The MIT Marine Industry Collegium
Opportunity Brief #17

Risks and Costs for Ocean Structures

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The MIT/Marine Industry Collegium

RISKS AND COSTS FOR OCEAN STRUCTURES

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PREFACE

This Opportunity Brief and the accompanying Workshop (held on May 9, 1979) were presented as part of the MIT/Marine Industry Collegium program, which is supported by the NOAA Office of Sea Grant, by MIT and by the more than 90 corporations and government agencies who are members of the Collegium. In this instance, the Workshop was presented jointly with the MIT Industrial Liaison Program in its series of Symposia. The underlying studies at MIT were carried out under the leadership of five faculty members: Professors Jerome C. Connor, Jr., Charles C. Ladd, Mohsen M. Baligh, and Gregory B. Baecher and Dr. W. Allen Marr. However, the author remains responsible for the assertions and conclusions presented herein.

Through Opportunity Briefs, Workshops, and other interactions the Collegium provides a means for technology transfer among academia, industry and government for mutual profit. For more information, contact the Marine Industry Advisory Services, MIT Sea Grant, at 617-253-4434.

John B. Bidwell

1 July, 1979

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1.0 A Business Perspective

A significant part of the high cost of building large offshore structures results from having to "over-design" to compensate for uncertainties in critical engineering parameters. Lacking more certain information on soil properties, on interaction of structures and foundations under fluctuating loads from wind and waves, and on other factors, designers have no choice but to incorporate very large and costly factors of safety.

Investigators at the Massachusetts Institute of Technology are working on a number of separate projects to advance techniques for measuring, modeling, and analyzing some of the critical engineering parameters, and the uncertainties associated with them. The end goal of these separate projects is to enhance both theory and practice in the design of offshore structures in order to reduce the risk and cost of building in the ocean. In the work presented here, this is being done by reducing some uncertainties and by better assessing the potential effects of others.

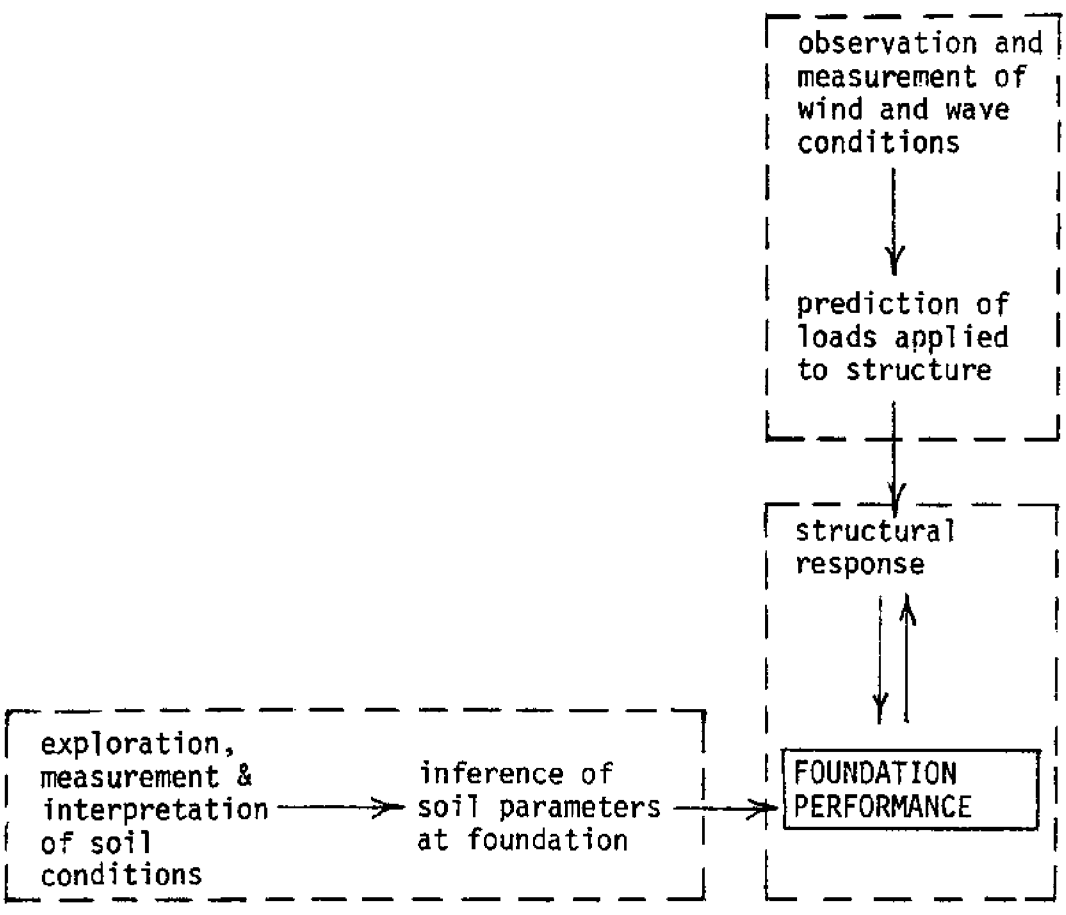
This Opportunity Brief summarizes five projects. The topics are:

1. A Review of Geotechnical Exploration Techniques
2. New Techniques for In Situ Measurements in a Marine Clay
3. Risk Analysis Applied to the Design of Offshore Structures
4. An Analysis of Long-Term Displacement of a Gravity Foundation Under Wave Loading
5. A Probabilistic Model for Degradation of Foundation Stiffness in Steel Jacket Structures Under Wave and Seismic Loads.

For those who provide services associated with planning, designing, operating and maintaining offshore structures, the topics provide insight into future directions and needs for new investigative techniques and methods of analysis. To do more than outline each of the five topics is beyond the scope of this Brief. It is our intention to present short summaries of the problems being addressed and a general indication of the approach that the solutions are taking. Viewed in total, these separate topics form a unified basis for approaching design of offshore structures in a more integrated way that strikes a better balance between costs and the risks associated with uncertainty.

2.0 Survey of Recent Work

Three domains of uncertainty affect the design and performance of offshore structures. One domain encompasses the sampling and testing of offshore soils and the extrapolation of soil conditions from discrete sampling points to areas under planned foundations. Another domain arises in considering the pattern of forces on offshore structures to be expected from winds and waves. The third arises in modeling the interaction of the system of sea/structure/foundation/soil. The following sections describe work at MIT oriented toward reducing the uncertainties in each of these three domains.



Propagation of Error in Predicting Geotechnical Performance

2.1 A State-of-the-Art Review

The predictive value of models in soil mechanics is determined to a large extent by the accuracy and reliability of input data. C.C. Ladd (in Reference 1) identifies and summarizes the principal soil parameters used to predict stability and deformation of foundation strata and also describes offshore geotechnical techniques of drilling, sampling and testing to evaluate these parameters.

There are two basic approaches to evaluation of parameters, laboratory testing and <u>in situ</u> testing. Empirical correlation with properties that act as indices of soil conditions may be involved in both approaches.

Laboratory tests have the advantage of being easier to control, but with greater uncertainty about applicability of the results to <u>in situ</u> conditions. Most of the advances in laboratory testing in recent years have been in improving ways of simulating <u>in situ</u> conditions. These developments include new and improved types of laboratory equipment ranging from modifications of conventional apparatus, such as the consolidometer cell, to sophisticated new devices, such as those for true triaxial shear measurements and for centrifugal model testing. The disturbance of <u>in situ</u> conditions by extraction of a soil sample remains a problem, but today less so for cohesive clays than for cohesionless sands.

Advances in laboratory testing procedures involving this new equipment have resulted from a greater understanding of the principal factors affecting the behavior of soils. Especially significant has been the recognition of the importance of simulating in the lab the <u>in situ</u>

initial stresses and the applied stress system. Ladd's work in particular has focused on techniques for reconsolidation in the laboratory of field samples of cohesive soils. An important result has been development of the SHANSEP technique (Stress History and Normalized Soil Engineering Properties), a design procedure for deriving strength-deformation properties of clay deposits that can be normalized with respect to consolidation stresses (see Reference 2).

2.2 In Situ Measurements

M. M. Bàligh is investigating new instruments and techniques for performing in situ measurements in marine clays. These investigations, which were the subject of an earlier Opportunity Brief, show considerable promise for avoiding the severe problems associated with the disturbance of samples tested in the laboratory. The techniques appear to improve measurements of soil variability and to reduce testing costs.

A current method of providing samples for routine classification and for indicating the consistency of clays and density of sands is the Standard Penetration Test. This test is considered indispensable in preliminary exploration programs. However, it does disturb the samples and is criticized for the crudeness of the technique and the unreliability of the data it produces, especially offshore. Despite the difficulties, in the United States the Standard Penetration Test is still used for offshore work. However, it may be superseded in the not-too-distant future by the Dutch cone test, which is regularly used in soil investigations in the North Sea.

The Dutch cone test is a simple device that measures the soil's resistance to penetration, from which other important parameters can be deduced. Another device described by Baligh, a piezometer, measures the pressure of the water in the pores between the solid grains of the soil. Measurements of penetration resistance and pore pressure together are used to estimate the undrained shear strength of the soil, the effective stress applied to the skeleton of soil particles, the location of various strata through which the instruments pass on their descent, and even the types of soil in the strata. The possibility of combining measurements of cone resistance and pore water pressure in a single instrument represents a useful and exciting prospect for the future.

2.3 A Systematic Treatment of Uncertainties

G. B. Baecher focuses on the consistent and coherent treatment of uncertainties in the behavior of foundations of offshore structures. His goal is to identify sources of uncertainty and their relative magnitudes, and procedures for incorporating them in analysis.

Uncertainties arise from inadequate knowledge of undersea soil conditions, from natural randomness of loads applied to structures in the offshore environment, and from inadequate models for predicting the behavior of foundations given the soil and sea conditions.

Estimation of soil conditions gives rise to uncertainties about the spatial variation of properties within given strata, about boundary conditions and the locations of different strata, and about the possible existence of geological details or anomalies within strata, such as clay or sand lenses. In this work, statistical techniques are applied to inferences of soil conditions from measurements taken in programs of field exploration. Most of the techniques of these analyses have been developed and tested at MIT for various applications, here including extension to offshore conditions.

The second source of uncertainty, that due to loading, is taken from parallel efforts as discussed in the presentations to follow.

The third source of uncertainty is introduced by the very fact of using models. Even if soil and sea conditions were fully known, the use of models would introduce errors caused by uncertainty in initial and boundary conditions, structural relations, theoretical understanding, numerical approximations and omissions. These uncertainties can be only partially resolved using alternative models, since modeling errors are often highly correlated. To some extent this problem can be addressed by analyzing variances and covariances among modeling errors and, hence, by providing estimates of combined uncertainties.

2.4 Displacement of a Gravity Foundation

W. A. Marr is investigating the displacements of gravity foundations on cohesionless soil. When samples of sands are subjected in the laboratory to cyclic stresses typical of offshore structures loaded by waves, permanent strains develop. The state of initial stress and the change in stress from applying the weight of the structure has proven important to the development of permanent strain. Marr discusses a program of laboratory tests to determine the relationships between the strains developed and the initial state of stress, the pattern of cyclic stresses applied, the density of the sample, and the number of cycles of applied load.

With the parameters derived from laboratory tests, permanent deformations under a foundation can be predicted with a computer program that uses the finite element method and that incorporates a stress-strain relation for permanent deformations resulting from cyclic loads. Different combinations of wave loadings or "design storms" can be used to determine a range of anticipated displacements of the structure. These calculated displacements for different storms then may be combined with probabilistic representations of storm loads to obtain an estimate of one type of uncertainty in the displacement of an offshore foundation.

The computer program is first used to generate the stresses from a selected "design storm." Then in the laboratory these stresses are applied to a sample of the soil to simulate key points in the foundaton. Next the computer is used to determine the pattern of stresses and strains in the overall structure that are consistent with behavior measured in the laboratory tests for the selected points. In the workshop presentation, calculated displacements for a major facility were shown to illustrate the procedure.

2.5 Modeling Stiffness Degradation in Steel Jacket Structures

J. J. Connor, Jr. presents an integrated method for analyzing steel jacket offshore structures in a non-stationary wave environment. A pile foundation on a cohesive or clay soil is considered.

The analysis begins with a deterministic modeling of the upper structure coupled with a similar model of the degradation of the stiffness of the foundation. A probabilistic model generates histories of wave loads that might be experienced by the structure. For each of a set of starting stiffnesses of the foundation, "n" hundreds of histories of storm loadings are run through the model of the foundation, producing "n" hundreds of responses. These are converted to a probability distribution of the foundation response to a single storm, measured in terms of the structure's stiffness at the conclusion of the storm, given its stiffness at the start. A set of such distributions for the range of starting stiffnesses constitutes a matrix of probabilities for state-transition of the foundation. Given the probability of being in any given initial state of stiffness, this Markov process matrix is used in a fourth model to analyze the time to failure of the structure in terms of numbers of storms.

This combination of models couples improved deterministic modeling of structure with improved probabilistic modeling of storm loads. Numerical studies using the models concluded that uncertainties in soil conditions are especially important. In these studies, for reasonable shifts in the values of soil properties, the response of the foundation to applied loads shifted significantly. As with Marr's analysis of a gravity foundation, the history of the application of stress is found to be an important element in predicting when a structure will fail.

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