction, and resulting efficiency of multiple anchoring systems. The need for procedures to evaluate performance and to test in-situ are discussed under the seven point papers concerning the various parameters listed on the Parametric Descript TBS 4.0 "Holding Capacity."

4.0 IMPACT OF RDT&E

The following programs are identified as having an impact on developing standards and criteria for the area of multiple anchor properties.

4.1 Holding Capacity of Direct Embedment Anchors

SCOPE - One task related to the program is the determination of anchor holding capacity of direct embedment anchors.

IMPACT - This program should provide the data from which criteria can be developed concerning the proper spacing of multiple embedment anchors.

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PUBLICATIONS

R. M. Beard, "Status Report: Development of an Expedient Site Investigation Tool and Investigations in Long-Term Anchor Holding Capacity," CEL Report by Letter to NAVFAC (to be forwarded).

4.2 Performance of Conventional Anchors

SCOPE - Several tasks relating to this program concerned the performance evaluation of all Navy anchors and the design of an improved burial anchor.

IMPACT - This program provided considerable data regarding the set distances and holding capacity of many anchors.

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PUBLICATIONS

CEL TN-097, "Tests of Anchors for Moorings and Ground Tackle Design in Mud Bottom," Port Hueneme, CA, R. C. Towne, 15 December 1954.

CEL TN-195, "Tests and BUSHIPS Anchors in Mud and Sand Bottoms," Port Hueneme, CA, R. C. Towne and J. V. Stalcup, 5 August 1954.

CEL TN-066, "Tests of Anchors for Moorings and Ground Tackle Design," Port Hueneme, CA, R. C. Towne, 10 June 1953.

5.0 RECOMMENDATIONS

Work is recommended under the "Holding Capacity" area (listed under Parametric Descriptor TBS 4.0) to evaluate conventional anchor performance. The analytical and experimental investigations recommended will provide data that can be used to generate criteria for the proper design of multiple anchor systems.

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POINT PAPER

AUTOMATIC MOORING SYSTEMS

1.0 DEFINITION OF S/C AREA

The area of automatic mooring systems encompasses anchors, lines, deployment systems, transportation and launch systems, and appurtenances suitable for achieving an automatically deployed and installed anchorage. Included are special variations and features required to achieve rapid payout of the line, free-falling of the anchor and appurtenances, and high-speed actuation of components -- especially the anchor firing system.

2.0 APPLICABILITY

Anchors required for mooring fixed ocean facilities presently must be installed by using expensive ship's gear, requiring substantial installation time. Automatic mooring systems are needed to effect installations rapidly from most available ships of appropriate size, as well as from other carriers that may be uniquely expedient for particular applications. Such systems have been evaluated and a flexible standard package has been recommended for development during recent work at CEL. This standard package may be used as is or with slight modifications to fit many requirements. With add-on modifications to achieve glide-out or powered-out deployment, it also will satisfy requirements for installing single or multiple anchors at points laterally distant from the launch point, alleviating requirements for carrier attendance.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following standards and criteria are needed in this area:

3.1 Selection and Design Criteria

Criteria are needed for selection of suitable automatic mooring systems to fit user needs, and for the design of such mooring systems by modifying, expanding, or simplifying available systems or by developing new systems as necessary.

4.0 IMPACT OF RDT&E

The following program has an impact upon developing standards and criteria in the area of automatic mooring systems:

4.1 Anchor Installation for Expedient Moorings

SCOPE - One aspect of this program involves the development of an expedient mooring system for rapid installation of the CEL Deep Water Anchor and the associated line, connections, and buoy. The standard package recommended for development can be launched as a package to provide a taut-line single leg surface-moored buoy having a net vertical support capacity of 15,000 pounds at a scope of 1.5. Components may be deleted to obtain simpler packages for step-by-step deployment from a ship's deck or for providing a slack moor. A buoyancy-increasing buoy may be added to provide a submerged full-capacity moor. Deployment sequencing may be changed to provide a system which will sink to the seafloor before package separation when required. Also, a lateral deployment feature may be added.

IMPACT - Results of this work represent a single case of system selection to fit a broad range of needs. The same considerations can provide a framework for developing selection and design criteria for any broad or narrow requirement.

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Work Unit Assignment Summary, YF53.535.004.01.006

"Deep Water Anchor Expedient Mooring System," by D. G. True, J. A. Drelicharz, and J. E. Smith, CEL Technical Note (in publication).

5.0 RECOMMENDATIONS

It is recommended that criteria for selecting and/or designing automatic mooring systems be developed to suit foreseeable requirements. Results of the RDT&E cited in paragraph 4.1 could be used as a basic framework for the selection and design criteria.

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POINT PAPER

DEADWEIGHT PENETRATION

1.0 DEFINITION OF S/C AREA

Deadweight penetration is the embedment of deadweight clumps commonly used as anchors or in conjunction with drag-embedment anchors in anchor systems. Excluded are weights shaped to affect penetrations, as these are included in the area of "drag penetration."

2.0 APPLICABILITY

Positively buoyant fixed ocean facilities require anchoring support. In many cases, this support is best provided by a deadweight acting as an anchor or as part of an anchor system. Static and/or dynamic uplift and horizontal forces may be applied to such a deadweight, resulting in a static and/or dynamic net bearing pressure and a drag resistance being produced by the seafloor sediment. The horizontal and short-term vertical holding capacities are strongly influenced by the depth of penetration of the deadweight. Conventional bearing capacity and settlement prediction procedures for foundations can be used effectively to predict deadweight penetrations by taking account of the effects of dynamic loading and horizontal loading as well as the conventional vertical loading. Research is required to verify this method, and to evaluate empirical constants by laboratory model and full-scale field testing.

3.0 NEEDS FOR STANDARDS AND CRITERIA

Standard procedures are needed for predicting deadweight penetration under static and dynamic uplift and side loading.

4.0 IMPACT OF RDT&E

The program "Penetration and Breakout Forces Associated with Naval Equipment" has an impact on developing standards and criteria in the area of deadweight penetration.

SCOPE - Results of recently completed work in rapid penetration into seafloor soils may be applied to deadweight penetration. This work includes viscous effects related to penetration resistance.

IMPACT - Results are applicable in modifying conventional foundation technology to account for transient behavior not normally included in longer-term foundation analysis.

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Migliore, H., and Lee, H. J., "Seafloor Penetration Tests: Presentation and Analysis of Results," NCEL TN-1178, August 1971.

True, D. G., "Rapid Penetration into Seafloor Soils," Offshore Technology Conference Paper No. OTC-2095, Houston, Texas, May 1974.

True, D. G., "Penetration into Seafloor Soils," CEL TR- (in publication).

5.0 RECOMMENDATIONS

It is recommended that standard procedures for predicting deadweight anchor penetration be formulated by modifying conventional foundation prediction methods to account for combined horizontal/vertical loading and dynamic/static loading and viscous effects in the soil and published as interim standards. The interim standards which would be based on existing empirical data, should then be validated and empirical constants evaluated by laboratory tests and full-scale field tests in the ocean prior to adoption as standards.

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POINT PAPER

DRAG PENETRATION

1.0 DEFINITION OF S/C AREA

Drag penetration involves the embedment of a drag-embedment anchor and/or the flukes of such an anchor as the anchor is dragged by a horizontal pull. Drag-embedment anchors range from highly efficient (weight-wise) anchors such as the STATO anchor to shaped weights such as the mushroom anchor.

2.0 APPLICABILITY

Drag embedment anchors offer high ratios of holding capacity to anchor weight when loads are applied horizontally. They are used widely in shallow water and together with weight clumps in deep water. Knowledge of drag penetration is needed to select efficient anchors for particular needs, to design mooring systems, and to predict the depth of embedment of drag anchors considered for use near vulnerable buried objects. The following areas of applicability require knowledge of drag penetration.

2.1 Performance of Conventional Drag-Embedment Anchors

Prediction of drag penetration of conventional anchors/anchor flukes in various typed seafloor material is necessary for the efficient selection of a conventional anchor to satisfy any particular need.

2.2 Design of Improved Conventional and Nonconventional Drag-Embedment Anchors

Knowledge of the drag penetration behavior of practical anchor, fluke, and snag shapes will permit the efficient design of improved drag embedment anchors for deep ocean uses, potentially even in environments, on seafloors, and for structures not previously suited to drag-embedment anchors.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following standards and criteria are needed in this area:

3.1 Drag Penetration Data

Data are required on penetration depth and set distance for practical existing standard drag and burial anchors These data are needed as input into mooring system design and as baseline data from which analytical projections can be made to estimate the performance of new or untested anchors. A small amount of data is available but is insufficient to meet the needs.

3.2 Standard Analysis Procedures of Penetration Depth

Analytical procedures are required to predict penetration behavior of standard drag and burial anchors. This technique will preclude the requirement for testing each new anchor as it becomes available.

3.3 Selection Criteria

Criteria are needed for selection of conventional drag-embedment anchors to provide the required holding capacity and control of penetration depth in particular seafloor materials.

4.0 IMPACT OF RDT&E

The program "Penetration and Breakout Forces Associated with Naval Equipment" has an impact on developing standards and criteria in the area of drag penetration.

SCOPE - Results of recently completed work in rapid penetration into seafloor soils may be applied to drag penetration. This work includes the effects of viscosity and side adhesion on penetration resistance.

IMPACT - Results can be applied by also accounting for the effects of fluke rotation and normal pressure on side adhesion.

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PUBLICATIONS

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True, D. G., "Penetration into Seafloor Soils," CEL TR- (in publication).

5.0 RECOMMENDATIONS

It is recommended:

5.1 That drag penetration depth and set distances data be generated by performing laboratory model tests and, where necessary, verification by field tests.

5.2 That analytical procedures be developed to predict penetration behavior of standard drag and burial anchors.

5.3 That the data and the analytical procedures be combined into criteria for the selection of anchors.

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POINT PAPER

BALLISTIC PENETRATION INTO SEAFLOOR MATERIALS

1.0 DEFINITION OF S/C AREA

"Ballistic penetration into seafloor materials" includes the penetration of a freely falling object whereby the kinetic energy and the weight of the object cause it to penetrate a seafloor material. Such objects commonly are dropped or launched downward from a gun to achieve the required kinetic energy. This area encompasses objects having simple and nonsimple shapes, following vertical and nonvertical downward trajectories, and penetrating moderately to very deeply relative to object breadth. Ballistic penetration is rapid, such that velocity related factors including inertia and viscosity are important, whereas long-term material behavior such as creep relaxation is unimportant.

2.0 APPLICABILITY

Areas of applicability in anchoring in support of ocean engineering and construction include the following:

2.1 Direct-Embedment Anchors

Propellant-launched and free-fall dropped penetrating, direct-embedment anchors function by the deep embedment of an element to resist uplift and horizonal loading. Simply shaped penetrating objects can be engineered by using prediction procedures developed recently at CEL; more complex shapes require simplifying assumptions for analysis.

2.2 Dynamic Penetrometers

A dynamic penetrometer is an instrumented penetrating object, normally freely dropped to achieve the energy required for embedment. Dynamic penetrometers can provide an effective tool for site investigation for selection of the fluke size and embedment energy required for a penetrating anchor to sustain a given load. Penetrometer data can be interpreted based upon the results of work in dynamic penetration recently completed at CEL.

2.3 Free-Fall Corers

Freely dropped piston corers can be used for soil sampling to determine the engineering properties of a soil for anchor design/selection purposes. Knowledge of the aspects of development of penetration resistance can be used to optimize corer design and utilization procedures to obtain deep penetration and high-quality samples with reasonable levels of corer size handling and support requirements, and cost.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following standards and criteria are needed in this area:

3.1 Design Criteria and Procedures

Criteria and procedures are required to design penetrating objects to achieve desired depths of embedment utilizing available sources and amounts of launching energy. Also, criteria are needed upon which to base simplifying assumptions for the design of more complex objects to achieve desired penetration.

3.2 Standard Object Penetration Data

Data are required on performance of actual hardware during installation in seafloor soil and rock. Required data includes information on the characteristics of the penetrating object, the launching procedure, and the seafloor materials.

3.3 Penetrometer Standards

Standards are required for probe configuration and data interpretation for dynamic penetrometers.

3.4 Corer Design Criteria

Criteria are required for the optimum design of corers to attain sampling depths of interest for anchor design with minimal soil disturbance.

4.0 IMPACT OF RDT&E

The following programs have impact on developing standards and criteria in the area of ballistic penetration.

4.1 Penetration and Breakout Forces Associated with Naval Equipment

SCOPE - Results of recently completed work in rapid penetration into seafloor soils are directly applicable to ballistic penetration of simple objects and to the evaluation of soil shear strength from dynamic penetrometer data. Also, Results can be applied to complex objects by using simplifying assumptions. Knowledge of the components of penetration resistance gained from this work can be used to optimize corer design.

IMPACT - Application of results to ballistic penetration is direct for simple objects, but requires that simplifying assumptions be used to idealize nonsimple objects. Confidence in applications will require testing of these assumptions. Application of results to penetrometers and corers is direct, but involves considerable use of engineering judgement. Verification of such application will come with testing and utilization of the actual penetrometers and cores.

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True, D. G., "Penetration into Seafloor Soils," CEL TR- (in publication).

4.2 Long-Term Holding Capacity of Direct-Embedment Anchors

SCOPE - One aspect of this work involves the development of expendable penetrometers for use in site investigations for the engineering of direct-embedment anchors to fit user requirements.

IMPACT - Testing and utilization of penetrometers will verify data interpretation methods; monitoring of performance of direct-embedment anchors installed at sites investigated using these penetrometers will provide data for verification of anchor penetration predictions from penetrometer data.

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PUBLICATIONS

Work Unit Assignment Summary, YF53.535.002.01.014

Beard, R. M., "Status Report: Development of an Expedient Site Investigation Tool and Investigations in Long-Term Anchor Holding Capacity," CEL Report by Letter to NAVFAC, to be forwarded.

5.0 RECOMMENDATIONS

It is recommended that the S/C program (1) maintain cognizance of the on-going research in holding capacity of direct embedment anchors involving penetrometer utilization and effectiveness, (2) obtain anchor embedment depth and seafloor strength data from actual installations, (3) from these and other available data formulate interim standards and criteria to meet the needs cited in paragraph 3.0, above. For unlithified sediments the interim design criteria would be based on existing procedures; for rock more data on penetration needs to be generated in order to develop design criteria for ballistic penetration of rock.

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POINT PAPER

POWERED AND AIDED PENETRATION

1.0 DEFINITION OF S/C AREA

Powered and aided penetration encompasses the penetration of objects under the action of externally applied driving forces or powering devices and/or with the aid of special features or independent devices which tend to excavate soil in the penetration path, reduce friction, or otherwise reduce penetration resistance. Powering devices include impact, vibratory, and jacking and other thrusting drivers, and devices supplying torsional forces to screw-in appropriately shaped objects. Aids include friction-reducing materials and shapes, jetting, and target material friction mitigators such as electrical and/or chemical treatments.

2.0 APPLICABILITY

Deadweight, drag-embedment, and direct embedment anchors utilized in support of fixed ocean facilities all derive substantial enhancement of performance from increased penetration. Also, piles are a prominent type of object used for anchoring deriving substantial benefit from powering and aiding devices to achieve penetration. The use of drivers (impact or vibratory, for examples), thrusting devices such as jacks, inclined surfaces such as auger blades, or aids such as drills, dredgers, jetting nozzles, aiding nose shapes, or outside clearances to achieve the needed depth of embedment offers an alternative to brute force upgrading of performance by using heavier deadweight or drag-embedment anchors or higher velocities for ballistically embedded direct-embedment anchors. A single external driver may be used for several anchors, reducing overall cost. Distress to anchors and peripheral components may be reduced substantially at no sacrifice in embedment depth by simultaneously reducing driving energy and utilizing aids to reduce penetration resistance, thereby possibly also reducing overall system weight and cost.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following standards and criteria are needed in this area:

3.1 Design Data

Data are needed for the design of deep-ocean drivers.

3.2 Design Criteria

Criteria are needed for the selection of viable aids for practical anchors, and for the optimum design of the integrated aided anchor.

3.3 Standard Prediction Procedures

Standard procedures are needed for the prediction of penetration behavior under the actions of driving forces or torques and resistance-reducing aids.

4.0 IMPACT OF RDT&E

The program "Penetration and Breakout Forces Associated with Naval Equipment" has an impact on developing standards and criteria in the area of powered and aided penetration.

SCOPE - Results of recently completed work in rapid penetration into seafloor soils may be applied to powered and aided penetration. This work includes dynamic effects, related to powered penetration, and soil contributions to penetration resistance related to the effects of aids in reducing resistance to penetration.

IMPACT - Driving forces can be included directly in the penetrator equation of motion recommended for prediction in the cited work. However, the possibility that repetitive loading and/or reversal of loading direction may alter behavior by changing soil resistance or system dynamics must be examined before predictions can be made with confidence. Simplifying assumptions are required to idealize the effects of soil alteration by aids; these must be verified by actual use data on aided penetration.

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True, D. G., "Penetration into Seafloor Soils," CEL TR-
(in publication).

5.0 RECOMMENDATIONS

It is recommended:

5.1 That the data needed for the design of deep-ocean drivers and for the evaluation of performance of penetration aiding devices be obtained.

5.2 That work to formulate the cited needed standards and criteria from these and other available data be performed.

5.3 That interim standards and criteria be prepared using existing data on impact, vibratory, and jacking penetration. Reasonable interim standards can be generated with existing data; however, these procedures should be updated using data for deep ocean installations. Screw-in penetration and penetration using new thrusting devices will require data and analysis.

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POINT PAPER

ANCHOR PULLOUT FORCE AND DIRECTION

1.0 DEFINITION OF S/C AREA

This standards and criteria area considers the force required to remove any type of anchor from a state of partial or total embedment in the seafloor. All types of loadings are considered (short-term static, long-term static, dynamic). The influence of the direction of the line load on the required pullout load is also considered.

2.0 APPLICABILITY

The utilization of positively buoyant moored structures, moored ships, and moored buoys requires anchorage systems designed to withstand certain line loads without pulling out. It is necessary to be able to predict these allowable forces if reliable anchorages are to be achieved. The allowable forces will be related to the seafloor sediment or rock properties, the nature of the loading, and the direction of the loading.

3.0 NEEDS FOR STANDARDS AND CRITERIA

The following types of standards and criteria are needed in this area.

3.1 Standard Procedures for Predicting the Static Pullout Force for Conventional Anchors

Conventional drag and dead weight type anchors are used in many practical O/E operations. Currently only rough rules exist for predicting the holding capacities of these anchors under the various possible horizontal, vertical, and dynamic loadings. These rules do not consider the sediment engineering properties (with the exception of rough sediment type classifications such as sand or mud) and are probably highly overconservative for most applications. Research is needed to improve these prediction procedures so that high design holding capacities can be achieved with lower weight anchors. These procedures should utilize the soil engineering properties to increase the anticipated accuracy of the procedures. These improved procedures should be verified and ultimately documented as standards for use by the ocean engineering community.

3.2 Standard Procedures for Predicting the Static Pullout Force for Direct Embedment Anchors

Direct embedment type anchors are used in a variety of special purpose, generally critical, mooring situations. Considerable research has been, and is being conducted to develop accurate procedures to predict the holding capacities of these anchors. The most advanced of these procedures need to be documented as standards.

3.3 Criteria for Selecting Site Surveys to Obtain Necessary Sediment Design Parameters

In many situations it is not clear to the design engineer what site soil parameters are needed to design a moored facility or how these parameters can be best obtained. Guidelines need to be established to advise the engineer as to the nature of site survey required for each of the possible anchored installations.

3.4 Criteria for Selecting Suitable Sites for Anchored Installations

In many situations it may be possible to vary the location of an anchored installation in order to take advantage of the most favorable bottom conditions. However, it may be difficult to state which conditions are favorable and which are not. Guidelines are needed to assist the engineer in selecting the best site.

3.5 Standard Procedures for Evaluating Interactions Among Anchors in Muliple Anchor Systems

If the anchors in a muliple anchor system are placed closely together, they may interact with each other. That is, the total holding capacity may be less than the sum of the individual holding capacities. Research is needed to identify the extent of these interactions and procedures need to be developed to predict them.

4.0 IMPACT OF RDT&E

The following programs are identified as having an impact on the standards and criteria area of anchor pullout force and direction.

4.1 Holding Capacity of Direct Embedment Anchors

SCOPE - Procedures will be developed for predicting the holding capacity of direct embedment anchors. Laboratory model testing and computer analyses will be performed and evaluated through field testing.

IMPACT - The results of this test program can serve as interim standards for 3.2 above.

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PUBLICATIONS

CEL Report by Letter, "Status Report: Development of an Expedient Site Investigation Tool and Investigations in Long-Term Anchor Holding Capacity," by R. M. Beard, to NAVFAC (to be forwarded).

4.2 Anchors for Mooring Navy Equipment in the Deep Sea

SCOPE - Considered procedures for predicting direct embedment anchor holding capacity. Work at CEL in this area now covered by paragraph 4.1.

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PUBLICATIONS

R. J. Taylor and H. J. Lee, "Direct Embedment Anchor Holding Capacity," CEL Technical Note N-1245, Port Hueneme, CA, December 1972.

4.3 Model Study of Long-Term Anchor Holding Capacity

SCOPE - Laboratory model analysis of long-term repeated load holding capacity of direct embedment anchors.

IMPACT - Input into work of paragraph 4.1.

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PUBLICATIONS

S. M. Bemben and E. H. Kalajian, "The Vertical Holding Capacity of Marine Anchors in Sand and Clay Subjected to Static and Cyclic Loading," Preprints, Offshore Technology Conference, Houston, Texas, 1973.

4.4 Research on Holding Capacity of Conventional Anchors

SCOPE - Developed empirical guidelines for estimating conventional anchor holding capacities.

IMPACT - Guidelines can serve as preliminary standards.

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PUBLICATIONS

Major results have been incorporated into Navy Design Manual DM 26.

4.5 Model Studies of Anchor Holding Capacities

SCOPE - Series of short-term model tests conducted to measure direct embedment anchor holding capacities.

IMPACT - Has been used as input into more recent research.

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PUBLICATIONS - Numerous, most recent:

A. S. Vesic, "Breakout Resistance of Objects Embedded in Ocean Bottom," ASCE Conference, Civil Engineering in the Oceans II, 1969.

4.6 Model Studies of Transmission Line Tower Anchorages

SCOPE - Short- and long-term model studies of transmision tower anchorage (similar to direct embedment anchors).

IMPACT - Results have been used as input in paragraph 4.1.

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PUBLICATIONS

G. G. Meyerhof and J. J. Adams, "The Ultimate Uplift Capacity of Foundations," Canadian Geotechnical Journal, Vol. 5, No. 4, November 1968.

5.0 RECOMMENDATIONS

It is recommended:

5.1 That interim standard procedures for predicting the static pullout force for direct embedment anchors be prepared based on work completed and currently underway at CEL. (See paragraph 3.2)

5.2 That new data be generated concerning holding capacities of deadweight and drag anchors as well as interactions among anchors in multiple anchor systems, all under various horizontal, vertical, and dynamic loadings. This data is needed for future standard procedures for predicting pullout of conventional anchors and interaction of anchors in groups (see paragraphs 3.1 and 3.5, above).

5.3 That criteria for selecting site surveys and criteria for selecting suitable sites for anchors be developed by working with individuals knowledgeable in practical anchorage operations and seafloor sediment behavior.

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POINT PAPER

ANCHOR LOAD-DISPLACEMENT BEHAVIOR

1.0 DEFINITION OF S/C AREA

This standards and criteria area considers the lateral or vertical displacement of anchors under applied line loadings. Complete pullout is considered in a separate standards and criteria area. All types of loadings are considered (short-term static, long-term static, dynamic).

2.0 APPLICABILITY

The utilization of positively buoyant moored structures, moored ships, and moored buoys may require anchorage systems which do not displace significantly under load. Drag-type conventional anchors are especially susceptible to being displaced large distances laterally rather than being pulled out. It would be desirable to be able to predict how far an anchor will move under a given applied load condition.

3.0 NEEDS FOR STANDARDS AND CRITERIA

3.1 Standard Procedures for Estimating Load-Displacement Behavior of Conventional Anchors

Conventional drag and dead weight type anchors are used in many practical O/E operations. Currently, only rough rules exist for predicting how far these anchors will move under applied loads. These rules do not take into account the material properties of the sediment. Research is needed to improve the prediction procedures so that ultimately they can be instituted as standards.

3.2 Standard Procedures for Estimating Load Displacement Behavior of Direct Embedment Anchors

Direct embedment-type anchors are used in a variety of special purpose, generally critical, mooring situations. Considerable research has been, and is being, conducted to develop accurate procedures to predict direct embedment anchor holding capacities and (to a lesser extent) load-displacement characteristics. The most advanced of these procedures need to be documented as standards.

3.3 Criteria for Evaluating the Acceptability of Estimated Displacements

Guidelines are needed for determining whether the predicted anchor vertical or horizontal displacements are tolerable for specific applications.

4.0 IMPACT OF RDT&E

Programs which could have an impact on the standards and criteria area of anchor load-displacement behavior are the same as those listed for the standards and criteria area of anchor pullout force and direction. While none of these programs specifically addresses the problem of load-displacement behavior, all contribute data which could be used in the analysis of this problem.

5.0 RECOMMENDATIONS

It is recommended:

5.1 That criteria for determining tolerable anchor displacements for specific applications be developed. This can best be accomplished through working with individuals in the fields of anchorage systems and soil mechanics and with individuals knowledgeable in the specific performance requirements of FOF's.

5.2 That procedures for predicting load-displacement behavior be developed during programs to develop procedures for predicting ultimate holding capacity (as recommended under "anchor pullout force and direction"). Procedures for direct embedment anchors can be prepared as interim standards based on available data; for conventional anchors more data needs to be generated before standards can be developed.

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POINT PAPER

SOIL PROPERTIES FOR HOLDING CAPACITY PREDICTION

1.0 DEFINITION OF S/C AREA

The determination of the undisturbed, in-place seafloor soil properties is covered in the AAT "Seafloor Soil Sampling and Testing." However, the emplacement of a conventional or direct embedment anchor can change these properties through disturbance and remolding. Following emplacement the properties change again through reconsolidation and thixotropy. This standards and criteria area considers the changes in soil properties which result from anchor installation.

2.0 APPLICABILITY

All types of anchors disturb or remold the sediment during installation, some to a greater extent than others. The holding capacity which the anchor is capable of developing is related to how much disturbance occurs. In order to design reliable anchorage, it is necessary to be able to evaluate this disturbance.

3.0 NEEDS FOR STANDARDS AND CRITERIA

3.1 Standard Procedure for Evaluating Changes in Soil Strength Produced by Anchor Installation

Procedures, probably empirical and based on field testing, need to be developed for predicting soil remolding resulting from anchor installation. The procedures should involve correlations with soil laboratory properties, e.g., sensitivity. These procedures should in turn be documented as standards.

3.2 Standard Procedure for Including Partially Remolded Strengths in Holding Capacity Predictions

An anchor mobilizes its holding capacity by stressing a large volume of soil. Only a portion of this soil is remolded during installation. Procedures need to be developed which take into account this variation in soil remolding over the volume of stressed soil.

4.0 IMPACT OF RDT&E

No research has been conducted to investigate the problem of soil disturbance during anchor installation. However, the effects of this disturbance have been observed during direct embedment anchor tests. The following program has been proposed to investigate this problem; current plans are to complete the work during FY75.

4.1 Evaluation of Embedment Anchor Holding Capacity Predictions

SCOPE - Would include mud flat field tests of an embedment anchor. Properties before and after installation would be measured, as would the anchor holding capacities.

IMPACT - Results of program would serve as interim standards.

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5.0 RECOMMENDATIONS

It is recommended that the results of the research program described above be used by the S/C program as interim standards.

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PRIORITIES OF S/C AREAS

RANKING

The S/C areas within the AAT "Anchor Systems" are ranked in the following order of relative priorities:

PD TBS Number	S/C Area	Relative Priority
4.2	Anchor Pullout Force and Direction	1
4.1.3	Ballistic Penetration	1
4.1.2	Drag Penetration	1
4.4	Soil Properties for Holding Capacity Prediction	1
4.3	Anchor Load/Displacement Behavior	1
1.1	Anchor Characteristics	2
4.1.1	Deadweight Penetration	2
1.1.1	Acoustic Energy Emission	3
1.2.3	Abrasion of Anchor System Ground Tackle	3
3.1	Multiple Anchor Properties	3
2.3	Installation Time of Anchor Systems	4
2.4	Hydrodynamics of Anchor Systems	4
3.2	Automatic Mooring Systems	4
4.1.4	Powered and Aided Penetration	4

RATIONALE

Applications. One of NAVFAC's most important OE/C mission requirements at the present time is the capability to design and construct large multi-legged moorings in the deep ocean that are structurally stiff and stable and maintain the position of the components relative to each other essentially unchanged over long periods of time. Such a mooring system requires anchors that are readily deployable in deep water, can be accurately emplaced, have a predictable holding capacity, have high holding capacity against horizontal and vertical loads, and do not creep significantly during the design life.

Other NAVFAC missions require single- and multi-leg moorings of buoys, platforms, and a variety of other surface and subsurface structures and equipment used for environmental monitoring and predictions, oceanographic research, and tracking ranges (for impact location, underwater weapons R&D, fleet training, etc.). These moorings require the design and installation of a variety of types and sizes of anchors in the deep ocean.

Priority "1". The five S/C areas ranked as Priority "1" have immediate application to the design of such moored systems. Some Interim Criteria can be established from existing data. However, there is a lack of information in penetration, pullout, and holding capacity prediction that will require additional research. Standard test procedures are necessary to improve predictability of performance (particularly long-term reliability) of anchors and to improve the designer's ability to design efficient mooring systems. It is important to have the information now (early in the program) because results obtained will be a determining factor on choice of not only which anchor systems to use now but which anchor systems should be given priority for development for future use.

Priority "2". The areas listed under Priority "2" should be addressed prior to the design of any strategically significant FOF's. The compilation of anchor characteristics data is necessary to assure that adequate consideration has been given to all potential anchoring candidates.

The area defining deadweight penetration is significant because this anchoring approach is being considered in many important installations. Knowledge of deadweight penetration between is a necessity if the impact of this type anchor on a mooring system is correctly considered.

Priority "3" includes three areas: acoustic energy emission, abrasion of anchor system ground tackle, and multiple anchor properties. Work in these areas is necessary at some time in the program because the derived information will impact FOF mooring design in that certain equipment may be unsuitable for certain applications. The designer should have this information during a detailed design effort.

Priority "4". The items listed under Priority "4" generally refer primarily to systems or procedures that may or may not be considered in future FOF's. However, as these areas become pertinent, and it is probable that most will, then they should be considered. An exception is the installation time area which will become extremely pertinent when installation planning and scheduling of sophisticated FOF's is performed.

Interim S/C. Interim design criteria and/or standards can be prepared at this time to meet at least a portion of the needs in each of the following nine S/C areas:

- Anchor Characteristics
- Acoustic Energy Emission
- Abrasion of Anchor Systems Ground Tackle
- Installation Time of Anchor Systems
- Hydrodynamics of Anchor Systems
- Deadweight Penetration
- Ballistic Penetration
- Powered and Aided Penetration
- Anchor Pullout Force and Direction

The interim S/C would be based on existing information that is either already documented or, in some cases, would need to be collected from individuals (e.g., field personnel) and documented. Preparation and publication of such interim S/C would provide a near-term impact on NAVFAC OE/C mission requirements.

Existing data are not available now in the other five S/C areas although, based on present R&D plans, holding capacity prediction information will likely be available in about one year.

REFERENCES

1. ''Ocean Engineering and Construction Standards and Criteria Program, Guidelines for Conducting the Phase I Study,'' Ocean Engineering and Construction Project Office, Chesapeake Division, Naval Facilities Engineering Command, Washington, D.C., 25 Jan 1974.

2. Ocean Facilities Engineering Criteria and Methods Program, Phase Ia, Report No. 1, Area of Technology: Anchor Systems, Civil Engineering Laboratory, Port Hueneme, California, Dec 1974.