FINAL TECHNICAL REPORT

SUBPROJECT CNRD 13-1

submitted
to
Conoco Norway, Inc.

through
Det norske Veritas
Oslo, Norway

by
Ertec, Inc.
One West Loop South, Suite 801
Houston, Texas

August 28, 1981

Project No. 81-204

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August 28, 1981
Project No. 81-204

Det Norske Veritas
Veritasveien 1
N-1322 HØVIK
Oslo, Norway

Attention: Mr. Tore J. Kvalstad

Subject: Final Report
Tension Pile Planning Study
Conoco Norway, Inc.
Subproject CNRD 13-1

Gentlemen:

In accordance with the contract between Ertec, Inc. and Det norske Veritas effective June 18, 1981, submitted herein is our Final Report for the subject study. This report presents the results of our completed work on Tasks 1 through 7 as described in the contract Technical Specifications, Exhibit "B".

Distribution of this report is as shown below. It is requested that Veritas forward the three copies designated for Conoco Norway.

If there are questions concerning this report or any other aspects of the study, please contact us. We appreciate the opportunity to conduct this study and look forward to performing the recommended field test program. As planned, Ertec representatives are scheduled to meet with Veritas and Conoco in Oslo during early September to further discuss the details of the proposed program.

Sincerely,

David F. Leake, P.E.
Manager, Gulf States Region

Distribution: (2) Det norske Veritas

(3) Conoco Norway, Inc.
Attention: R. L. Gratz

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PREFACE

Conoco is presently designing the first prototype tension leg platform (TLP) for the Hutton field and considers this platform type feasible for other deepwater sites. The TLP concept involves design and installation of foundation piles capable of withstanding large tensile forces produced by the buoyant platform. Tension pile behavior under cyclic loading is poorly understood at the present.

In order to advance this understanding, Conoco has authorized Veritas and Ertec, as a designated subcontractor, to conduct a planning study addressing all aspects of performing a comprehensive pile load test program, with the objective of improving tension pile design procedures. The comprehensive test program was to define a study involving a large scale field test of an instrumented pile and a laboratory model test study.

Authorization for the tension pile test planning study was provided in a contract between Veritas and Conoco Norway and designated as Subproject CNRD 13-1. As a part of this study, Ertec was subcontracted, as designated, to Veritas effective June 18, 1981. Although working jointly toward a common objective, in effect Veritas was responsible for the planning of the laboratory test program and Ertec was responsible for planning of the large scale field test of an instrumented pile.

The results of this planning study for the large scale field test program are presented in this final report. The study has been prepared through the joint efforts of several Ertec, Inc. professional engineers with the cooperation and assistance of personnel from Conoco, Inc., Houston.

Overall project planning and administration was conducted by Thomas K. Hamilton. J. Dewaine Bogard and Ronald L. Boggess were responsible for instrumentation feasibility. Liaison with Conoco and investigation of operational aspects were handled by G. Leon Holloway.

David Stuessy and Lino Cheang conducted the literature review. Ignatius Po Lam assisted in this review and assessed existing analytical methods.

Conoco, Houston supported the Ertec staff with Jack H.C. Chan and Harold V. Phenix providing pertinent technical data. Assistance in evaluation of operational matters was furnished by Horace F. House.

Hudson Matlock provided general guidance in the conduct of this study. This report has been reviewed by Hudson Matlock, David F. Leake, and Jean M. E. Audibert.

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EXECUTIVE SUMMARY

Introduction

Conoco is sponsoring a research program with the objective of improving the understanding of pile-soil interaction during cyclic tensile loading. Such loading is expected to be produced by a deep-water Tension Leg Platform (TLP). The first portion of the program is a twelve week planning study to produce a recommended procedure for conducting the program. Emphasis is to be placed on application of the results to Gulf of Mexico Blocks 864 and 908 of Viosca Knoll and Blocks 137 and 184 of Green Canyon.

Ertec, Inc., working as a designated subcontractor to Det norske Veritas, has been requested to plan a field test study for the program. An Interim Technical Report (ITR) submitted by Ertec on 16 June 1981, presented the results of the study completed as of that date including feasibility of, and recommendations for, the field test program. A meeting was held in Houston on 13 August 1981 and was attended by representatives of Ertec, Veritas, and Conoco. The information presented in the ITR as well as pertinent data compiled by Ertec subsequent to submission of the ITR was discussed in detail. Based on evaluation of the alternative test sites it was unanimously agreed by all parties that the planning study should be oriented to developing expanded plans for conducting the test program at an offshore site.

This final report describes the work completed in the course of the twelve-week planning study. Included within this document are portions of the ITR.

Background and Feasibility Study

The initial sections of this report include a survey of existing literature pertaining to pile capacity prediction methods. It was concluded that present technology does not adequately address the special problems of tension leg platform foundations where piles are loaded cyclically in tension.

The need for identification of some appropriate theoretical concepts was addressed. Relevant existing computer programs were reviewed which would be used, or modified for use, in the project. The need for a more versatile constitutive soil model was also noted.

The requirement for the field testing program and the feasibility of such a program have been evaluated. Onshore and offshore candidate sites were reviewed. The resulting review and evaluation led to the selection of a site in the West Delta area of the Gulf of Mexico as the recommended test location.

A two-phase field testing program was recommended. This program would consist of small-diameter segment tests and a large-diameter deep pile test at the West Delta location. This Final Report addresses the program in detail.

Recommended Program

The first phase of the recommended field program would consist of testing a small segment in the same stratum where a large-diameter pile would subsequently be tested. Instrumentation of the small segment would be similar to that of the large pile and would specifically have the ability to measure shear transfer, displacement, total soil pressure and pore water pressure. Both peak and degraded values of skin friction would be measured.

The advantage of the small segment experiments, performed well in advance of the large-diameter test, is that parameters can be investigated at various stages of consolidation and loading history. Because of the smaller diameter, consolidation times will be much shorter, allowing multiple tests to be performed at different periods of time after insertion of the tool. The results of the small-diameter segment test will be used to develop and calibrate a predictive model which will provide confidence in extrapolating the results of the experiments using a 76.2 cm. (30 in.) diameter test pile to larger prototype pile sizes.

The second phase of the field testing program would consist of construction, installation, and testing of an instrumented pile offshore. The plan calls for a pile with 67 m. (220 ft.) embedded length, and a diameter of 76.2 cm. (30 in.)

Measurements of load, total soil pressure and pore water pressure would be made at approximately 9.1 m. (30 ft.) intervals along the embedded section. Load and displacement would also be measured at the pile head.

Three test periods are planned. The first would occur immediately after installation to obtain an as-driven capacity. The second would involve a series of tests which would take place after a consolidation period corresponding to that expected for larger prototype TLP piles. The testing program would include application of a bias tension load, and cycling at predetermined percentages of the expected initial ultimate load. A sophisticated data acquisition system would be used to sample and process data from each of the instrument stations. A third series of tests would occur after a long set-up period, possibly up to one year. The sequence of testing would essentially be the same as that previously performed. The purpose of this test sequence would be to determine the effects of continued consolidation and to investigate the permanence or the healing of frictional degradation due to cycling from earlier testing periods.

The results of the research program will be presented after the second field test in a final report. This report would include results of both small and large-diameter pile tests, the results of parallel theoretical development efforts and recommendations for TLP foundation design.

At the conclusion of the described research program, preparation of general guideline specifications for the design of tension leg platform foundations in soft clay will begin. These specifications would be based on the results of the research program but would also address items such as site investigation and laboratory and field testing requirements.

The total cost of the program is estimated to be $2,735,351. Of this amount, Ertec's fee would be $1,769,331, including a 25% risk and uncertainties factor. Since a large portion of the project cost involves fabrication and offshore construction, it would be advantageous for Conoco to procure those services directly. The estimated costs which Conoco would incur would be approximately $966,020.

The project schedule was developed to fit the field installation and testing periods, which must aim for good-weather conditions. For this reason it is extremely important to begin work by the designated project start date of 1 October 1981.

REVIEW OF PERTINENT LITERATURE

General

The existing technology relevant to the design of pile foundations for tension leg platforms is based on studies of the frictional component of pile capacity. Several methods of analysis have been used in research and practice to estimate the frictional capacity of piles, with varying (or unknown) degrees of accuracy. The complicated mechanism of interaction between soil and pile, the uncertainty of in-situ soil properties, and the limited number of field load tests on instrumented piles combine to make conventional prediction of frictional capacity of piles a matter of empiricism and educated guesswork. Even less information is available on the behavior of piles under cyclic tensile loading. Degradation of soil shear resistance during cyclic loading may be accounted for through conservative design, but is not usually recognized in current practice.

Existing Methods of Analysis for Friction Piles in Clay

The frictional capacity of a long pile in clay is usually calculated using one of several approaches:

1. Empirical correlation methods
2. Total stress methods
3. Effective stress methods

These approaches are briefly described in the following paragraphs.

Empirical correlation methods. The empirical correlation method essentially correlates the results of field penetration tests to the bearing resistance and skin friction of piles. Field penetration tests such as the Standard Penetration Test (SPT) (Schmertman, 1967) and Cone Penetration Tests (Begemann, 1965) have been used.

SPT measurements have been interpreted to provide crude and approximate values of bearing resistance and skin friction and have been utilized for the design of onshore pile foundations. However, due to its poor reproducibility, great variability, and impractibility (Schmertman, 1976), the SPT method is not recommended for offshore application.

For offshore foundation design, especially in the North Sea, cone penetration tests (CPT) are usually included in the site investigation activities. The large amount of correlation data between CPT results (cone tip resistance and sleeve resistance) and laboratory and field load tests on short piles have led to the following correlations (de Ruiter et al, 1979) for piles in clay:

$$f = \alpha' \, q_c/N_R = k_f \, q_c$$

where f = unit skin friction,
q_c = cone resistance,
α' = empirical adhesion factor,
N_R' = cone factor defined as a ratio of q_c to undrained shear strength, and
k_f = empirical correlation factor

A series of static load pullout tests on piles in clay has been performed and the results of correlations between cone resistance and local friction for various soil and pile types have been summarized by Begemann (1969). As with any empirical method, use of the CPT method without sufficient local experience may lead to either unsafe or uneconomical design.

Total stress methods. In the total stress approach, the unit skin friction for piles in clay is correlated to the undrained shear strength, S_u, by a dimensionless multipler, α, viz:

$$f = \alpha S_u$$

Correlations based on results of various investigations (Tomlinson, 1957; Vesic, 1967; Flaate et al, 1978) indicate that the value of α vary as a function of the soil undrained shear strength from 0.4 to 1.6. For offshore pile foundation design, API RP2A recommends α -values (API, 1981) of between 0.5 and 1.0.

The total stress method is also empirical in nature and considerable judgment and local experience (in terms of pile load tests) is required to make a realistic choice for the value to be used. Several major factors contribute to the uncertainty of this method:

1. Data on which the α -values are based originated from a limited number of pile load tests on relatively short, stiff piles.

2. The effects of remolding and reconsolidation are not considered.

3. Conventional methods of offshore sampling and testing do not permit undrained shear strengths to be obtained with an adequate degree of consistency as their onshore counterparts (on which the method is empirically based) do.

Effective stress methods. There are several effective stress methods currently in use or in developmental stages. These are as follows:

1. The λ -Method (Vijayvergiya et al; 1972)

2. The β -Methods (Chandler, 1968; Burland, 1973; Meyerhof, 1976; and Parry et al; 1977)

3. General Effective Stress Methods (Esrig et al, 1979; and Wroth et al, 1979)

The Lambda (λ) methods is, in fact, a hybrid between effective stress and total stress methods. It is based on the assumption that pile driving displaces soil sufficiently to develop passive soil pressure. This method yields the following relationship for the average frictional resistance over the full length of the pile:

$$f = \lambda (\bar{\sigma}_m + 2C_m)$$

where $\bar{\sigma}_m$ = average vertical effective stress, and
C_m = average undrained shear strength over the embedded depth.

Values of the λ factor vary from 0.49 at the ground surface to about 0.12 for a pile embedded 61 m. (200 ft.) or more. These values were empirically determined from interpretation of the results of 47 pile load tests, many of these being the same tests from which the API criteria were developed. It should be noted that the Lamba-method does not describe the variation in unit friction along the pile length, but is primarily a method by which the total pile-head capacity may be calculated. It is therefore difficult to apply in the case of layered stratigraphies.

The effective stress at failure (β) method has been suggested by Chandler (1968) and Burland (1973) and is expressed by the following relationships:

$$f = \bar{\sigma}_n \tan \delta$$

where $\bar{\sigma}_n$ = the lateral effective stress, and
δ = the friction angle between soil and pile.

The relationship is further described by the following assumption (Burland, 1973) with respect to $\bar{\sigma}_n$:

$$\bar{\sigma}_n = K_o \bar{\sigma}_{vo}$$

where K_o = the coefficient of lateral earth pressure at rest, and
$\bar{\sigma}_{vo}$ = the vertical effective stress prior to the pile installation.

Thus, it is assumed that the state of stress in the soil is not changed by pile installation, subsequent reconsolidation and loading. It is further assumed that, for normally consolidated clay, K_o can be described with the following relationship (Jaky, 1944):

$$K_o = 1 - \sin \bar{\phi}$$

where $\bar{\phi}$ = the effective friction angle of the soil (δ is usually assumed to be equal to $\bar{\phi}$ for soft clays).

Thus, the equation for skin friction becomes:

$$f = (1 - \sin \bar{\phi})\, \bar{\sigma}_{vo} \tan \bar{\phi} = \beta \bar{\sigma}_{vo}$$

β varies between 0.24 and 0.30 for $\bar{\Phi}$ values ranging from 20° to 35°.

A slight variation to the equation for β has been proposed by Parry and Swain (1977). Analytical procedures were developed by the authors which limit the values of β to vary between 0.29 and 0.35 for $\bar{\Phi}$ values ranging from 20° to 35°.

Correlations of pile load test data (Flaate et al, 1978 and Meyerhof, 1976) suggest that β values decrease with pile penetration. After an extensive examination of various pile load test data, Flaate and Selnes (1978) devised another relationship for the unit skin friction which uses a depth dependent reduction factor and utilizes the square root of the initial overconsolidation ratio (OCR). Again, the majority of the piles used for correlation were driven to relatively shallow depths.

Recently, much effort has been expended to develop an effective stress model based on the theory of cavity expansion (Wroth, 1979) and the critical state soil mechanics model (Kirby et al 1977). This method is categorized as the "general effective stress method" (GESM) and postulates that the effective lateral stress depends on four items:

1. The initial state of stress prior to pile installation,
2. The stress change due to pile installation,
3. The stress change due to pile set-up (reconsolidation due to dissipation of the excess pore pressures induced during pile driving), and
4. The stress change due to loading the pile to failure.

The following assumptions were made by the proponents of the GESM:

1. Changes of lateral stress due to pile driving can be estimated by plane-strain cylindrical cavity expansion theory.

2. Stress changes due to soil reconsolidation can be estimated using the concept of critical state soil mechanics. The critical state condition is defined as that in which the soil has been sheared to such large strains that further strains result in no additional change in volume.

3. Changes in mean normal total stress can be modeled by finite element analyses based on the following assumptions:
   (a) Linear elastic behavior of the pile and soil.
   (b) No slippage between soil and pile.

For preliminary design purposes, Esrig et al (1979) suggested that:

$$f = \beta \sigma'_{vo},$$

where = a coefficient from Figure 10 or 11 of the referenced paper.

Calculated values are given in the referenced paper. Although this method is a significant step toward a rational prediction of ultimate skin friction, it has not yet proved adequate and may yield unconservative values. This is primarily due to the failure of the soil model to reflect the special conditions of large displacements concentrated along the critical surface of slip located at, or near, the pile-soil interface. Also, no effort was made to account for the degradation of frictional resistance resulting from the cyclic motion of the upper portion of the pile.

Recent Laboratory and Field Research

The previous paragraphs described the most common methods used by industry to predict frictional capacity of long piles in clay. Also outlined were some of the inadequacies inherent to each method. The most noticeable of these inadequacies can be summarized as follow:

1. The methods rely heavily upon basic soil parameters that must be obtained from laboratory tests on recovered soil samples. The irreparable damage to soil specimens caused by sampling, stress relief,

and handling is universally recognized and as such the soil characterization data base is expected to be somewhat uncertain.

2. The amount of detailed field data required for verification purposes is lacking. Most of the field load tests used for empirical correlation were performed on piles driven to depths of less than 30 m. (100 ft.), and none of the piles tested were instrumented to simultaneously record shear transfer, lateral soil pressure, and pore water pressure.

3. Cyclic loading was not included in the field load tests used for the correlations. Rather, the objective of the tests was the determination of the long-term "ultimate" capacity of the piles under sustained compressive service loads.

Recent research by several investigators, some currently members of the Ertec engineering staff, has been directed toward understanding the mechanism of soil-pile interaction. At The University of Texas at Austin, Holmquist and Matlock (1975), Bogard and Matlock (1979) and Cheang (1979) performed a series of experiments on axially-loaded pile segment models. The principal conclusions of the research efforts were as follows:

1. The frictional resistance of a pile is significantly affected by driving and the resulting local reconsolidation (which can be duplicated in laboratory model tests).

2. Under two-way cyclic loading, the frictional resistance degrades to a stable fraction of the initial ultimate resistance; and, in this state, the soil begins to behave very nearly as an ideal elastic-plastic medium.

3. Variations in the pore pressures measured at the pile wall did not directly account for the degradation in frictional resistance, as conventional effective stress theory might suggest.

4. The recovery of frictional resistance after cyclic degradation was shown to be time-dependent, but was not attributable to conventional consolidation processes, as reflected by the absence of excess pore-water pressures at the end of loading.

Additional experimental work by Ertec staff members has included a large-scale instrumented pile test and a small-diameter pile segment test at Long Beach, California, and a large-scale instrumented pile test at Iwaki City, Japan. The tests in Long Beach were performed in a stiff silty clay whereas the soil at the Japanese test site was a loose, crushable volcanic sand. Although performed in radically different soil types, these field test results are reasonably consistent with those obtained in The University of Texas tests. Thus, there appears to be a high probability that a single, unifying explanation of shear transfer during static and cyclic loading can be developed. Well-documented, realistic data from pile load tests, including careful measurements of shear transfer, lateral soil pressure at the pile wall, and pore pressure, are essential for developing a rational analytical design method. Is is believed that the testing program sponsored by Conoco will help to close this gap.

SELECTION OF ANALYTICAL METHODS

General

Recent advances in new concepts for tension-leg platforms have introduced new design considerations for pile foundations. One of the major uncertainties currently lies with the axial behavior of piles under the combination of static and cyclic tensile loads. To provide rational solutions for such considerations, it is necessary to study the factors affecting the side-friction capacity of a pile. Some of the more important factors are listed below:

1. In-situ soil conditions before pile installation,
2. Changes in the soil conditions due to pile installation,
3. Changes in the soil conditions from reconsolidation of the soil mass after installation, and
4. Changes in the soil conditions from subsequent static and cyclic axial loading.

Three analytical methods are discussed below which may play a significant role in understanding the behavior of tension piles.

Cavity Expansion

In recent years, a number of researchers (Esrig et al; 1979; Wroth et al; 1979; Kirby et al; 1977; Randolph et al; 1978 and 1981; Carter et al; 1978 and 1979) have attempted to predict pile capacity analytically by incorporating consideration of all of the above factors. The pile driving process was modeled as the expansion of a cylindrical cavity and reconsolidation as pore pressure dissipation in the soil mass adjacent to the pile. The final values of effective stresses are then used to predict the unit friction using effective strength parameters.

A wide variety of constitutive models has been used by researchers. The most widely recognized is the critical state model (Esrig et al; 1977 and 1979; Carter et al; 1978 and 1979; Randolph et al; 1978 and 1981). So far, such analytical solutions have not been able to successfully duplicate measurements from laboratory or field pile load tests, possibly due to the selection of a mathematical procedure which is too restrictive.

Ertec has continuously been involved with similar analytical developments. These concepts are partially illustrated on Plate 1 (Vesić, 1967). The processes of installation and soil reconsolidation are simulated mathematically as the lateral expansion of an infinitely long, cylindrical cavity in the soil mass. The soil mass is simulated by a two-phase soil model, a nonlinear soil skeleton coupled with a pore fluid. A typical solution of the computed pore pressure and radial effective stress variation with time is shown on Plate 2 (Matlock et al; 1980). Some parametric variations with such solutions reveal that the final effective stress is quite sensitive to the amount of expansion (related to the amount of soil displaced outside the pile) as shown on Plate 3. Since most offshore piles are driven open-ended, the ability to analyze the soil plug formation and flow pattern at the pile tip appears to be necessary to apply such cavity expansion solutions.

Preliminary parametric studies performed by Ertec using cavity expansion theory revealed that the computed effective stress, and thus pile capacity, is not very sensitive to the constitutive model used to simulate the soil skeleton. One experimental study (Matlock et al; 1980; and Bogard et al; 1979) provided a strong indication that pile capacity is controlled by the shear zone behavior in the near vicinity of the pile wall (Plate 4). Thus, the constitutive model selected will be required to simulate the cyclic remolding near the pile wall taking place during pile driving and also during cyclic movement at the top of the pile.

Two major areas of future improvement in the constitutive soil model are:

1. A more flexible loading scheme is required to model the concept of the staged processes of (a) cavity expansion, (b) consolidation, and (c) pile axial loading. In reality, these processes overlap during pile driving, continued construction and service life of the structure.

2. A more flexible constitutive model is required to allow total freedom in back-fitting instrumented pile load test results (Matlock et al; 1980). Past researchers in mathematical modeling of soil behavior

have depended heavily on the premise that soils behave according to simplifying laws. The development of the generalized concepts such as the "critical state line" is the result of such a simplifying assumption. However, experience has proved that many of these assumptions are too restrictive to model the complicated shear zone behavior characterized by extremely intensive cyclic remolding of soil on the surface of slip. Therefore, to provide realistic, practical answers, flexibility and versatility in the constitutive model is extremely important, especially in the volumetric behavior during shear. Ertec is currently proceeding with a research effort to provide flexibility in both dilative and volumetric collapse mechanisms. These volumetric changes can arise from static and cyclic shearing of the soil due to any of the processes of cavity expansion, consolidation, and static and cyclic pile loadings. By providing freedom in describing these two mechanisms, pile load test results can be back-fitted.

The above two efforts were initiated through an in-house research and development program at Ertec. A computer program developed for cavity expansion and axial shearing of a single slice of soil is expected to be completed in time for back-fitting results from the proposed pile load test.

Additional Analytical Methods

Apart from the analytical developments of the cavity expansion program, two additional computer programs are relevant to the current study. These two programs are DIRT II and DRIVE 10.

DIRT II is a finite element program originally developed by Hughes and Prévost (1979) at the California Institute of Technology. The program can efficiently evaluate static and pseudo-static loading problems. The element library of DIRT II includes: (1) three-dimensional brick, (2) two-dimensional plane, and (3) two-dimensional axisymmetric elements. A wide array of linear and nonlinear constitutive models can be used to simulate the behavior of both clay and sand. DIRT II has been applied to perform analyses of static and cyclic loading on offshore gravity structures (Prévost, 1979). The validity of selected solutions has been verified by centrifuge tests. The DIRT II program models the soil mass as a single-phase medium and, therefore, cannot presently be used for consolidation solutions. However, under undrained conditions, it has a very flexible constitutive model, especially for cyclic loading considerations. Potential applications for DIRT II include analyzing the flow pattern at the pile tip.

The DRIVE program (Matlock et al; 1979) is a dynamic axial beam-column program that can be used both for pile driving and for cyclic loading analyses. A general hysteretic, degrading support model in the form of a composite set of parallel elasto-plastic sub-elements can be used to model practically any form of shear transfer relationship. Included in the uses of the program are the prediction of pile driveability, residual pile stresses after driving, and the effects of static and cyclic loading on pile displacements, frictional resistance, and residual stress distribution under the expected service load conditions.

The DRIVE program allows any desired time-history of loading to be applied, so that the effects of a static bias load and subsequent cyclic loading may be evaluated. Examples (Matlock and Foo, 1979; and Matlock, 1981) have demonstrated the progressive transfer of load to deeper soils as the result of soil support degradation due to the cyclic motion of the upper portion of a long, elastic pile. The support model has recently been calibrated against large-scale pile load test data and found to perform quite satisfactorily. The DRIVE program can be used to extrapolate shear-transfer and soil degradation behavior observed in pile load tests (Plate 5) to the design of prototype TLP piles.

Development of Theoretical Model

The unusual loading condition imposed on a TLP pile foundation requires an advancement of current understanding of factors affecting skin friction of a pile (e.g. the complex soil behavior at the shear zone) by a theoretical model. To achieve the above goal, the following steps are envisioned:

1. Using existing literature, and laboratory model and soil tests, as well as small and large-diameter field pile load test results, a versatile and comprehensive theoretical model will be formed which considers installation, consolidation, and subsequent static and cyclic loading.

2. Using preliminary soil data and the theoretical model, predictions on the small and large-diameter pile load tests will be made for test planning purposes.
3. The theoretical model will then be refined and calibrated against test data from the small-diameter pile segment tests for a wide variety of load cases. With the refined procedure, predictions on the large diameter pile test will be made.
4. Upon completion of all testing, final refinement and calibration of the theoretical model will be made.
5. The subsequent theoretical model can then serve as a basis to extrapolate existing pile load test data to the prototype condition.

The calibrated theoretical model is expected to advance current state-of-the art as well as general practice procedures in offshore pile design.

FEASIBILITY OF FIELD TESTS

Fundamental Requirements of Field Test Program

In contrast to the requirements of static design problems, a rational approach to the design of foundation piles for anchoring tension leg platforms must include consideration of the hysteretic response of the foundation soil, including consideration of the rate and degree of cyclic degradation in frictional resistance and the possible ability of the soil to later recover a portion of the strength lost during periods of extreme loading. The design procedures presently available do not include such considerations, but are limited to predictions of the long-term, or "ultimate", frictional resistance under constant service loads.

Analytical methods, such as the DRIVE computer program previously discussed, are available which allow the pile-soil system to be realistically modeled, including consideration of the effects of transient or cyclic loads on the short-term capacity. At present, however, methods for the prediction of the required soil parameters are not available. It is therefore necessary to obtain estimates of the characteristic soil behavior from model or large-scale pile tests, and to then empirically extrapolate the observed behavior to the prototype pile under the expected range of service loads. By performing experiments on piles which are instrumented to measure the proper soil parameters in the same or very similar soils, the response of the actual foundation piles can be rationally estimated. An additional and very important benefit of such an instrumented pile load test is the collection of data against which more advanced analytical predictive techniques may be tested.

In addition to those soil properties routinely measured in the laboratory, the soil parameters required for extrapolation of the load test results to a different site include the frictional resistance, the normal effective pressures, and the excess pore-water pressures developed along the pile. Each of these parameters are functions of depth, pile diameter, and time after installation, and are also affected by relative pile-soil displacement during loading and the particular time-history of loading applied.

The relationships between the frictional resistance, normal effective pressures, excess pore-water pressures, and time after pile installation are presently estimated from analytical solutions of radial consolidation using permeability and compressibility factors from one-dimensional consolidation tests, with the frictional resistance being estimated from the results of drained triaxial compression tests. Although such assumptions may be valid for the long-term, "ultimate" conditions after complete reconsolidation, the time required to achieve such a condition may be measured in years for a large pile driven into a highly plastic clay.

The effects of reconsolidation time on various pile sizes are illustrated on Plate 6. The curves were developed from the equation:

$$T_{ps} = \frac{c_v t}{r_o^2}$$

where T_{ps} = a dimensionless time constant,

c_v = coefficient of consolidation which depends on soil permeability and compressibility,

t = time, and

r_o = the pile radius.

As can be seen, the time required for reconsolidation after driving increases with the square of the pile radius, as reported by Vesić (1975). For the purpose of illustration in Plate 6, the time constant, T_{ps}, was converted to percent reconsolidation (100% being total set-up), and c_v was taken to be 3.5×10^{-4} cm^2/sec (from the results of consolidation tests on samples from the Green Canyon site).

For three piles, 7.62 cm. (3 in.), 76.2 cm. (30 in.), and 183 cm. (72 in.) in diameter driven at the same time, the time required for 60% reconsolidation would be 1, 100, and 600 days, respectively.

It is therefore of considerable importance that the relationships among frictional resistance, normal effective pressure, excess pore-water pressure, time after installation, and relative pile-soil displacement history be established with reasonable certainty for the relatively short time period after installation in which the prototype piles will be subjected to loading.

The field test program should therefore be directed toward achieving two goals: (1) the collection of data from small-diameter pile segment experiments which can be tested against the actual test pile, and (2) the collection of data relating frictional resistance, normal effective stress, embedment depth, time, and pile-soil displacement history, which can then be extrapolated to the prototype pile by more advanced analytical procedures.

The first goal can best be achieved by the use of multiple installations of miniature pile-segment models tested at various times after installation and at several depths. Because of the significant decrease in reconsolidation time with reduction in diameter, a number of pile-segment model experiments can be performed during the reconsolidation period for one load test of a large pile. The range of soil responses at various degrees of reconsolidation can thus be explored.

The second goal can best be attained by testing a pile more nearly approaching the prototype pile in diameter, embedment depth, soil type, and load history. Economic and physical arrangement considerations limit the size of the pile to be tested; site availability and knowledge of actual loading patterns limit the ability to duplicate these aspects of the problem. Compromises must therefore be made between the most ideal large-scale test and the most practical and reasonable program. The diameter and embedment depth of the large-scale pile must be determined after selecting a specific test site and estimating the amount of available reaction force from either an existing platform or from a reaction frame which can be constructed at the test site.

The data from the small-diameter pile tests can then be tested against the large-diameter test pile to expand and calibrate the developing analytical models and allow extrapolation to the full-size piles to be used to anchor tension-leg platforms.

Considerations for Site Selection

Four candidate locations were identified for consideration as a field test site. A fifth potential site was investigated but was determined at an early stage to be unsuitable. The primary consideration was to choose a site with soil conditions most representative of those documented in Green Canyon, Block 137, and expected to exist at the other deep-water Gulf of Mexico TLP prospects. This material is a highly plastic, slightly underconsolidated to normally consolidated clay.

Homogeneity of the clay stratum at the selected test site is very desirable particularly if a large-scale test is to be performed. Significant layers of sand could potentially cause confusion in the interpretation of test results. This has occurred in previous pile tests where the measured friction on an isolated pile segment did not logically correspond to adjacent segments. The result was indecision over whether the measured values were a phenomenon of the pile-soil behavior or a product of the dissimilar soil types and/or possible shearing effects from one layer into the other due to pile installation.

Another important consideration is stratum thickness. In the past, the offshore technical community has expressed skepticism over results obtained from shallow pile tests and segment tests. With the common belief that pile length is an important consideration for determination of ultimate frictional capacity, a long pile test, where the in-situ soil pressures approach those experienced by offshore production piles, is desirable for credibility of results. Both large-scale pile tests previously performed by Ertec personnel, and several other deep tests, have essentially been segment tests where drilling and casing were required to reach the desired test stratum. Although this was necessary to isolate the effects of the unwanted soil above the test section, the fact that a "fully-embedded long pile" was not tested cast some doubts on test results. In addition, a thick stratum would allow a test where total shear reversal at the pile-soil interface would be possible with only one-directional cycling applied at the pile head, due to the elastic deformations in a long pile. This condition would best simulate the loading conditions expected for the prototype TLP foundation piles.

For a test performed offshore, with either a long pile or a small diameter instrumented segment, a site with a shallow water depth would be preferable. This would allow better control of displacements in small-scale segment tests because of the reduction in elastic strain energy stored in the drill rod used to load the segment. If a large-scale pile test is performed, field assembly and driveability problems would also be of lesser concern. Since the pore-water pressure is, in itself, neutral, an onshore or shallow-water site was acceptable, providing that the soils at the site are recent sediments and are therefore normally-consolidated and below the water table.

Operational Considerations for Small-Diameter Segment Tests

The operational problems which can be overcome in a field test program are basically functions of the amount of time and money which can be budgeted for the project. For a small-diameter pile segment, fabrication, transportation, handling, and testing equipment costs are obviously significantly smaller than for a large instrumented pile. Fabrication would be under laboratory conditions with no need for large fabrication facilities. Transportation to the test site would be routine with the exception being transportation offshore, whereby special provisions through Conoco would have to be made.

Support equipment for onshore testing would be provided by Ertec. If offshore, a small crane would be needed to lift and handle test equipment, data acquisition systems, power supplies, loading systems and personnel. Transportation of personnel to and from the site and housing, either onshore or offshore, would be needed.

Operational Considerations for a Large-Diameter Test Pile

Initially, it was thought that the operational and budgetary requirements for an offshore large-diameter pile test would greatly exceed those for an onshore program. Further investigation, based on equipment and personnel requirements, indicated that, for onshore and offshore test programs of equal technical merit, there was little difference in cost. Also, the logistic and scheduling problems were found to be significantly simpler at an offshore site. The basis for these conclusions are addressed in the following paragraphs. For this comparative analysis, the offshore site was considered to be at one of the existing CAGC platforms identified for removal and the onshore site considered was a hypothetical site of equal technical acceptibility.

Reaction System. Assuming that a long, fully-embedded test pile is to be used in similar soil conditions, offshore or onshore, the reaction system requirements would be essentially the same. The existing offshore platforms are supported by large-diameter piles driven to a suitable depth below the seafloor. The piles have been in place for a number of years and will provide maximum frictional resistance plus added tip reaction for a test pile loaded in tension. The loading frame concept envisioned would utilize four of the existing platform legs. In addition, the loading frame could be fabricated from existing materials, and the design would be such that only a limited number of construction tasks would be required in the field. In fact, only one lift with a derrick barge crane would be required to stab the load frame into socket type connectors positioned on the four platform legs.

No readily available structure would exist at an onshore site. The reaction system would be considerably different in design, consisting of a stiff template-type reaction framework supported by possibly four piles equal in size and capacity to the test pile. Since the reaction piles and test pile would be loaded at approximately the same time in their consolidation history, the factor of safety of the load frame would be approximately equal to the number of reaction piles, provided the reaction piles and test piles were driven to equal depths. Previous large-scale tests have been performed using reaction systems with shorter, smaller diameter piles. However, these tests were segment tests where the casing provided a large additional amount of reaction.

Fabrication. The cost of fabricating a test system would be approximately the same, whether an onshore or offshore test were to be performed. For an offshore test, additional uninstrumented piling would be needed to extend from the mudline to the top of the existing platform. Fabrication of the previously discussed stab-on load frame would be required as well as some pre-installation platform preparation. For a comparable onshore load test, an overall shorter test pile could be used since it would be driven from ground level. However, additional material and installation costs would be incurred due to reaction pile requirements.

One great advantage of an offshore program would be that a completely prefabricated, proof-tested, and calibrated test pile up to 55 m.(180 ft.) in length could be built under the controlled conditions of a fabrication facility. This would not be possible if an onshore site were selected. Because of trucking restrictions, i.e. legal transportable length, some test pile fabrication would be required on-site after smaller sections were transported from the fabrication yard. The test pile would also have to be installed in sections, rather than continuously driven, due to the smaller boom heights and load limitations of existing onshore cranes.

Transportation. For an offshore test, all system components would be loaded on a single barge and shipped to the site. The transportation cost would be that of the barge and tow vessel.

For an onshore test, the cost would depend on the distance from the fabrication yard to the test site. A greater amount of control and scheduling would be required for organizing and coordinating the number of trips required to bring all the reaction piles, test pile and load frame to the site. Therefore, it is anticipated that the cost of transportation of materials from the fabrication yard to the test site would be approximately the same, whether offshore or onshore.

The cost for transporting people and small equipment to and from an offshore site would be more expensive than if an onshore test were performed. However, compared to the total project estimate, this difference is nominal.

Installation. The installation of the test system offshore would be simpler than for a similar test onshore. This is due primarily to the availability of a large construction barge. These units eliminate the need for mobilizing many different pieces of equipment to an onshore site. Also, the boom height and lifting capacities of these cranes would allow the primary test arrangement to consist of three pieces: the instrumented test pile section, the uninstrumented test pile section, and the load frame. As described later in this report, the total on-site installation process should be completed in less than three days.

Although the day rate of equipment onshore would be less, the time on site would be considerably more due to the need for completing fabrication of the test pile and reaction frame on site. Also, optimum scheduling of the multiple pieces of equipment and contractors at an onshore site would be considerably more troublesome and difficult to achieve.

Other Operational Factors. There are many factors which can be compared in evaluating offshore versus onshore testing. Poor weather onshore would cause difficult working conditions (mud) which could linger throughout the project. Offshore, weather conditions would affect work for a shorter period of time, but down time may be more costly per hour.

Twenty-four hour site security would be required at an onshore site from pile installation through final testing to prevent vandalism and for liability purposes. Similar security would not be needed offshore.

Logistics in the form of parts requirements, subsistence, and communications would be simpler onshore. Site leasing (permitting), preparation, and post-test restoration would not be required offshore to the same extent as onshore. Support and standby vessels may be needed offshore during periods of installation and testing.

Regardless of whether an onshore or offshore site is selected, close scheduling of work would be required to assure maximum efficiency of men and equipment. Because of platform ownership responsibilities, Conoco should directly contract offshore services through their well-established procurement channels. Joint participation by both Ertec and Conoco in structural design modifications for the candidate platform, field assembly procedures for the test pile, and scheduling of the construction phase would be essential to a successful, cost effective program.

Evaluation of Instrument Types

Of primary concern in the design of the field test arrangement is the ability to extrapolate the results of the field study to prototype pile sizes at deep-water sites. The test pile would therefore be instrumented to measure the required soil parameters: total normal pressure, pore-water pressure, shear transfer, and displacement at several depths along the embedded length. Values of ultimate frictional resistance may then be determined as functions of normal effective pressure, and therefore depth. Curves relating shear transfer with displacement (t-z curves) can also be developed, which, in turn, can then be related to larger pile diameters and different depths. The results of the experiment can thus be directly extrapolated to the deep-water site with little intermediate manipulation.

In order to more fully understand the pile-soil interaction process, more sophisticated analyses of the measurements will be required. Among the phenomena to be examined are the magnitudes of excess total and pore-water pressure during pile installation, the rate of decay with time in total and pore-water pressures and associated increases in effective normal pressures after installation, the changes in total and pore-water pressure during loading, and the effects of changes in total and pore-water pressures on shear transfer during cyclic loading.

The measurements desired along an instrumented test pile are (1) strains in the pile wall at each of several embedded depths, (2) total and pore-water pressures at depths mid-way between strain-measurement levels, (3) pile displacement at the pile head and at preferably two embedded depths, and (4) the strain in the pile immediately below the point of load application. Although the exact placement of the instruments would be determined after a detailed examination of the stratigraphy at the test site, it is expected that the distance between strain-measuring levels would be in the range of fifteen to twenty pile diameters, with a total instrumented length of 80 to 100 diameters. It is also desirable to record the elevation of the internal soil plug during driving and the blow count as a function of pile penetration.

The strains can be measured with prefabricated, sealed units utilizing foil resistance strain gages as the sensing elements. In addition, redundant strain measurements can be made at selected elevations using drop-in mechanical extensometers resting on machined and polished seats. Electrical displacement transducers can be used to obtain values of strain from the changes in distance between the support points during the application of load, as well as obtaining measurements of residual pile stresses. Difference in strain at successive levels will be used to compute changes in the average shear transfer between instrumented levels, including changes in residual shear transfer during quiescent periods.

The total normal pressure can be measured by weighing the total load exerted by the soil on a steel platen. The total pressure cells would be prefabricated, calibrated, and sealed in the laboratory prior to shipment and installation in the pile.

Pore-water pressures can be measured by commercially available diaphragm-type strain-gage pressure transducers mounted behind porous filter elements. The pore-water pressure transducer units should also be prefabricated, calibrated, and sealed prior to shipment and installation in the pile wall. The filter elements would be saturated immediately prior to being lowered under the surface of the water at the test site.

Each of the instrument types envisioned for a test pile have been successfully used in prior experiments. Similar, but improved, designs would be fabricated in Houston by Ertec for the proposed field test.

The miniature pile-segment models would be lengths of steel tubing having a maximum diameter of 10 cm. (4 in.) with foil resistance strain gages placed at cross-sections 8 diameters apart to measure shear transfer between gage locations. The total normal pressure midway between strain gage locations can be measured by weighing the load exerted by the soil on a steel platen machined to conform to the surface of the model. The pore-water pressure can be measured by a commercial diaphragm-type pressure transducer mounted behind a porous filter element in the pile wall. The pile-segment models would be prefabricated, calibrated, sealed, and proof-tested in Houston by Ertec prior to shipment to the test site and subsequent installation in the field. Ertec has already successfully developed and used a 3-inch diameter model in the Long Beach tests and is presently developing a smaller unit for more routine use.

The primary data acquisition system desired for non-static data recording is an integrated system consisting of a minicomputer for control of the system, a high-speed scanner, a digital voltmeter, a high-speed printer, and a magnetic disc drive for permanent data storage. Data can be processed and printed on command or at pre-determined intervals in engineering units, and can be stored directly on the magnetic discs as raw voltage readings for later post-processing in Houston.

The primary standardization system for static readings during quiescent periods, for confirmation of stability, and for calibration should be a precise bridge-balance box and null indicator circuit. This system provides highly precise readings of the strain gage bridges, and can be used to confirm or update zero and calibration data for the automatic data acquisition system at intervals during the testing period. This system will be used to confirm measured deviations from original no-load zero readings by maintaining continuous records of the absolute imbalance of all strain gage bridges throughout the life history of each transducer element, from the time of manufacture until the end of the test program. For a long, elastic pile, it is imperative that such precise measurement be made in order to record the real shear forces.

In addition to the above instrumentation, accelerometers and strain transducers would also be installed at the pile head to observe the dynamic behavior of the pile during driving. The measurements will include (1) blowcount, (2) acceleration-time history for selected blows, and (3) strain-time history for selected blows. The recorded data, in conjunction with the DRIVE computer program, can be used to predict the driveability of the prototype piles.

The elevation of the interval soil plug during pile driving will also be monitored. The elevation of the soil plug will be used to estimate the amount of cavity expansion that is occurring at the pile tip.

FIELD TEST SITE SELECTION

General

Design procedures for foundations of tension leg platforms may be found to vary for different soil conditions. Therefore, at the onset of developing an improved understanding of these foundation systems, it is important to perform the field testing phase in soils with properties similar to those expected at proposed TLP sites in the Gulf of Mexico. Specifically, the field test site conditions should conform as closely as possible to those found at Green Canyon, Blocks 137 and 184 and Viosca Knoll, Blocks 864 and 908.

This section describes the soil conditions at the proposed TLP sites as well as conditions identified at candidate field test sites. Also included is supplementary data pertaining to an existing offshore platform, operational information gathered, and a report on a field trip to the recommended candidate site.

Proposed TLP Sites

Green Canyon, Blocks 137 and 184. Primary sources of information on the Green Canyon sites were 1) a report entitled "Engineering Geology and Geotechnical Considerations, Upper Continental Slope Offshore Louisiana," May, 1981, by McClelland Engineers, Inc., and 2) a soil boring completed May 11, 1981 in Green Canyon, Block 137.

Based on the geologic report, the shallow materials in both blocks are likely to consist mostly of clay and silty clay. An erosional surface of slightly to moderately overconsolidated sediment possibly exists in the southeastern quadrant of Block 137. The southern quarter of Block 137 lies on the extreme northern edge of a shallow diapir, the result being local landslides, steep slopes and complex faulting in that portion of the block. A possible submarine landslide was indicated in the report at the northern boundary of Block 184. Shallow, closely spaced folds are indicated around the possible slide area and extending to about mid-block. The lower half of Block 184 is characterized as steeply sloping, greater than five percent, from northwest to southeast. Shallow gas is probable, according to the report, in the upper 150 m. at both sites; the presence of gas below 150 m. is likely in the southwest portion of Block 184. The water depth in Block 137 ranges from approximately 300 m. to 500 m.; while in Block 184 it varies between 325 m. and 650 m.

A site specific investigative soil boring was made in Block 137. The soil conditions encountered for the boring generally consist of normally consolidated soft to stiff clay. The near surface soils are very soft to soft, olive gray clay with scattered shell fragments to a depth of approximately 15 m. The interpreted undrained shear strength increases linearly from 2.4 kPa to 21.5 kPa from the mudline to a depth of 15 m. The submerged unit weights of this clay average 370 kg/m^3 to a depth of approximately 4.5 m. with the unit weight then increasing over the next 3 m. where it again remains constant at a value of 530 kg/m^3 to a depth of 15 m.

The intermediate soils from 15 m. to 90 m. also consist of normally consolidated clay. Some very scattered silt and sand pockets along with structure modifications are noted in this zone. The undrained shear strength continues to increase linearly from 21.5 kPa to approximately 145 kPa at 90 m. with the submerged unit weight averaging 640 kg/m^3 over the entire zone.

The deeper sediments, below 90 m., contain numerous silt and sand partings, pockets and seams which account for the increase in submerged unit weight by 80 kg/m^3 to 160 kg/m^3. The interpreted undrained shear strength averages 145 kPa, but a high degree of variability is observed in this zone, probably due to the presence of the cohesionless material.

Preliminary results of consolidation tests performed on representative samples was provided by Conoco. Based on tests performed on push samples, the soil is typically normally consolidated with a coefficient of consolidation, c_v, equal to approximately 3.5 x 10^{-4} cm/sec^2. Shear strength ratios, $Su/\bar{\sigma}_v$, are also indicative of a normally consolidated clay.

Viosca Knoll, Blocks 864 and 908. Evaluation of site conditions in Blocks 864 and 908 of the Viosca Knoll Area is more difficult since little data is available. This area was not included in the McClelland report, nor were any soil borings available.

The two blocks are generally located approximately 80 km. east of the southeast pass of the Mississippi River. The 400 m. water depth contour bisects the two adjoining blocks with Block 864 generally being in water shallower and Block 908 in water deeper than 400 m. With both blocks in line with both the southeast and Main Passes of the river, a rapid sedimentation process would be expected at the sites. The distance from the mouth of the river would allow the majority of the coarse-grained material to fall out of suspension prior to reaching the Viosca Knoll sites. Some small amount of sand would be expected due to downslope sediment movement.

Although no specific geotechnical information on the Viosca Knoll blocks was available, Conoco provided results from a well site survey performed by Intersea Research Corporation. The high-resolution geophysical survey indicated water depths of 340 m. along the northern border of Block 864 to 565 m. in the southeast corner of Block 908. The seafloor slope averaged approximately three percent. Block 864 has an even, smooth bottom topography and remains such southward through Block 908 until the southern border is approached. Here relief becomes more pronounced. Along the eastern border of Block 908 a diapir intrusion has caused slumping and unstable surface-sediment conditions.

Sediments in the upper 300 m. of Blocks 864 and 908 are indicative of an outer shelf edge and consist of bedded clays and silts (possibly underconsolidated) with minor amounts of fine sands. This is due to recent fault movements which caused various amounts of sea floor slumping adjacent to and over the diapir.

Shallow gas is also believed to be present within the block, the largest zone trending northwest across the eastern border of Block 864. Seafloor hazards also include a sunken ship approximately 55 m. long by 11 m. wide in the northeast corner of Block 908.

Candidate Field Test Sites

Several sites are reviewed in this section which have been identified as candidate locations for performing field tests. Two onshore and three offshore locations along with descriptions of soil conditions are presented. Selection of the candidate sites was based on information available from the proposed TLP sites in Green Canyon and Viosca Knoll which indicated the foundation piles would be installed primarily in slightly underconsolidated to normally consolidated clay. Therefore, more emphasis is given to describing the strata which contains this material as a test medium.

Empire, Louisiana. The Empire location is the site of a previous series of pile load tests performed in 1975 by Chevron Oil Field Research Company with 13 other participants, including Conoco. This site was attractive since an abundant quantity of documentation is available. Numerous soil borings with companion laboratory studies, gamma-ray and resistivity logs, in-situ remote vane test and cone penetrometer test results are available, as well as the pile load test results. A telephone conversation with Mr. John Bigham of Chevron, U.S.A. in New Orleans disclosed that Chevron no longer holds a lease on the site. However, the owner has been identified and Mr. Bigham indicated he would expect few problems in acquiring access should this site be selected for further testing.

A description of the stratigraphy is found in the January, 1981 volume of Proceedings of the American Society of Civil Engineers, Geotechnical Division and in Plate 7. The top 23 m. consist primarily of sand with several layers of clay approximately three meters thick. The stratum from 23 m. to 54 m. consists of firm, uniform, highly plastic clay. The undrained shear strength of the clay increases from 30 kPa to 60 kPa within the stratum. The plastic and liquid limits average 25% and 85%, respectively. A layer of sandy clay to silty sand exists from 54 m. to 57 m. below ground elevation. The next significant stratum lies from 57 m. to 113 m. and consists of stiff gray clay. The interpreted shear strength ranges linearly from 72 kPa to 134 kPa. However, numerous seams of sand, silty sand, and sandy silt are interbedded within this stratum. This can be seen in the variability of strength tests, Atterberg limits and geophysical logs.

Grand Isle CAGC Terminal (Onshore). Few onshore soil borings were found which were deep enough to allow evaluation as a potential test site. In addition to the Empire site, one boring to approximately 61 m. was identified at the Grand Isle, Louisiana CAGC Terminal. However, the statigraphy at this site was reported to consist of approximately equal percentages of clay and sand existing in a layered structure. Due to the non-homogenous nature of the soil, this site was eliminated from further consideration.

Grand Isle, Block 48. The soil conditions for Block 48 of the Grand Isle area (Plates 8 and 9) generally consist of normally consolidated very soft to stiff clay overlying dense to very dense sands and hard clay. The near surface clay soils within the upper 15 m. contain silt and sand pockets, seams and layers which account for the majority of the intrusions in this zone. Moisture contents in the top three meters average 80% with the value decreasing to an average of approximately 50% for the remainder of the upper 16 m. The average plastic and liquid limits are 30% and 80%, respectively, with submerged unit weights averaging 480 kg/m^3 for the upper 3 m. then increasing to over 650 kg/m^3 for the remaining portion of the clay in this zone. Undrained shear strengths average 5 kPa for the first three meters then increase to 38 kPa over the next 3 m.where it remains constant for the remaining 9 m.

The clay stratum between 16 m. and 46 m. has fewer intrusions than the upper portion and exhibits a flocculated structure which was not present in the near surface soils. Moisture contents average slightly over 40% with plastic and liquid limits averaging 30% and 80%, respectively. The submerged unit weight is consistent with that found in the upper zone below 3 m., averaging 670 kg/m^3. The interpreted undrained shear strength increases linearly with depth from 38 kPa to 72 kPa.

A dense to very dense fine sand exists between 46 m. and 91 m. Some small clay layers are noted below 82 m. with traces of gravel being present between 68.5 m. and 81 m.

East Cameron, Block 63. The subsurface conditions found at East Cameron, Block 63 consist of alternating layers of cohesive and cohesionless soils as shown in Plates 10 and 11. Three small layers consisting of a medium sandy silt, an overconsolidated clay and a medium dense silty fine sand make up the top 5.5 m. A normally consolidated clay is present between 5.5 m. and 51.5 m. Numerous silt partings, pockets, and seams along with traces of organic material and a flocculated structure are present between these depths. Moisture contents average 40% with submerged unit weights increasing from 720 kg/m^3 to 960 kg/m^3. The plastic limits are somewhat constant at 30%. With the high variability of other materials present, no general trends exist for the liquid limits, which vary between 50% and 80%. The interpreted shear strength increases gradually from 36 kPa to 96 kPa for the stratum between 5.5 m. and 51.5 m. A medium dense gray fine sand is encountered from 51.5 m. to the termination depth of the boring at 77.7 m.

West Delta, Block 58. Soil conditions encountered in Boring 2, Block 58 of the West Delta area generally consist of a gray clay ranging from very soft to very stiff, overlying dense to very dense granular soils. The boring log for this location is shown on Plates 12 and 13.

Numerous sand seams and silt pockets and seams are noted in the top 12 m. Moisture contents in this zone average 70% with average plastic and liquid limits ranging between 30% and 85%, respectively. The interpreted undrained shear strength to a depth of 3 m.below the mudline is constant at 3.0 kPa. At this depth, the shear strength increases to 7 kPa and linearly increases to 16 kPa at 12 m.

The remaining portion of clay in this boring to 76 m. does not contain any appreciable amounts of sand or silt. Moisture contents for this zone fall into two distinct values of approximately 40% to 60%, with the higher values being deeper than 49 m. The plastic and liquid limits also fall into two distinct ranges. Average values of 30% and 60% for the plastic and liquid limits are noted between 30 m. and 49 m. with the remaining limits ranging between 39% and 90%, respectively. The submerged unit weights for this zone are fairly constant at 640 kg/m^3. The undrained shear strength gradually increases from 16 kPa at

12 m. to 21 kPa at 37 m. A steeper increase in shear strength occurs for the remainder of the clay stratum to an interpreted value of 64 kPa. The remaining portion of the boring to the termination depth of 116 m. consists of silty fine sand to fine sand with mica.

Technical Evaluation of Candidate Test Sites

Soil type and stress history. Evaluation of the four candidate field sites was based on the considerations previously discussed. The initial qualification for candidacy was the existence of a significant stratum of normally consolidated or slightly underconsolidated clay. Stress history was estimated by calculating the rate of increase of shear strength with depth for the potential test stratum at each site under consideration. Results of these calculations are as follows:

Candidate Site	Shear Strength Ratio, $S_u/\bar{\sigma}_v$
Empire, LA (onshore)	0.23
West Delta, Block 58	0.15
East Cameron, Block 63	0.40
Grand Isle, Block 48	0.31

Field test results from the Green Canyon, Block 137, location indicated a shear strength ratio of 0.18. The Viosca Knoll locations are believed to be equally or slightly less consolidated than Green Canyon, (and would therefore have a comparable ratio of ($S_u/\bar{\sigma}_v$)). Thus the Empire and West Delta sites were judged to be the most representative, since their ratio of shear strength to depth ($S_u/\bar{\sigma}_v$) are nearest to that of the Green Canyon site. All compared shear strengths were based on field and laboratory tests performed on percussion samples. Sample disturbance due to sampling and stress relief is unknown, but would certainly influence laboratory strength test results and subsequent comparisons. A comparison of the shear strength profiles for all the candidate sites and Green Canyon are shown on Plate 14.

Test stratum homogeneity. Evaluation of homogeneity of the prospective test stratum at each site was based on boring log inspection with consideration given to variations in plasticity index, unit weights, shear strength, and sample descriptions. At the Empire site, the stratum from 23 m. to 54 m. was judged to be extremely homogeneous. However, the clay layer from 57 m. to 113 m. included seams of sand and silt of varying thicknesses and would not be desirable as a test stratum for the present purposes.

The potential test stratum at East Cameron, Block 63 extended from 5.5 m. to 51.5 m. The scatter in strength data, Atterberg limits and water contents indicate many inclusions of granular material. This is also verified by the sample descriptions which identify numerous silt partings and seams.

Grand Isle, Block 48 is attractive from 16 m. to 46 m. Little scatter in strength data, limits, or water contents was observed.

Below 12.5 m. and extending to 76 m., the West Delta, Block 58 site is extremely homogeneous with no report of silt or sand seams in the sample description log. Silt seams were noted from 3.5 m. to 12.5 m. A decrease in the plastic limit was noted between 30 m. and 49 m., but this was considered to be of only slight importance in evaluating the site.

Stratum thickness. Evaluation of a stratum not only includes the thickness of the useable stratum at each site, but also the depth at which the stratum begins.

The table given below shows for each site the limits of the useable test stratum, and the total stratum thickness considered appropriate for testing.

Candidate Site	Limits of Stratum, meters From	To	Stratum Thickness, meters
Empire, Louisiana	23.0	54.0	31.0
West Delta, Block 58	12.5	76.0	63.5
East Cameron, Block 63	5.5	51.5	46.0
Grand Isle, Block 48	16.0	46.0	30.0

Water depth. Water depths at the West Delta and East Cameron sites are approximately the same, about 15 m. The Grand Isle location has a water depth of approximately 28.5 m. A difference of 13.5 m. in water depth does not significantly affect the preference of one site over another. Although water depth was not applicable to the Empire site, the significant amount of casing which would be required to reach the test stratum was considered.

Operational Considerations, West Delta Site

The three offshore sites are considered attractive since the existing platforms have been targeted for salvaging. Thus, use of the facilities would be available without interfering with construction activities or production operations.

Based on the preliminary technical evaluation, the West Delta, Block 58 site was determined to be the prime candidate site. Therefore, additional information concerning the platform at this location was obtained from Conoco. This data included construction plans for evaluation of the structure as a potential field test facility. The plans for a "Deck Lifting Frame" were also obtained for evaluating future use of the available truss system as a means to transfer loads to a test pile.

A field trip to the West Delta candidate site was made June 30, 1981, by G. Leon Holloway and Jack H. C. Chan. The site was one of CAGC's abandoned platforms identified to be removed in the near future. The structure is located in approximately 15 m. of water. The purpose of the trip was to identify the facilities remaining on the platform and to evaluate the structure as a potential test site. Photographs were taken for subsequent reference.

The overall evaluation for use of this platform for conducting the load test offshore was very favorable. Some structural reinforcing is deemed to be necessary to provide safe working conditions on the stair landings and walkways. Portions of the wooden deck would need to be changed, but no severe structural degradation was noted which would prohibit use of this platform for the intened purpose.

A trip to the Avondale fabrication yard in Morgan City, Louisiana was made the same day. The purpose of this visit was to inspect a deck lifting frame for possible use as component of the loading frame in a tension pile load test.

Numerous photographs of the structural framing were taken for later evaluation. Again, a positive attitude was expressed by both Conoco and Ertec parties that some of the members could definitely be utilized.

RECOMMENDED FIELD TEST PROGRAM

General

Based on the considerations and evaluations presented herein, a two-phase offshore test program is proposed for the West Delta, Block 58 site. The first phase would consist of running small-diameter pile segment tests and applying the results to predict the large-scale pile test. The first phase would also provide important site specific parameters for the analytical development effort, and the results of this phase would be used to guide the large-scale test program and laboratory analysis.

The second phase of the program would consist of testing a large-scale instrumented pile. The results of this portion of the program can be translated to the design of the TLP prototype piles and also serve as additional input for verification of the analytical procedures and small-scale tests.

Ideally, the results of the combined field test program should provide justification for using a small pile segment test for future TLP pile predictions through 1) direct extrapolation from small tool friction-displacement (t-z) data, or 2) input of measured in-situ reconsolidation and pressure information into an advanced analytical solution, or 3) a combination of both 1) and 2).

A summary of the recommended program is further detailed in the following paragraphs.

Site

The site recommended is the West Delta, Block 58 location. A general location map of the West Delta site is presented on Plate 15. Photographs of the recommended platform are shown on Plate 16. The advantages of this site are considerable compared to other prospective sites and are as follows:

1. Soil conditions appear to be very similar to the proposed offshore TLP sites.

2. The continuous, homogeneous stratigraphy to approximately 76 m. would allow a long test pile of relative stiffness comparable to the prototype piles to be installed.

3. Representative in-situ total pressures and pore pressure can be measured for analytical method development due to the capability of using a long test pile.

4. No concern on how much excess pore pressure would have been created and would remain undissipated from the driving of the reaction piles needed for an onshore site.

5. The availability of the platform and Conoco's lifting frame simplify the requirements for the loading system.

Phase 1 Test Program

Reasons for recommending the small-diameter pile segment testing program as the first phase include the following:

1. A significant amount of data can be acquired for a relatively small cost.

2. The program can be performed in conjunction with a soil sampling and conventional in-situ testing program.

3. Due to the small diameter, reconsolidation times and site specific soil parameters can be obtained to guide the large-scale test program (Phase 2).

4. Frictional data, both first cycle and after degradation, can be obtained and correlated to different reconsolidation times.

5. Resulting friction-displacement data can be used to predict large-scale test results.

6. Lateral pressure measurements can be used to further extend analytical methods for predicting the large-scale test results.

The Phase 1 program would be performed sufficiently in advance of the large-scale test to allow processing, interpreting, and analyzing of data for use in guiding the larger test. In general, the program would consist of performing tests at several penetration depths and at varying degrees of reconsolidation corresponding to significant events in the lives of both the subsequent test pile and prototype TLP piles. These key events would include driving, set-up, and short- and long-term loading.

Phase 2 Test Program

Reasons for recommending the companion large-scale test program include the following:

1. The test pile would approach the actual geometry of the proposed TLP piles.

2. Representative loading patterns can be applied to determine t-z data in soil conditions similar to those expected to exist at the proposed TLP sites.

3. A fully embedded, long pile could be tested, thus allowing simultaneous observation of pile-soil behavior in both elastic and elastic-plastic regions, with comparable residual stress effects.

4. Results could be compared to the small-diameter test results to determine the existence or non-existence of scale effects due to the geometric differences and allow confident extrapolation to full design size.

5. Pressure data from the large-scale test can be used to further extend analytical methods, particularly if data compares favorably to the small-scale test results.

The initial test of the Phase 2 program would be a static tension test immediately after driving. This information could be used in conjunction with pile head strain and acceleration measurements for driveability interpretation purposes. After the initial testing, the pile would be redriven to restore the "as driven" residual stresses in the pile. Following an appropriate reconsolidation time, based on previous small tool test results and on the soil pressures acting against the long pile, the test pile would be loaded statically and then cyclically to determine set-up effects and skin friction degradation characteristics. A follow-up test series may be considered to assess the degree of permanent skin friction degradation resulting from the first cyclic test series.

SOIL SAMPLING AND TESTING PROGRAM

General

In order to fully understand the results of subsequent field tests on a large diameter pile, it would be necessary to determine site specific soil parameters for comparison and evaluation of predictive pile capacity methods. The soil sampling and testing program would consist of in-situ tests as well as standard and sophisticated laboratory soil tests on high quality samples. Some of the samples would be made available to Det norske Veritas for laboratory model pile testing.

Cone Penetrometer Test (CPT)

The initial site specific test would be a cone penetrometer test (CPT) to verify the continuity and homogeneity of the test stratum. This test would take place prior to final determination of the location of the test pile instruments, particularly pressure cells. This measure would assure that the pressure information gathered is representative of the soil type contributing the major portion of support and not an anomaly within the test stratum. In addition, predictive pile capacity methods based on standard CPT results could be evaluated using the data gathered and later compared to the large and small-diameter field test results.

Soil Sampling Program

A soil sampling program would be conducted immediately following CPT testing. The recommended sampling program is shown on Plate 17. Sampling intervals were chosen to optimize comparisons of field test and laboratory soil test results. The sampling would be performed through drill pipe using push sampling techniques. In this way, mechanical sample disturbance would be kept to a minimum.

In-situ vane shear tests are proposed at the depths shown on Plate 17. This data would provide additional soil shear strength information as well as provide an indication of the degree of disturbance suffered by the recovered samples due to volumetric expansion from total stress relief and dissolved gases coming out of solution. In addition, the use of shear strength data (corrected vs. uncorrected) pile design could be evaluated.

Laboratory Testing Program

A laboratory soil testing program to determine soil parameters at the proposed test site is given on Plate 18. The primary purpose of the program is to allow comparisons of measured field load test results to pile capacity prediction methods based on laboratory soil test parameters. Since the majority of the existing capacity methods are dependent on laboratory soil testing, a comprehensive testing program has been designed to provide the soil parameters required for these methods.

Both total and effective stress parameters will be obtained from the proposed laboratory test program. Total stress capacity methods will utilize results from unconsolidated undrained (UU) triaxial tests and miniature vane shear (MV) tests which result in undrained shear strength values (S_u or C_m). Effective stress pile capacity predictions require the friction angle ($\bar{\phi}$) and stress path information determined from soil tests where pore pressure measurements are incorporated. These include isotropically or K_o - consolidated undrained triaxial tests (CIU or CK_oU, respectively) and direct simple shear tests (DSS). The results from all consolidated tests (CIU, CK_oU, and DSS) will be normalized using SHANSEP procedures (Ladd et al, 1974) to reduce the effects of sample disturbance on test results.

Prior to extruding samples in the laboratory, all sample tubes will be x-rayed to determine the best portion of each sample for testing. The areas of extreme disturbance are more apparent from x-rays since the act of extruding often masks disturbed zones of soil. A number of samples have been tentatively selected for shipment to Veritas for use in the laboratory model test program. These are also shown on Plate 18.

PHASE 1 SMALL-DIAMETER SEGMENT TESTS

General

As outlined in the recommended program, cyclic testing with a small-diameter pile segment will be performed prior to the major testing phase for the large test pile. This program would take place immediately following installation of the large test pile since the personnel and data acquisition systems would already be in place on the proposed platform. Results of the small-diameter segment test is expected to guide the final planning of the large-scale testing program. In addition, it may be found that data gathered from small tools using rational testing techniques can be used to provide many of the necessary parameters for prototype pile design.

Instrumentation Description

A small-diameter pile segment has been developed which can be deployed through standard drill pipe to measure local soil friction. This tool employs an instrumented sleeve segment to directly measure the shear transfer as well as total lateral pressure and pore water pressure to determine the associated effective stress parameters. After pushing or driving the tool into the soil ahead of the drill string, the reconsolidation of the soil around the tool is monitored using the total and pore pressure instruments. Measurements can be made with this tool either open or closed-ended to detect differences that a soil plug might make. Plate 19 illustrates the tool used in a previous program.

For this study a displacement reference anchor will be added to allow down hole measurement of the relative soil-tool displacement. The measurement of small displacements of a deeply embedded tool using tell-tales would be unsatisfactory for the depths required. In order to improve the displacement measurements, movement of the instrumented portion relative to this anchor segment will be measured using a DCDT.

All other measurements will be made using full bridge strain gage transducers. Data will be collected using a computer controlled digital data acquisition system. Calibration and stability will be verified using a precision shunt balance circuit incorporating special bridge rotation for verification of zero readings and absolute bridge imbalance.

Test Sequence

The small-diameter instrumented probe is intended to model a segment of a large-diameter pile. Test sequences used for the probe will therefore include displacement histories designed to reasonably duplicate the displacement history of segments of a long pile at various depths. Such sequences will include full reversals to failure at shallow depths and one-way cycling at load levels up to failure at greater depths.

It is presently planned to perform a number of experiments at each of several depths, in order to explore the effects of time on the normal stresses and the frictional resistance. The sequence of events outlined below describes the procedures to be followed for each experiment at each depth.

Step 1. Advance a borehole to a depth ten or more probe diameters above the test depth.

Step 2. Insert the tool into the drill string, and advance the probe to the test depth using a wire-line hammer or a similar device.

Step 3. Load the instrumented probe to failure in tension, recording the frictional resistance "as-driven".

Step 4. Reseat the probe with a small number of additional blows.

Step 5. Monitor the dissipation of excess pore pressures for the desired period of time.

Step 6. Load to failure in tension, followed by a number of cycles to failure alternating between tension and compression, until the cyclic degradation process is completed.

Step 7. Allow the normal stresses to equilibrate.

Step 8. Repeat the loading sequence in Step 6, in order to record any recovery in frictional resistance during Step 7.

The sequence of events given in Steps 1 through 8 will be performed a number of times at each depth, to define the relationships among normal stresses, pore pressures, frictional resistance (both initial maximum and cyclic minimum), displacement history, and time for the clay in various stages of reconsolidation. Steps 7 and 8 are particularly important in defining the long-term behavior of a tension pile subjected to severe loading quite early in its intended useful life.

Variations in the imposed load or displacement history will be performed in subsequent experiments, to more reasonably duplicate the expected displacement history at each depth. The variations will be performed in lieu of Steps 6 through 8, with the sequences shown in Steps 6 through 8 performed at the end of the experiment, becoming Steps 9 through 11 in the sequence. The effects of the variation in displacement history can then be determined by comparing Steps 9 through 11 with Steps 6 through 8 of the earlier experiment.

Analysis of Data

The use of a minicomputer to control the acquisition and processing of the data will permit rapid analysis and assimilation of the experimental data. The data can be immediately converted to engineering units, and cross-plotted during the course of the experiment. The cross-plotting of the data during the experiment will aid greatly in controlling the tests, with the effects of varying load or displacement being immediately seen.

During the reconsolidation phase of the experiments, the normal pressures (total, pore-water, and effective) and the residual shear transfer will be plotted with time. Such plotting will assist in the immediate evaluation of the progress of reconsolidation, and will allow the load sequences to be performed at the proper stage of consolidation.

During the load testing phase of the experiments, the normal pressures (total, pore-water, and effective) and the shear transfer will be plotted as functions of displacement. In addition, the ratio of the shear transfer to the normal effective stress will be plotted as a function of displacement. In this manner, the shear transfer-displacement (t-z) relationships can be immediately established and used to aid in controlling the test. Although the ratio of shear transfer to normal effective stress does not fully represent a stress path (the other principal stresses are not known), the trends observed are expected to add to the visualization and understanding of the phenomena involved in cyclic degradation.

At the conclusion of the experiments, the data will be back-analyzed to evaluate the relevant soil parameters for the calibration and evaluation of the various mathematical models of soil properties. The data will also allow the various pile capacity predictive methods to be evaluated. The results of the experiments can thus be extrapolated to the large-diameter test pile empirically, as well as by means of more rational analytical methods.

PHASE 2 LARGE-DIAMETER PILE TEST

General

Based on the feasibility study completed in Task 4, a large-diameter instrumented pile load test was recommended as the second phase of the two-part field testing program. Two similar load tests have been conducted recently by Ertec personnel. Due to the need for a tension load test in the cohesive soils of the Gulf of Mexico by the summer of 1982, it is an attractive approach to utilize as many of the developments of the previous programs as possible. An additional advantage to this approach is that operational experience gained from the previous programs can be applied so that mistakes may be avoided. Specific aspects of the previous programs pertaining to instrumentation can also be used, thereby allowing existing and proven techniques for instrument design, construction and installation to be utilized. This not only would reduce the overall project budget, but by using proven instruments, a sense of confidence would be added to the test results obtained. The overall test program for Phase 2 will be divided in the following sections listed below:

1. Test arrangement
2. Instrumentation
3. Data Acquisition
4. Fabrication of test system
5. Installation of test system
6. Test sequences
7. Data reduction and analysis

Test Arrangement

The overall arrangement of the test system is shown on Plate 20. The system is composed of the test pile, the loading frame, and a hydraulic loading system. The two-piece test pile and the loading frame would be pre-fabricated onshore and barged to the test site. Final assembly would then be accomplished and the test pile driven. The designs of all components of the field test system will be such that only minimal construction activities will be required at the test site, thereby reducing expensive barge time. Details of fabrication and installation aspects are given later in this report.

Test pile. The two-piece test pile conceived for this load test consists of a continuous instrumented section 54.9 m. (180 ft.) in length and an uninstrumented section 44.2 m. (145 ft.) in length. The instrumented section would be tipped at a penetration of 67 m. (220 ft.) below the mudline with the uninstrumented section joining at 12.2 m. (40 ft.) below the mudline and extending to approximately 3 m. (10 ft.) above the platform deck. A loading head would be part of the uninstrumented section near the top of the pile to serve as the mechanism for transferring the load into the pile from the hydraulic loading system.

The lower instrumented section would contain the instrumentation required for measurements on the embedded pile. The basic components of the package include total and pore water pressure cells, strain gage modules, and mechanical strain sensor (extensometer) gage sections. Details of all instruments are discussed in a later section.

In addition to these instruments, some internal access tubes would be required for insertion of instruments after the pile is driven to final penetration. These access tubes begin in the test section, run internally the full length of the pile and exit at the pile head. Instrument cables from pressure cells and strain gage modules would run internally to a point just below the splice location and then externally the remaining length of the pile. The right hand portion of Plate 20 shows two cross sections of the pile at locations above and below the stab-joint connection illustrating where the access tubes and cables are located.

The test pile would be assembled from sections of 76 cm. (30 in.) diameter ASTM 572 grade 50 steel pipe. A wall thickness of 1.27 cm. (0.50 in.) is specified. A thin-wall pile is desired to produce greater elastic stretch and thereby larger soil-pile slip displacements. Thinner-wall piles also reduce total pile weight, which is advantageous for handling. However, the higher strength steel is required to accommodate the stresses anticipated during driving and loading.

Loading system. The basic requirements for the loading system are to provide (1) a reactive capacity well in excess of the capacity of the test pile, both for reasons of safety and to minimize the deformation of the reaction system, (2) the capability for loading of the test pile with minimal delay after driving, (3) the capability for compressive loading of the pile, if desired, and (4) convenient access to the top of the test pile for repair or replacement of external pile-head strain gage bridges and for access to the interior of the pile for placement of the drop-in extensometer units.

A conceptual design for the reaction frame is given in Plates 21 and 22. With the exception of stiffener plates and other small members, the materials used in the design are owned by Conoco, and have been made available for use in this project. As shown in Plate 22, provision has been made for loading the test pile in compression, although such loading is presently optional. The primary load sequences will be performed using only the upper set of hydraulic rams, placing the test pile in tension.

The load frame would be fabricated onshore, and transported to the test site in one piece. Base dimensions of the load frame are nominally 9.1 m. (30 ft.) in width by 12.2 m. (40 ft.) in length, with actual dimensions being determined after more precise measurements of the platform.

Modifications to the existing platform would be minor, including the removal of two diagonal braces below deck level, removal of the wooden decking and its supporting trusswork, and the preparation of four jacket legs for welding. The on-site erection work would consist of setting the frame in place, leveling, and welding the four corners to the jacket legs.

As presently conceived, four hydraulic rams will be required to apply the tensile loads. The size of the hydraulic rams and the pump system will be chosen for compatibility between flow rate and the rate of loading to be applied to the test pile. Consideration will be given to servo-controlled systems for improved control in applying the cyclic tensile loads.

The top surface of the reaction frame will be covered with decking to provide safe and convenient access to the hydraulic system and the test pile. A scaffolding arrangement will be erected over the test pile to provide access for instrument placement.

Instrumentation

The pile instrumentation will be designed to provide high-quality measurements of the variables required for extrapolation of the observed behavior to the design of offshore tension pile foundations. Experience with instrumentation design gained from past large-scale pile load tests will be drawn upon for the proposed test. This experience will allow the instruments to satisfy the following requirements:

1. Adequate precision and stability in the measurement of each variable.
2. Prefabrication of each unit to permit precise precalibration with proof of linearity and stability prior to placement in the pile.

The principal objectives of the instrument package are to provide the capability to measure load-displacement behavior of the test pile under cyclic axial loading and to measure shear transfer along the embedded length of the test pile. Objectives also include measuring parameters believed to affect the shear transfer, such as pore water pressure and total soil pressure acting normal to the pile wall.

The selection of instruments and locations is planned so that duplicate measurements of most parameters can be made. Some of the instruments would be installed after pile driving. Using these techniques, independent verification of data would be available and total loss of data due to failure of a particular instrument would be less likely. The following types of instruments are required to accomplish the test objectives:

1) Axial strain sensors on the embedded pile,
2) Displacement measuring instruments on the embedded pile,
3) Pressure transducers,
4) Pile head measurement systems, and
5) Pile driving data.

Axial strain sensors. Axial strain in the pile, which would subsequently be converted to load, will be measured using both electrical and mechanical (extensometer) strain sensors. Two units of each type will be placed at each level, diametrically opposed so that effects of bending may be cancelled.

The resistance strain gage modules consist of foil resistance strain gages mounted on a thin walled tube and surrounded by a concentric steel tube for protection. The outer tube is then cradled and welded longitudinally in a steel channel section. The tube and channel unit serves to mechanically transfer the strain in the pile wall to the inner tube. The modules thus become an integral part of the pile cross-section, experiencing changes in strain equal to that in the larger cross-section. The outer tube will also serve as a protective cover for the instrumented inner tube. The modular arrangement allows for ease of installation in the test pile and permits numerous sets of zero readings to be made prior to pile driving to verify the stability of the units as-welded. An illustration of a strain module is given on Plate 23.

The extensometers are electro-mechanical devices which measure the changes in length of a section of the pile during application of load. An illustration of an extensometer in place is given on Plate 24. The removable, or drop-in , unit consists of a DCDT (Direct Current Displacement Transducer) enclosed in a bullet-shaped housing which rests on a three-point support previously welded into a gage section on the interior pile wall. The DCDT will be used to provide an electrical signal proportional to the change in distance between the support points. The changes in length over the gage section may then be used to determine the changes in the average strain in the pile wall.

The electro-mechanical extensometers have several advantages over the welded-in strain modules. The units are not in-place during driving, and are thus not subject to damage from impact stresses. The units are completely interchangeable (any drop-in unit can be used in any set of gage seats), thus a malfunction in any unit will not alter the ability to make strain measurements. By comparing the lengths of each welded-in set of gage seats to an unstressed standard bar before and after driving, the units may be used to obtain residual strains in the pile after driving, independently or in lieu of the resistance strain gage modules.

The adoption of a gage length of 1.52 m. (60 in.) and a DCDT having an output characteristic of 1.57 volts per mm. (40 volts per in.) results in an output for the drop-in units of approximately 2.4 mv. per microstrain. The units will thus have a sensitivity which is comparable to the resistance strain gage modules, which is planned to be $\pm$ 1 micro strain.

Displacement measurements. The displacement measurements at selected elevations along the pile will be made by tell-tales. The system utilizes a cylindrical anchor with a flat spring-steel wire attached. This anchor is lowered into an access tube after the pile is driven to its final penetration. The wire extends to the surface and is passed through a DCDT-and-dial gage assembly mounted on a stationary reference beam. A weight is attached to the free end of the wire for providing constant tension on the tell-tale. As displacements occur at the respective elevations, the wire also displaces, with movement measured by both the DCDT and dial gage. An illustration of the tell-tale assembly is shown on Plate 25.

Pressure transducers. The soil parameters required for interpretation of the frictional behavior include simultaneous values of the frictional resistance and the effective stress acting normal to the surface of shear. The normal effective soil pressure acting against the pile will be determined by measuring the pore-water pressures in the soil adjacent to the pile wall and the total soil pressure exerted on the pile wall by both solid and fluid constituents. By subtracting the pore-water pressure from the total pressure, the average intergranular, or effective, pressure can be calculated.

The total and pore-water pressures will be measured by prefabricated, sealed units which have been calibrated and proof-tested prior to being placed in the pile. The faces of the units will be machined to conform to the curvature of the pile wall, and will be of adequate stiffness that the presence of the transducers does not affect the pressures to be measured.

A conceptual drawing of the total pressure transducer is shown in Plate 26. The unit is similar to those previously used to successfully measure total soil pressures on large piles. It is expected that some redesign of the instruments will be necessary for mounting the units on the thinner walls of the proposed test pile. Similar units will be designed and fabricated for the pore pressure measurements, which will be made using commercially available strain-gaged pressure transducers. Access to the pore-water will be provided through porous filter elements machined to conform to the pile wall curvature.

The resolution of the soil pressure measurements will be in the range of $\pm$ 1 kPa ($\pm$0.02 ksf), which is approximately 0.1 percent of the total vertical pressure at the elevation of the deepest instrument.

Pile head measurement systems. In addition to measurements from the embedded pile section, load and displacement will be measured at the pile head. Strain gages will be attached just below the loading sleeve to allow the load applied at the pile head to be determined. Pressure transducers will be attached to the hydraulic rams to monitor system pressure during testing and may also be used as a back-up system to the strain gages. However, these pressure transducers have been shown to give erroneous measures of non-static loads, since the pressure head includes components related to flow velocity.

Displacement of the pile head will be recorded using a dial gage and a DCDT mounted in a measuring module attached between the pile and a reference beam. An engineer's level will also be used as a back-up for monitoring pile movements.

Dynamic measurements will be made during driving of the pile using strain transducers and accelerometers mounted on the test pile below the loading head. The data from these two instruments will be recorded and processed to determine force, velocity, and energy transmitted to the head of the pile during driving.

At the present time, direct correlation between dynamic behavior measured during driving and static pile capacity has not been adequately established. Measurements made during driving will provide some useful information upon which rational hindcasting can be based. Installation of the prototype piles at the offshore site could be planned with greater confidence using these data. Several contractors currently have this equipment available.

Instrument locations. The general layout of the instrumentation is shown on Plate 20. Strain measurements at six levels will be used to determine the average shear transfer in each interval between strain modules over the embedded length of the pile. Pressure transducers are proposed to be positioned at the midpoint of each interval. This will allow average values of total and pore water pressure measurements in each interval to be made simultaneously with that of shear transfer. The final determination of the pressure transducer location will be made following a detailed cone penetrometer sounding (CPT) so that the transducers will not be located in any small layers not representative of the average soil conditions.

The extensometer strain sensors will be placed at the two extreme ends of the test section at the same level as the resistance strain modules and at one intermediate level, also at the same level as a pair of resistance strain modules. This will serve two purposes; 1) it will allow redundant measurements to be made to verify that readings being made by the strain modules and extens-ometers are consistent, and 2) it will define two major zones on the pile which could be utilized to define the average shear transfer along the pile if the strain modules were damaged during driving.

Tell-tales would be placed at both the top and bottom levels of instrumentation on the test pile section. These two positions would provide displacement measurements for t-z analyses and another check for the load transferred between their respective locations. The remaining instruments would be placed near the top of the pile. These instruments would consist of accelerometers, strain gages, strain transducers, and a plug follower.

Instrument installation. The installation of each instrument within the test section would be carried out according to carefully detailed instrumentation installation drawings and specifications. The general requirements for the assembly of the test pile are discussed in the following paragraphs.

The resistance strain gage modules will be prefabricated self-contained units. To install the units in the test section, all that is required is to weld the units in place. The mechanical extensometer strain sensors and the tell-tales require installation of access tubing which extends internally to the top of the test pile.

Placement and alignment of these tubes are critical, and coupling sleeves are required at the pile splice locations such that a water tight connection in the extensometer tubes can be achieved when the splice connection is made. External stabbing guides are also required at the splice locations to aid in aligning the pile and instrument tubing while splicing the add-on section.

Special mounting rings for the pressure cells will be machined and welded into the pile so that installation of the pressure cells to the test section requires only attaching the cables to both the pile wall and pressure cell and then bolting the cell to the mounting ring. These mounts are designed so that no shear force is transferred to the mounting bolts during driving.

Both the strain modules and pressure cells require cables to run the full length of the test pile. The cables will be bundled around three steel reinforcing bars welded diametrically opposed on the internal pile wall. Both the instruments and cables will be covered with a continuous plate. The cables will exit the pile at the top of the instrumented section and run externally the remaining length of the test pile to the surface. Cover plates will be required to cover the external cables. The cables will be attached to the external pile wall by the same method used for the internal wall. A cross-section of the test pile illustrating the cable arrangement is shown on Plate 27.

Schedules for preparation of the test pile and fabrication of the instruments is included in a later section. As indicated, several activities are planned to proceed simultaneously, while others depend heavily on the preceding activity. Most of the instruments are not off-the-shelf items. Therefore, sufficient lead time will be required for the acquisition and fabrication of necessary components.

Proof-testing and calibration. In order to insure the durability of the instruments and the reliability of the measurements, each transducer element must be calibrated and proof-tested prior to use.

The total pressure transducers will be calibrated with a series of equivalent dead-weight loads beyond the range of expected pressures. The pore-pressure transducers will be calibrated against a piston-and-dead weight pressure source.

After calibration, the proper functioning of the units will be verified by immersing the units in a water-filled pressure vessel and applying fluid pressure. At the same time, the transducer units and their associated cable and cable connections will be pressure-tested for leaks by maintaining the pressure for a reasonable period of time and monitoring the resistance of the strain gage bridges to the transducer housing. In this manner, proper functioning of the units can be verified prior to placing the units in the test pile.

In a similar manner, each resistance strain gage module can be tested for water-tightness prior to welding the units in the test pile. During the fabrication of the units, all welds will be pressure-tested by subjecting the internal chamber to helium pressure and checking for leaks with a soap solution and a "sniffer".

The resistance strain modules will be calibrated after being welded in the test pile by applying compressive loads to the instrumented pile section. This calibration will eliminate uncertainties about the elastic properties of the test section. Measurements of the total deformation of the test section will also be made, so that the computation of the relative movement of each instrumented section can be corrected for elastic deformations due to strain.

The electrical displacement transducers (DCDT's) used for measuring displacement of the tell-tales and used in the extensometer units for measuring strain will be calibrated against mechanical dial indicators. In addition, the extensometer units will be pressure-tested for water-tightness in a manner similar to the pressure transducer and resistance strain units.

The calibration and proof-testing of each instrument is of extreme importance. Provisions will be made in the test schedule for thorough proof-testing of each instrument to avoid or minimize failures in the field due to deficiencies in the design or construction of the instruments.

The calibration of the instruments will be made with a precise shunt-balance and null indicator circuit. The output units from this system will then be directly related to the measured variables in engineering units of pressure or load. Shunt resistors will then be externally applied to each strain gage bridge, and the offsets created by the shunt determined in engineering units. These resistors will then be used to provide convenient checks on the calibration of the automatic data acquisition system. All instruments will be read periodically during the test using the precise bridge-balancing circuit, and the results compared with the data taken using the automatic systems. In this manner, the digital data can be independently verified throughout the progress of the test, and related directly to the calibration without any intermediate computation.

Data Acquisition

A dedicated data acquisition system will be used to gather, store, and process all the results of the tension pile load test. The system is divided into four main parts which consist of the following integrated components:

1. Main Console
2. Computer
3. Data Scanning Unit
4. Storage and Display

Main Console. The Main Console will include all plugs, cable terminals, switches, power supplies, and associated wiring for manual checkout and switching of all instrument signals. It will allow access directly to the transducers in order to manually verify both excitation and output voltage levels prior to entry into the automatic data acquisition equipment, and to allow routine checks of the resistance to ground for additional verification of stability. The system allows each transducer to be connected to a manual shunt-balance circuit in order to precisely determine bridge imbalance at various stages of the test. This manual bridge balance is important because it provides an independent check on bridge condition and output.

Computer. Control of the data gathering, storage and processing will be handled by a 16-bit minicomputer capable of multitask operation. The significance of multitasking is that data collection can be accomplished without interruption regardless of input/output or processing tasks.

Programming of this computer controller will be done in FORTRAN or BASIC. Both languages are well suited to data gathering and processing. The program will be written so that the sample rate can be changed during the test without interrupting the systematic collection of data. An onboard real-time clock will be sampled with each data scan so that the time relationship is preserved in all data. All power supplies will be monitored by the computer during the test and a record kept of their output. All variations in power supply output voltage will be automatically applied to the calibration factors of each transducer. The operator will be alerted if any power supply malfunction is detected, and thus provided with the option of continuing with the test or stopping it to determine the problem.

Data scanning unit. The data scanning unit (Hewlett-Packard 3054C) is capable of monitoring strain gage bridges and analog voltage signals, allowing up to 300 readings per second with nominal 100 nanovolt precision. Each transducer signal can be selected either sequentially or randomly under control of the computer program. The output is then digitized, and the digital data stored and/or converted into engineering units (stress, strain, pressure, displacement, etc.) and displayed.

The strain gage bridge outputs will be sampled without using amplification or balance circuitry. This will insure the best possible representation of the absolute values of stress and strain. (The addition of any circuitry to amplify or balance the strain gage signal increases noise and thermal instability.) A special plug-in unit developed by HP for use in the 3054 System allows 100 nanovolt resolution of strain gage bridge signals when used in conjunction with their 6 1/2 digit digital voltmeter.

In addition, a shunt calibration resistor can be switched across each strain gage transducer periodically (under program control). This calibration resistor simulates a known change in transducer output which can be used to verify system and transducer stability.

Storage and display. The unprocessed voltage output from each transducer, as well as power supply voltages and time of day, will be stored on magnetic disc for future laboratory processing. Some of the transducer signals will be converted in real-time to engineering units and displayed in order to monitor the test progress. These selected parameters can be simultaneously displayed on one or more video-graphic terminals or plotted on digital X-Y plotters.

Fabrication of Test System

The fabrication of the test pile is one of the most important phases of the entire field test program. Extreme care must be taken throughout the fabrication process so that all instruments will reach the site undamaged. Proper fitting of the two test pile components and the load frame are also important to assure efficient field installation.

Listed below are some of the requirements for fabrication facility and the contractor:

1. Site for fabrication should be protected from weather and shaded from sunlight.

2. Overhead cranes or crane access within facility should be available.

3. Sufficient space should be provided to permit all sections of the test pile to rest end-to-end on supports during alignment and construction.

4. Pile supports mounted on rollers or similar device which permit easy rotation will be required.

5. Pile supports should also be such that axial translation can be accomplished, thus permitting precise longitudinal fitting.

6. Contractor should be prepared for welding and working inside test pile sections.

7. Surveyor's transit should be available for use in the alignment process.

8. Fabrication shop should have access to barge and shipping facilities.

9. Contractor should supply normal office space with appropriate facilities.

10. Air compressor and necessary support equipment would be required.

Complete specifications for fabrication with associated drawings will be furnished to Conoco and in turn sent to possible fabricators. This will allow the fabricator to be thoroughly familiar with construction details prior to submitting their bids for the work. Exact details and requirements pertaining to the fabrication facility and tasks will be further discussed with the selected contractor. Ertec will provide at least one engineer to supervise and monitor the fabrication of the test pile.

Installation of Test System

The construction activities at the test site have been planned to minimize time on site for the derrick barge. Some prior modifications to the platform would be necessary before the arrival of the derrick and material barges at the site. These are listed as follows:

1. Clear or re-position existing facilities from or on platform deck.

2. Remove wood decking from test frame location.

3. Prepare jacket legs and attach stab guides for load frame.

4. Remove diagonal bracing below deck level where required.

5. Install guide ring near water surface (if needed for compression testing).

With the above items accomplished, the remaining events will require a derrick barge crane of 500 tons or greater capacity. This size barge is required because of the existing deck height that the boom will have to overcome and still be able to lift a significant length of pile section.

The first step in the installation process would be the attachment of the load frame to the existing platform. The load frame would be a self-contained prefabricated unit which acts as a transfer mechanism through which the load is distributed into the platform piles. It would be lifted into place and positioned on stab guides already installed on the platform deck. An illustrative schematic of this operation is shown on Plate 28. Support and test equipment would then be brought onto the platform as the load frame was being securely welded to the deck. Activities concerning the test pile preparation would also be proceeding as the derrick barge was being used for the load frame hoist.

Protective cover plates on both ends of the test pile would be removed and the temporary spools of transmission cables (strain modules and pressure transducers) would be brought out. The cables would be rolled out until the spools could be inserted into pre-attached support brackets near the pile tip. The loose cables would be restrained by protective covers from further movement during the lift of the test section.

The main derrick crane and a smaller crawler crane would be required to assist in the lift of the test pile. A schematic drawing illustrating this procedure for the instrumented section is shown on Plate 29.

Once the instrumented section becomes vertical, the derrick crane would position it over the loading frame. The transmission cable spools would then be removed, and the test pile lowered into the water. Zero readings for the instruments would be made prior to allowing the pile tip to reach the mud line. After zeroes are collected, the instrumented section would be allowed to sink under its own weight as far as possible and then driven to a convenient working position above the load frame. Installation of the instrumented pile section would then proceed as shown on Plates 30 and 31.

The next step in the assembly process would be for the add-on section to be aligned and attached to the instrumented section. Handling would be by the two crane method outlined earlier. The transmission cables would then be attached on both sides of the add-on section by a two level wrap-around working cage. A winch on the platform would hoist the work cage up the pile as workers bundled the cables to pre-welded reinforcing bars and attached the protective cover plates. Addition of the uninstrumented section is shown on Plates 32 and 33.

The test pile would then be driven until the load head would reach the appropriate distance from the hydraulic rams. The first tension test would be performed within minutes after the pile was driven. This would allow the as driven capacity to be measured before excess pore water pressures generated during driving had dissipated significantly.

Immediately upon completion of the first test, the pile would be redriven to restore the initial residual stress conditions. The derrick barge would then be released with no further use anticipated throughout the remaining test program. The estimated time the derrick barge would be on location is less than three days.

Test Sequence

The load test program on the large-diameter test pile will be performed in three series, with each series being performed at a different time in the soil consolidation history. Each test series is further described below:

First test series. The initial series will consist of a tensile loading to failure immediately after driving. The hydraulic rams will be in place during the pile driving operation, thus the only delay prior to loading will be the time required to attach a temporary displacement-measuring device between the pile head and the load frame. After loading the pile to failure, the rams will be retracted and the pile redriven for an additional penetration of about 0.3 m. The redrive is essential to restore the proper residual stress conditions between pile and soil, and will also serve to calibrate the Drive 10 computer program for prediction of driveability of the prototype piles.

Second test series. The second series of load testing will be performed after the soil has been allowed to reconsolidate for a predetermined period of time. This period of time is currently estimated to be approximately 90 days. However, final determination will be based on the results of the small-diameter tests and estimates provided by Conoco for the time to be allowed between installation and tensioning of prototype TLP foundation piles. The frictional capacity of the soil will also be pre-estimated based on the results of the experiments with the small-diameter instrumented probe.

The load sequence to be applied will consist of a slowly-applied static bias load (approximately 1/3 the predicted total capacity), with cyclic components then being superimposed on the static bias, up to a value of load equal to the bias load. The cyclic component of load will be progressively increased with the number of cycles of loading being determined by the observed results. If no changes are observed, only a minimum number of cycles will be performed. If changes begin to occur (progressive pile slip or degradation), cycling will continue until equilibrium is established. The pile will then be loaded to failure in tension, and possibly loaded to failure repeatedly, until the amount of accumulated slip is excessive.

Third test series. The third loading sequence is expected to be an abbreviated version of the second series, with possibly fewer cycles of loading, but to larger levels of load. The loading sequence should resemble, as nearly as possible, the final sequence of loads from the second test series. The results of the second and third test series can thus be directly compared, with the recovery in resistance (if any) being related to time and intervening changes in the normal stresses. This series would ideally take place after an extended set-up period, possibly one year. Testing may be performed earlier if instrument readings indicate that normal pressures are showing no further changes with time.

Data Reduction and Analysis

The same data processing and analysis techniques described previously (for the small-diameter segment test) will be used to process the large-diameter pile test data. Some processing and display, as required for test control, will be performed in the field. The remainder of the analysis will be performed in Houston after the completion of the major test program.

Comparisons will be made between large and small-scale test results. These comparisons will include plotting of measured values of friction, normal pressure, pore pressure, and displacement to assess applicability of existing technology and to determine trends which could be applied to the development of new soil models which realistically simulate piles loaded cyclically in tension.

REPORTS

Report on Field Testing Program

The final report may be issued in two parts. The first part would consist of a presentation of the results of the research program, including the results of the second series of load tests. This report will include the results of the laboratory soil test program and the experimental data from the large and small-diameter pile tests.

The second part of the final report would include a more general application of the results of the program. The analysis will include procedures for computing the distribution of maximum frictional resistance along the pile and a method for developing nonlinear resistance-displacement (t-z) relationships. Also included will be procedures for computing the minimum (degraded) frictional resistance, either as a function of depth or of the initial maximum resistance.

The nonlinear resistance-displacement relationships and the distribution of maximum and minimum frictional resistance with depth will be used in a quasi-static DRIVE 10 analysis to predict the behavior of the prototype piles under service loads. Pile lengths and factors of safety will then be determined on the basis of partially-degraded frictional capacity. Recommendations will also be made regarding the long-term capacity of the foundation after determining the presence or absence of any ability of the soil to recover with time after cyclic loading.

Complete documentation of all phases of design, fabrication, pile installation and testing programs will be included in the final report.

Design Specifications for Tension Leg Platforms

At the conclusion of the previously described field and laboratory research programs, the development of a general set of guidelines and specifications for the design of foundations for tension leg platforms will begin. This work is envisioned as being a joint effort which will place Conoco in a leadership position to guide subsequent industry specifications for this type of offshore structure.

The results of the research program will provide the basis for the general design manual. Also included would be items such as site investigation requirements, laboratory and in-situ testing requirements and recommendations for selecting appropriate factors of safety.

PROJECT ORGANIZATION

The Ertec project team will work closely with Det norske Veritas and Conoco through the duration of the field testing portion of the Tension Pile Study. The Ertec team will be under the technical direction of Hudson Matlock, Vice President for Research and Development, and the administrative direction of David F. Leake, Associate and Manager, Gulf States Region. Jean M. E. Audibert, Manager of Engineering in Houston, will advise on all phases of the project.

The Project Manager will be Thomas K. Hamilton. His duties will be to coordinate the activities of the four discipline supervisors whose duties have been assigned according to their areas of expertise. The disciplines and supervisors are listed below:

1. Theory Development - Ignatius Po Lam
2. Operations - G. Leon Holloway
3. Testing and Analysis - J. Dewaine Bogard
4. Instrumentation and Data Acquisition - Ronald L. Boggess

An organizational chart for the Tension Pile Study Program is shown on Plate 34. Resumes of key personnel involved in this study are given in Appendix IV.

SUMMARY OF PROJECT ACTIVITIES

Due to the complicated, and often iterative, nature of research projects of this magnitude, the project has been divided into Tasks in which related activities are performed. These Tasks are generally chronological in their order of initiation, but not necessarily in their time of completion. A description of each of the fourteen separate Tasks and the estimated duration is described below. Note that all project administration is included in Task 12. Also, since technical direction and review of several Tasks may be taking place simultaneously, Task 12 includes all work performed by the project's Technical and Administrative Directors and Advisors.

Task 1 - Preparation of Design Drawings and Specifications for the Physical Test System

Description of Task: Plan final pile size, material, location of types of instruments, methods for construction, sequencing of construction and installation events. Prepare design and fabrication drawings for test pile and load frame. Prepare detailed specifications for test pile and load frame. Prepare detailed specifications for test pile construction and installation. Results of Task 1 will provide Conoco information required for letting fabrication and construction bids.

Time Required: Primary phase will require a maximum two months extending from 1 October to 1 December, 1981. Follow-up may be required until test pile fabrication begins.

Task 2 - Site Investigation and Laboratory Testing

Description of Task: Plan and perform soil sampling and in-situ testing program at the test site. In-situ tests would include cone penetrometer tests (CPT) and downhole vane shear. Laboratory program would include a series of tests to determine soil parameters required for the various pile capacity prediction methods.

Time Required: The field program is expected to last approximately three days and should be completed prior to beginning test pile fabrication. The laboratory program should be completed within 90 days after the field site investigation work is complete.

Task 3 - Design, Fabrication, Testing, and Calibration of Instrumentation for Large-Diameter Pile

Description of Task: Design, produce machine drawings, and contract for fabrication of parts for pile instruments. Purchase hardware and required electronic components and provide labor to assemble, proof test and calibrate instruments. Several spares for each instrument type will be assembled. Final calibration of each instrument will be performed using dedicated data acquisition system. (see Task 5)

Time Required: 1 October 81 to 15 March 82.

Task 4 - Design Modifications and Calibration of Small Diameter Pile Segment

Description of Task: Design, produce machine drawings, and contract for fabrication of parts for small diameter pile segment. Purchase hardware and required electronic parts and provide labor to assemble, proof test and calibrate instrument. Instrument will be similar to previously used tool. Task will include system and technique for deployment.

Time Required: 1 November 81 to 10 April 82.

Task 5 - Development of Data Acquisition System and Software

Description of Task: Determine requirements of system and software packages. Task includes lease of computer equipment, data system housing, instrument panels and plotters. Also includes software development for sampling, storing, and processing data. Dedicated system will be used during individual instrument calibrations, test pile calibration, small diameter segment testing, test pile installation, test data gathering and final data processing and analysis.

Time Required: Data acquisition system will be used throughout the project. System and software development (Task 5) will extend from 1 October 81 to 1 March 82.

Task 6 - Test Pile Fabrication, Installation, and Initial Test

Description of Task: Supervise all phases of test pile fabrication, installation, and initial test. Provide labor and equipment to assist with instrument installation and test pile calibration. Provide personnel to perform test sequence immediately after driving. Task will include cost of all labor, housing, subsistance, and transportation not provided by Conoco. Material costs will include hydraulic ram system leasing and any miscellaneous supplies purchased by Ertec during this phase. Conoco will contract facilities, labor, and major materials during fabrication; transportation of test components and personnel offshore; construction equipment, labor and required support including communication systems required.

Time Required: 20 January to 15 May, 1982

Task 7 - Planning and Implementation of Small-Diameter Segment Test

Description of Task: Plan all phases of small-diameter pile segment test to begin immediately following large test pile installation. Provide labor and equipment to perform test program. Conoco will provide transportation and logistics support during testing.

Time Required: Planning will be accomplished 1 December to 31 December, 1981. Testing to be performed 15 May to 30 May, 1982.

Task 8 - Planning and Performing Major Field Test

Description of Task: Plan major field test which will include test sequencing, load patterns, data monitoring and techniques for data processing and display. Task will include mobilization of equipment and personnel, labor to perform the tests, equipment required for testing, and housing, subsistence and transportation not provided by Conoco.

Time Required: Planning to be accomplished 1 July to 15 August, 1982. Tests to be performed 15 August to 25 August, 1982.

Task 9 - Data Reduction and Analysis

Task Description: Process, analyze, interpret and present results of Tasks 7 & 8. Results will be reported with information and recommendations for design of foundations for TLP structures in soil conditions similar to those tested in the field. General design procedure will be developed from Tasks 10 and 11.

Time Required: 25 August 1982 to 1 October 1982.

Task 10 - Theory Development

Description of Task: Develop, from all available information, an analytical procedure for general design of TLP foundations. Information will include existing literature, laboratory model tests, laboratory soil tests, small-diameter segment tests and large-diameter pile tests.

Time Required: 1 October 81 to 15 December 82.

Task 11 - Report and Recommendations

Task Description: Report all phases of the development program with final results and recommendations for the general design of TLP foundations.

Time Required: 15 May 82 to 15 December 82.

Task 12 - Project Administration and Review

Task Description: All administration, coordination, meetings with Conoco and other participants, administrative and review related travel expenses, and other miscellaneous costs, not clearly specified in other Tasks, are combined into Task 12.

Time Required: Entire project duration.

Task 13 - Planning and Performing Follow-up Test

Description of Task: Task is similar to Task 8 except it will be performed at a presently unknown date. Purpose will be to determine long-term effects of reconsolidation and loading history. Report will be an Addendum to the final report.

Time Required: Presently unspecified.

Task 14 - Design Specifications for Tension Leg Platforms

Description of Task: Development of general specifications for the design of foundations for tension leg platforms. Specifications would include items such as site investigation requirements, laboratory and in-situ testing requirements, analytical procedures and determination of factors of safety.

Time Required: Task will begin after delivery of Task 11 Final Report. Completion expected in six-months.

BUDGET

A budget has been prepared based on completing the fourteen previously described Tasks. A summary of costs by Task as well as the detailed itemized budget is presented in Appendix I of this report. The costs are divided into the fees which would be billed by Ertec on a fixed fee basis and cost estimates for materials, labor, and services which would be advantageous for Conoco to procure directly. The latter estimates are based on the experience of Ertec personnel in projects of this type and on cost information for offshore operations from Conoco and Brown & Root.

Ertec's fee for the project would be $1,769,331. This amount includes a "risk and uncertainties" factor of 25 percent of the projected costs of time and materials to cover unforeseen events as well as additional work which, although not presently apparent, may result as the project develops. The estimated cost of materials and services Conoco would procure directly is $966,020. This figure includes reasonable delays for weather, etc., but does not include an overall project contingency factor. The estimated total cost of the field testing and analysis program would, therefore, be $2,735,351.

Conoco may wish to consider contracting Ertec to perform the designated work on a Time and Materials basis. This would allow a reduction in the "risk and uncertainties" figure as well as other possible decreases in the total cost to Conoco if the designated Tasks are completed under budget. Regardless of the type of contract, no short cuts or quality compromises will be made by Ertec in any phase of planning, fabrication, testing or analysis.

It is important to note that Ertec invoices professional and technical staff services on the basis of a multiplier applied to the individual payroll cost. Thus, rates billed for individuals may vary within a given catagory and are a direct function of salary levels current at the time of invoicing. For the purpose of budget projections presented herein, average hourly rates were used for Ertec personnel.

SCHEDULE

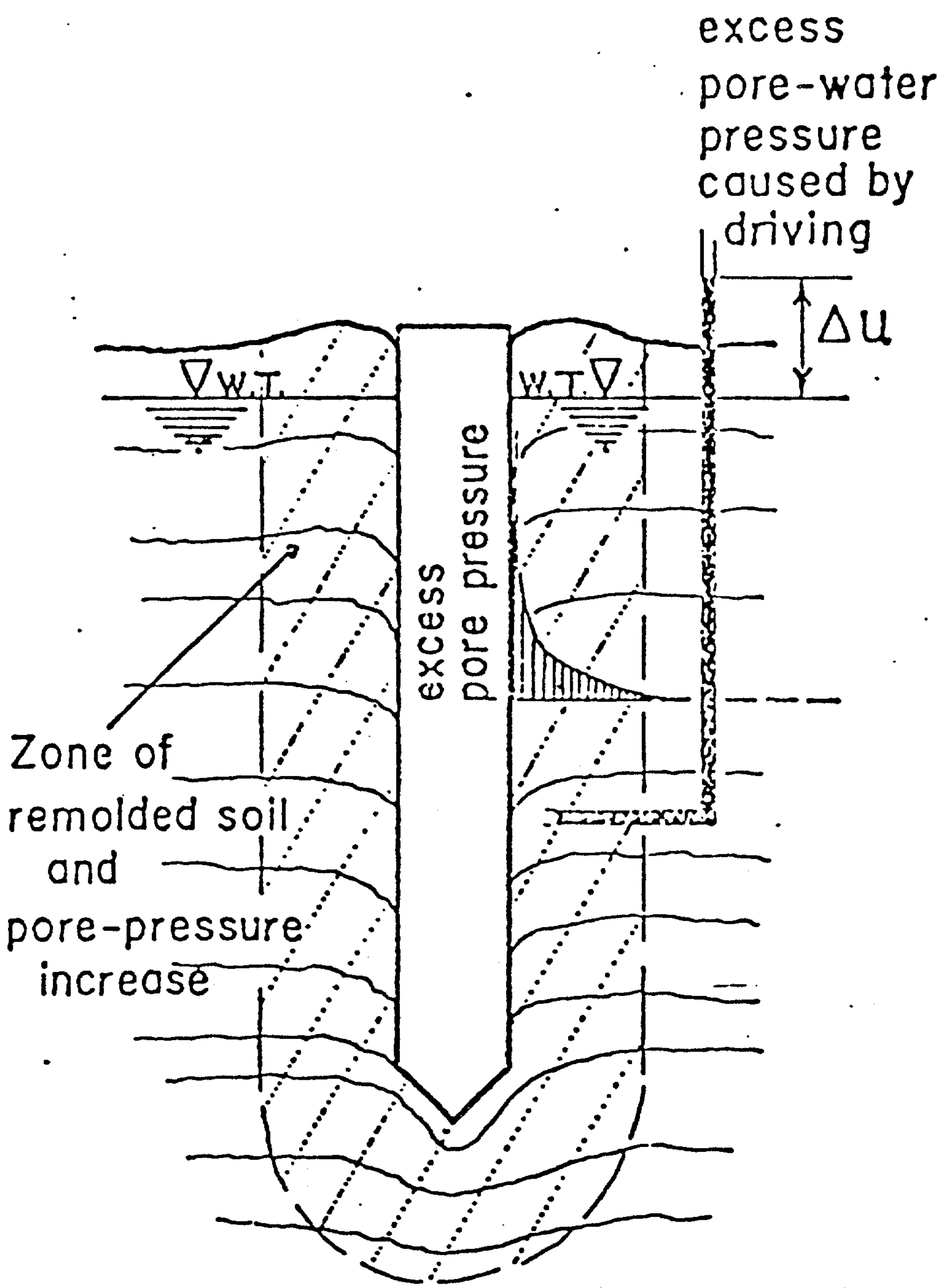
A project schedule has been prepared with primary emphasis placed on performing expensive construction tasks and sensitive testing sequences during periods of the year with historically favorable weather conditions. Due to the assumed requirement for a fixed price quotation, it is essential that an authorization to proceed be issued by October 1, 1981, the initiation date for the schedule. Significant delays in authorization could cause changes in the fixed price and would certainly cause shifts in the delivery date of a final report.

Plate 35 presents a list of milestones for the project which must be met for the project to flow smoothly to a cost effective and timely conclusion. Some are indicative of crossroads where the activities of two or more discipline groups, described previously, merge at a critical node on the project schedule.

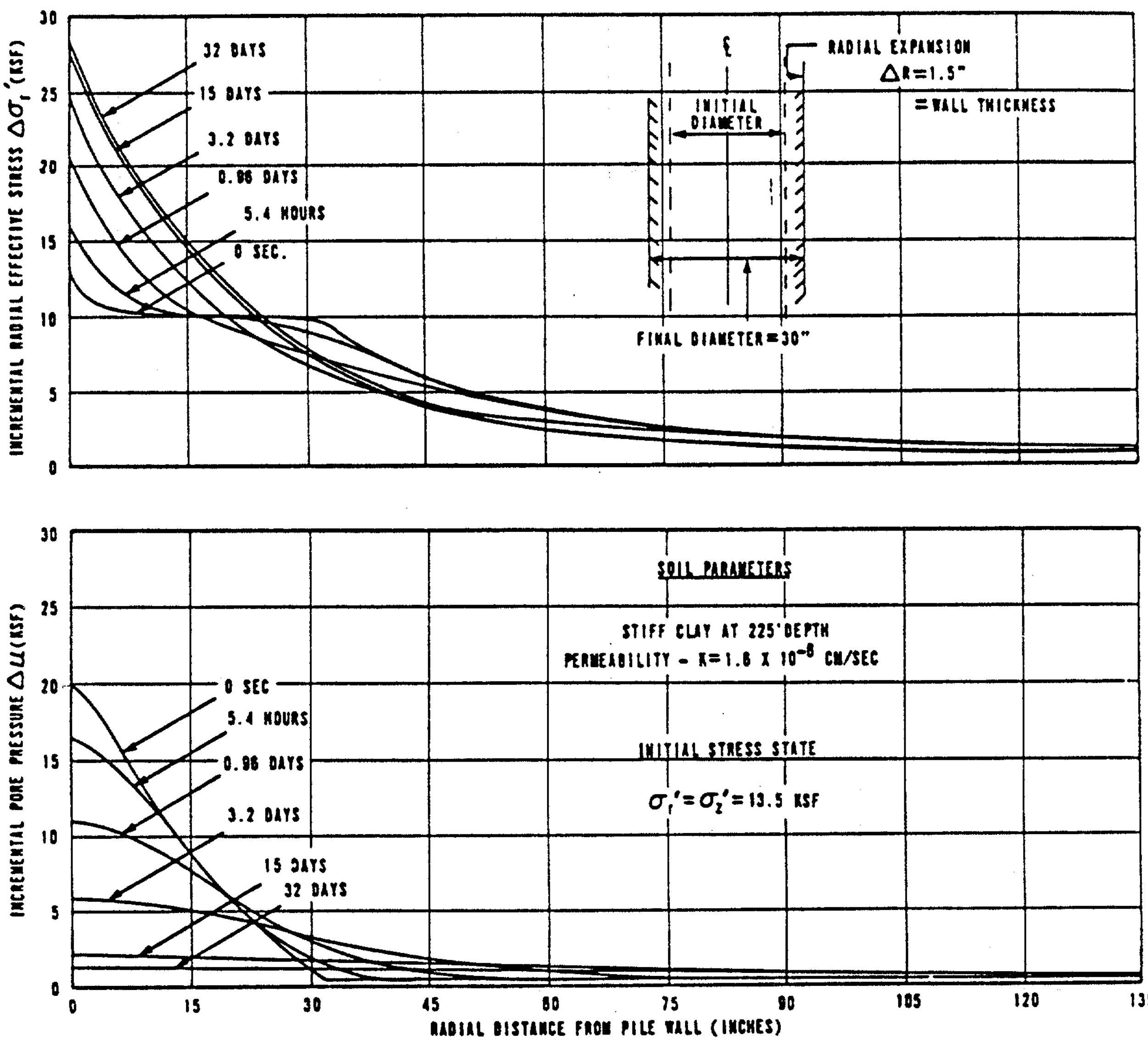
Individual discipline group schedules are shown on Plates 36 through 38. These groups are Operations, Instrumentation and Data Acquisition, and Testing and Analysis, respectively. The fourth discipline group, Theory Development, will proceed independently until later in the project. However, data gathered as the program develops will be input into the analytical theory advancement.

Plate 39 is a flow chart depicting the flow and integration of the various activities at three separate locations: 1) Office (Houston and Long Beach), 2) Fabrication Facility, and 3) Test Site. Plate 40 shows the duration and overlap of the previously described Tasks.

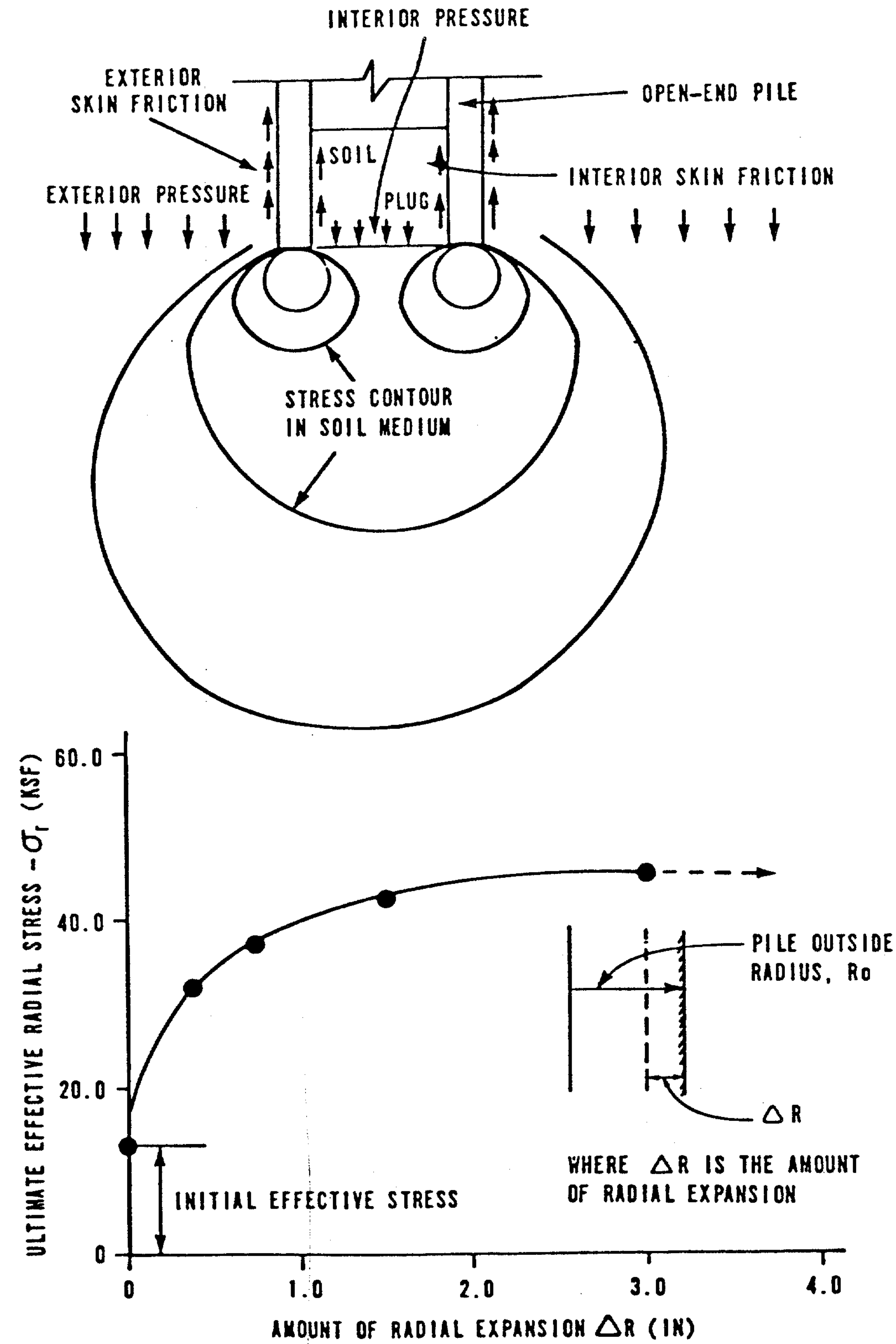
ILLUSTRATIONS



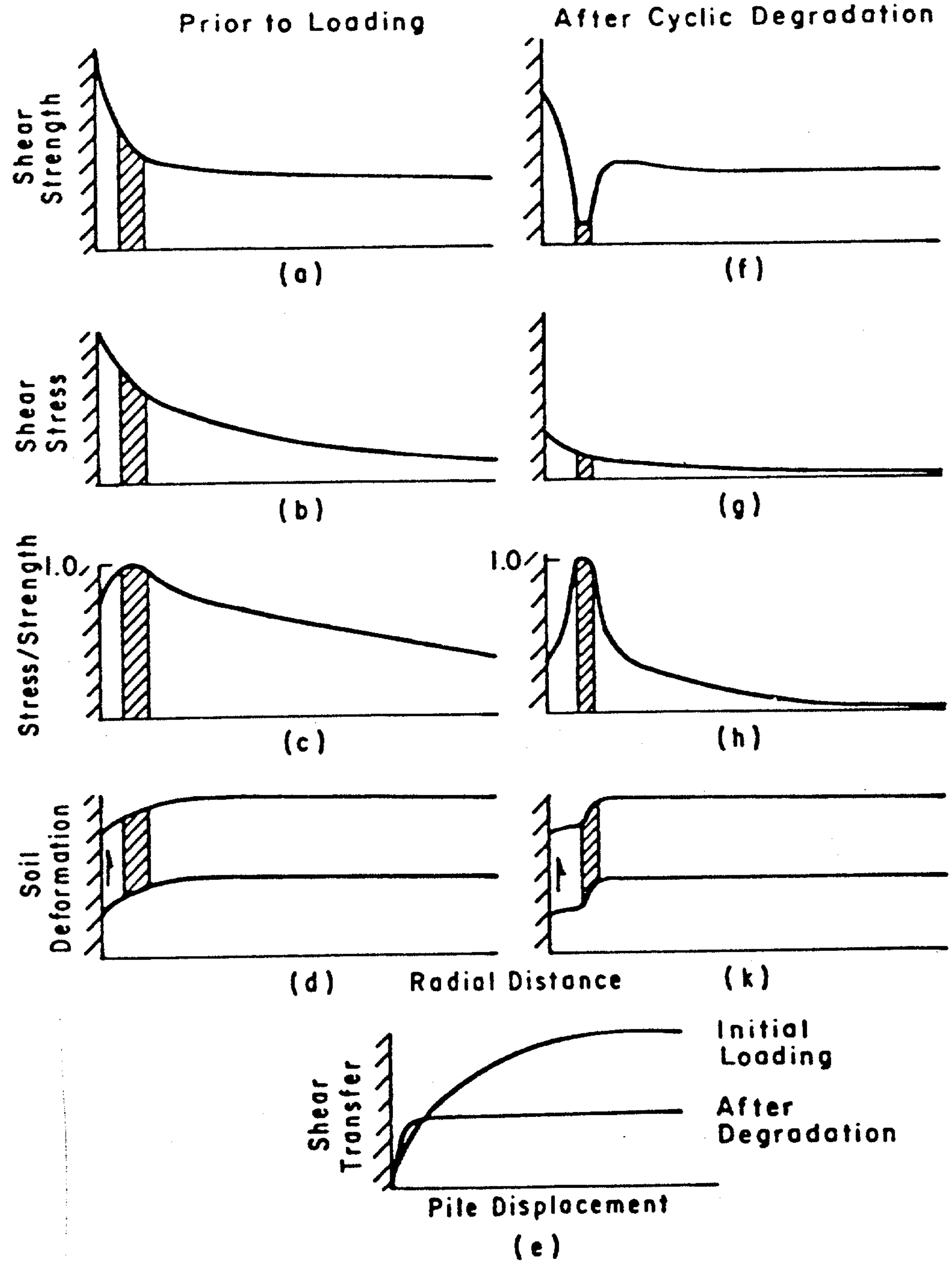
Schematic Illustration of
Effective Stress Concepts
(After Vesič, 1967)



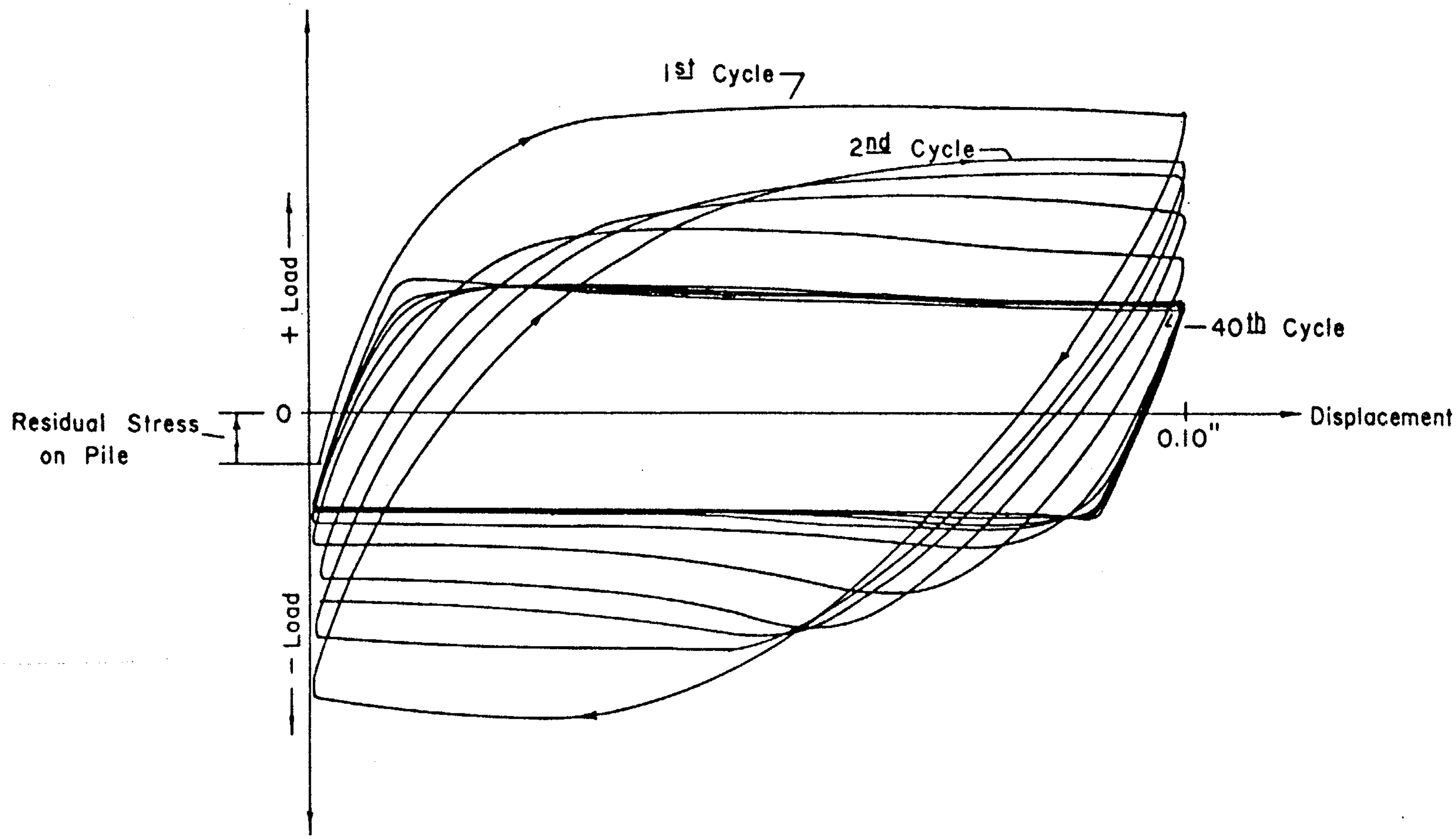
AN EXAMPLE OF CAVITY EXPANSION SOLUTION ON
EFFECTIVE STRESS AND PORE PRESSURE
(AFTER MATLOCK ET AL, 1980)



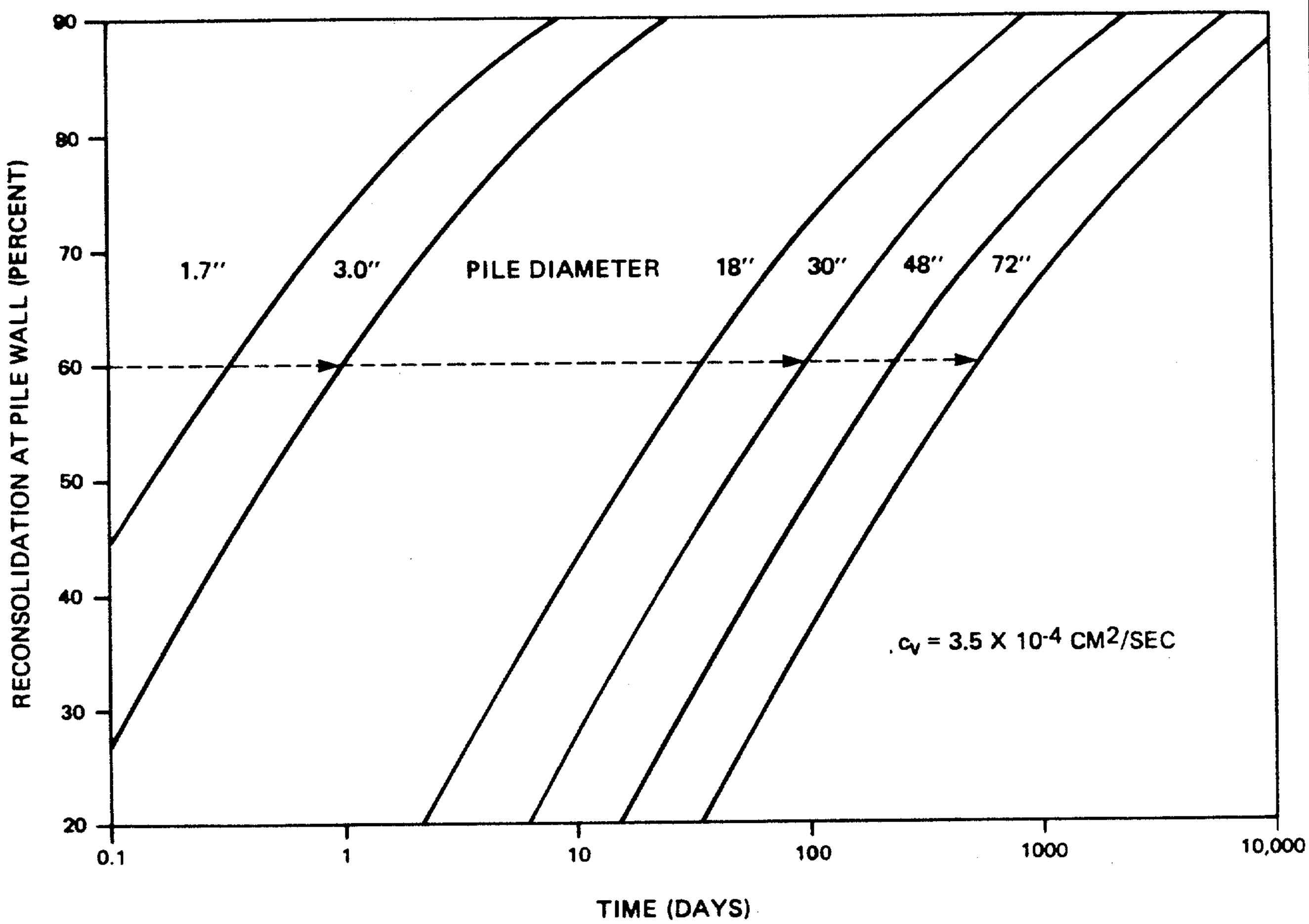
ULTIMATE EFFECTIVE RADIAL STRESS VS AMOUNT OF CAVITY EXPANSION



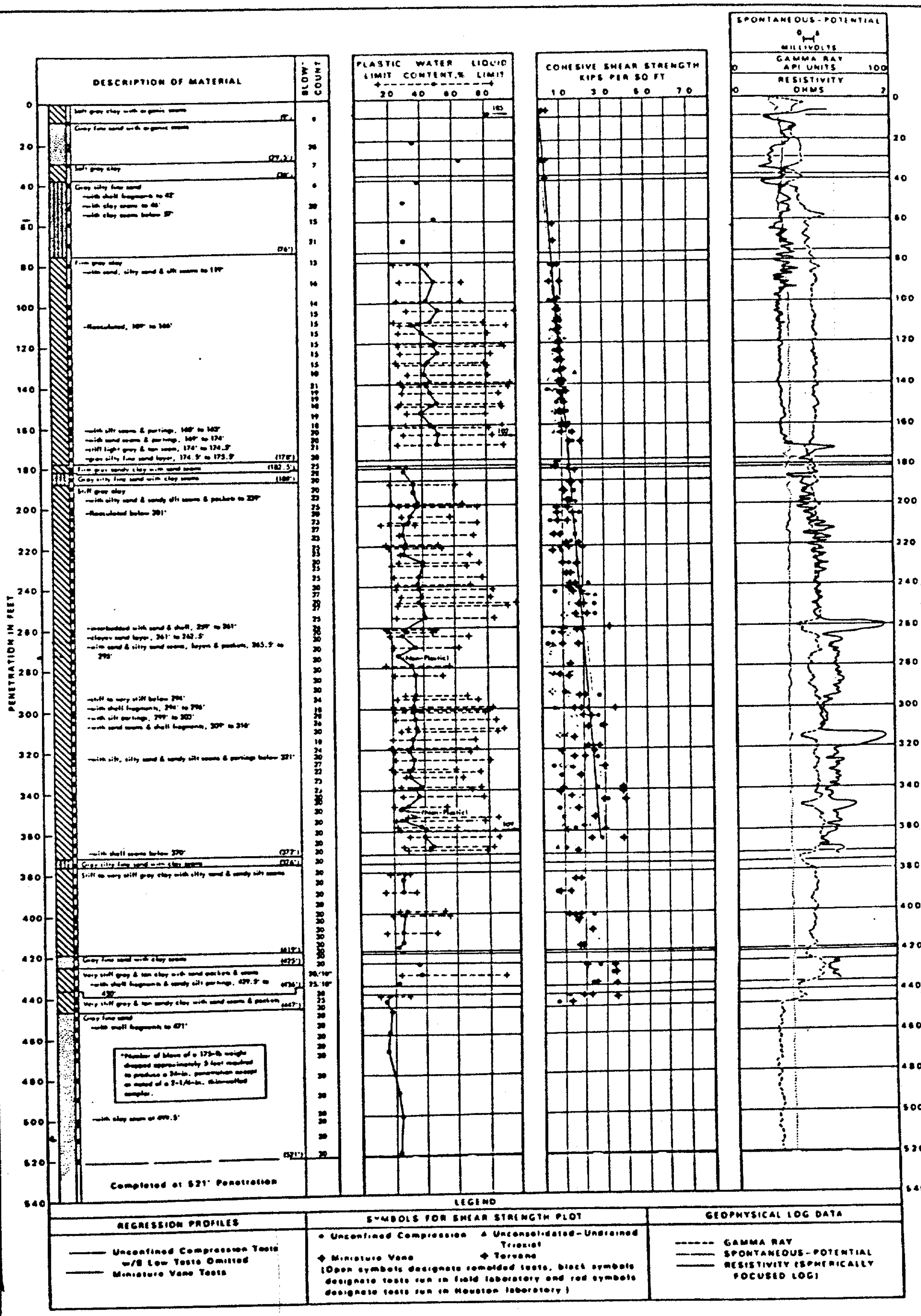
MECHANISTIC INTERPRETATION OF CYCLIC DEGRADATION PROCESS



TYPICAL HYSTERETIC BEHAVIOR OF A MODEL AXIAL PILE SEGMENT IN CLAY

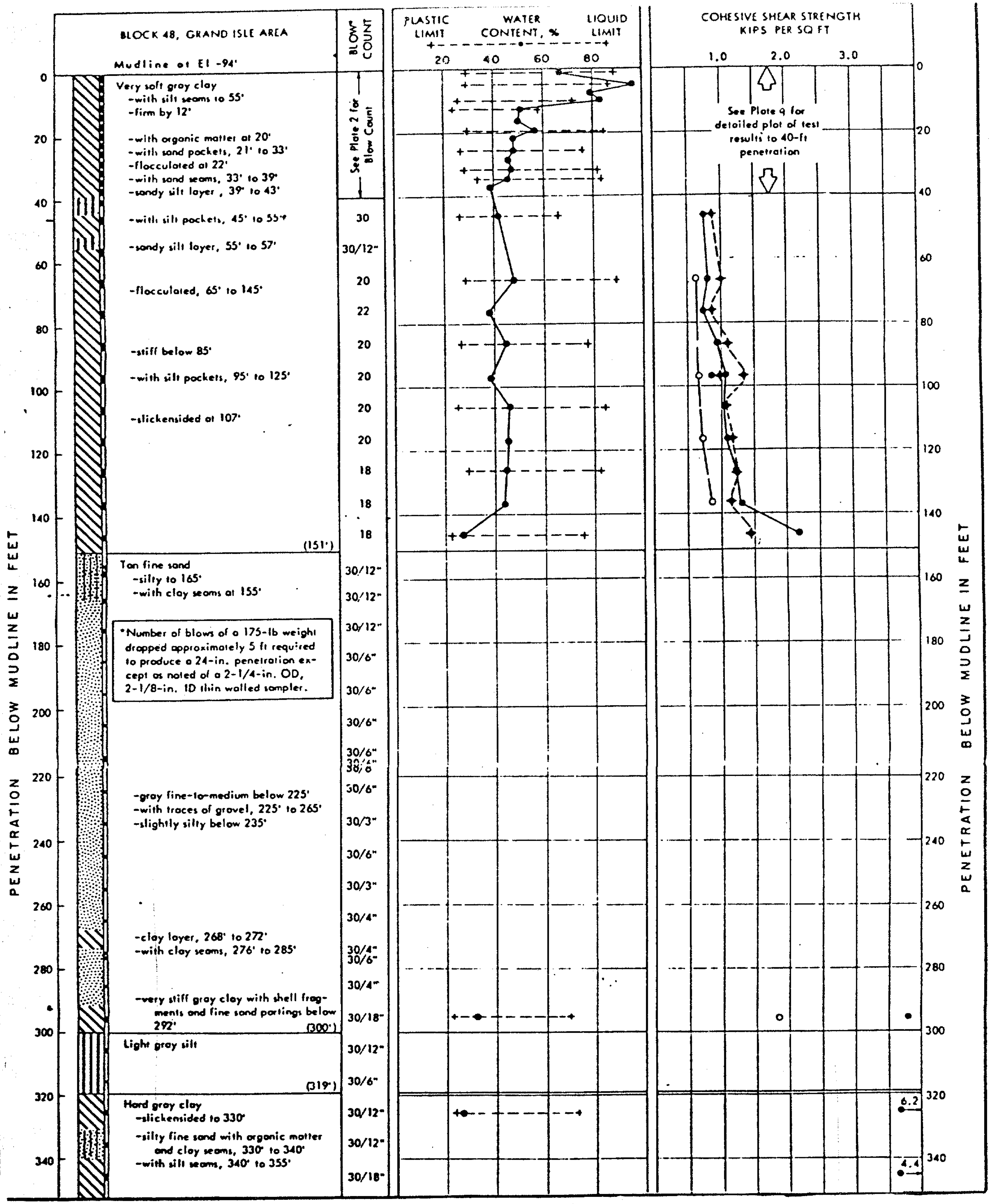


TIME OF RECONSOLIDATION FOR VARIOUS PILE DIAMETERS

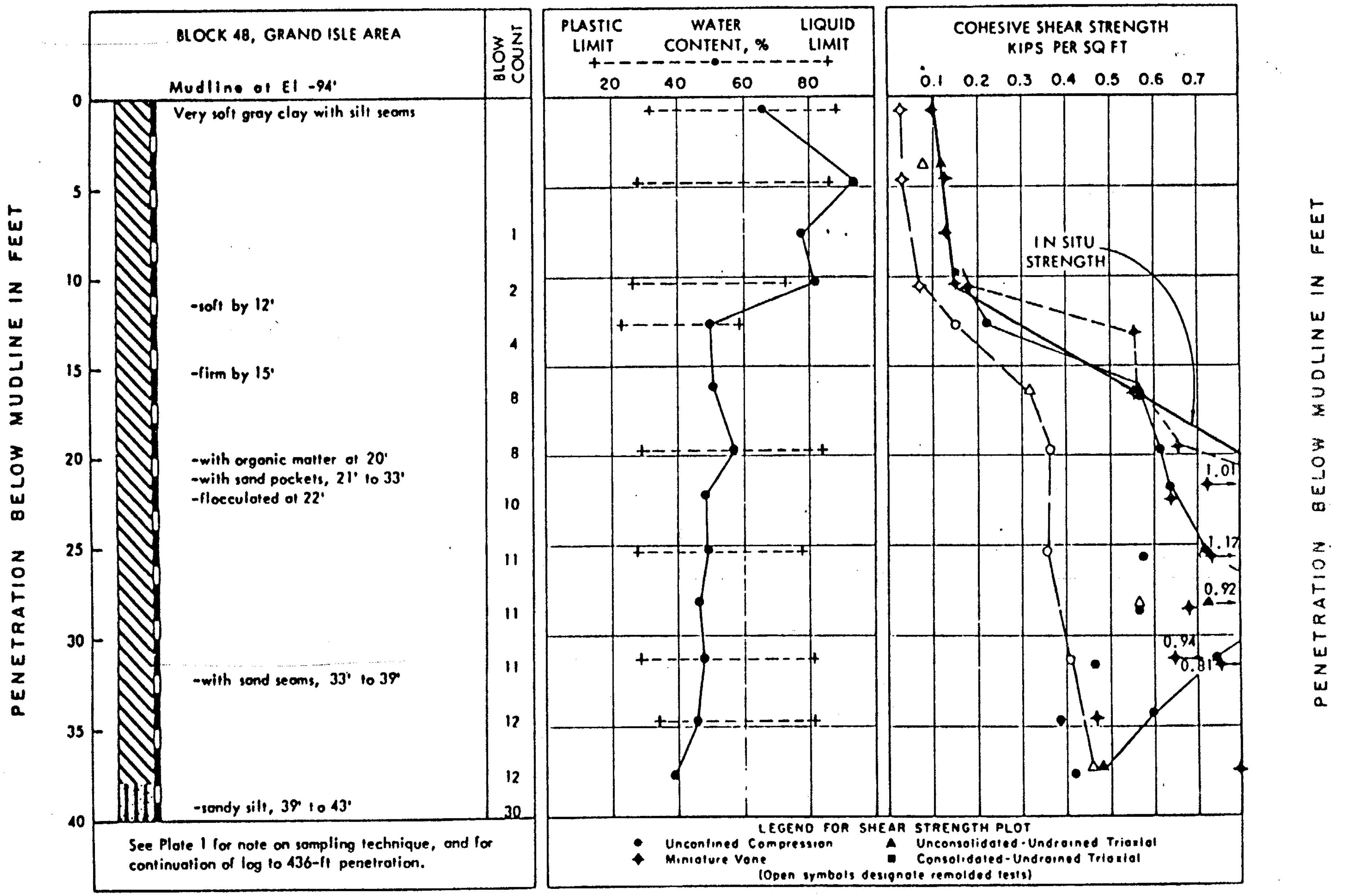


LOG OF BORING AND TEST RESULTS
BORING 3

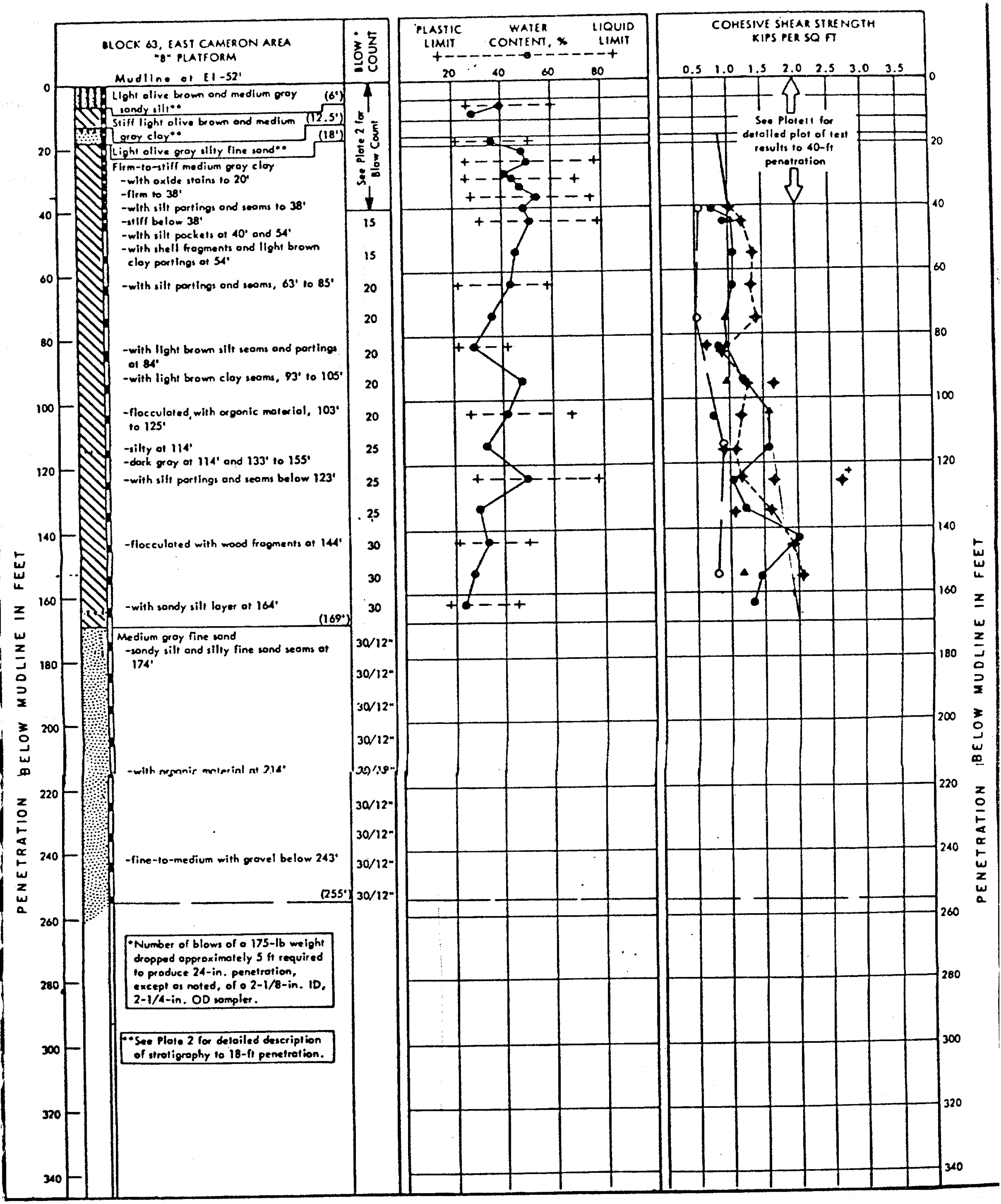
Empire, Louisiana



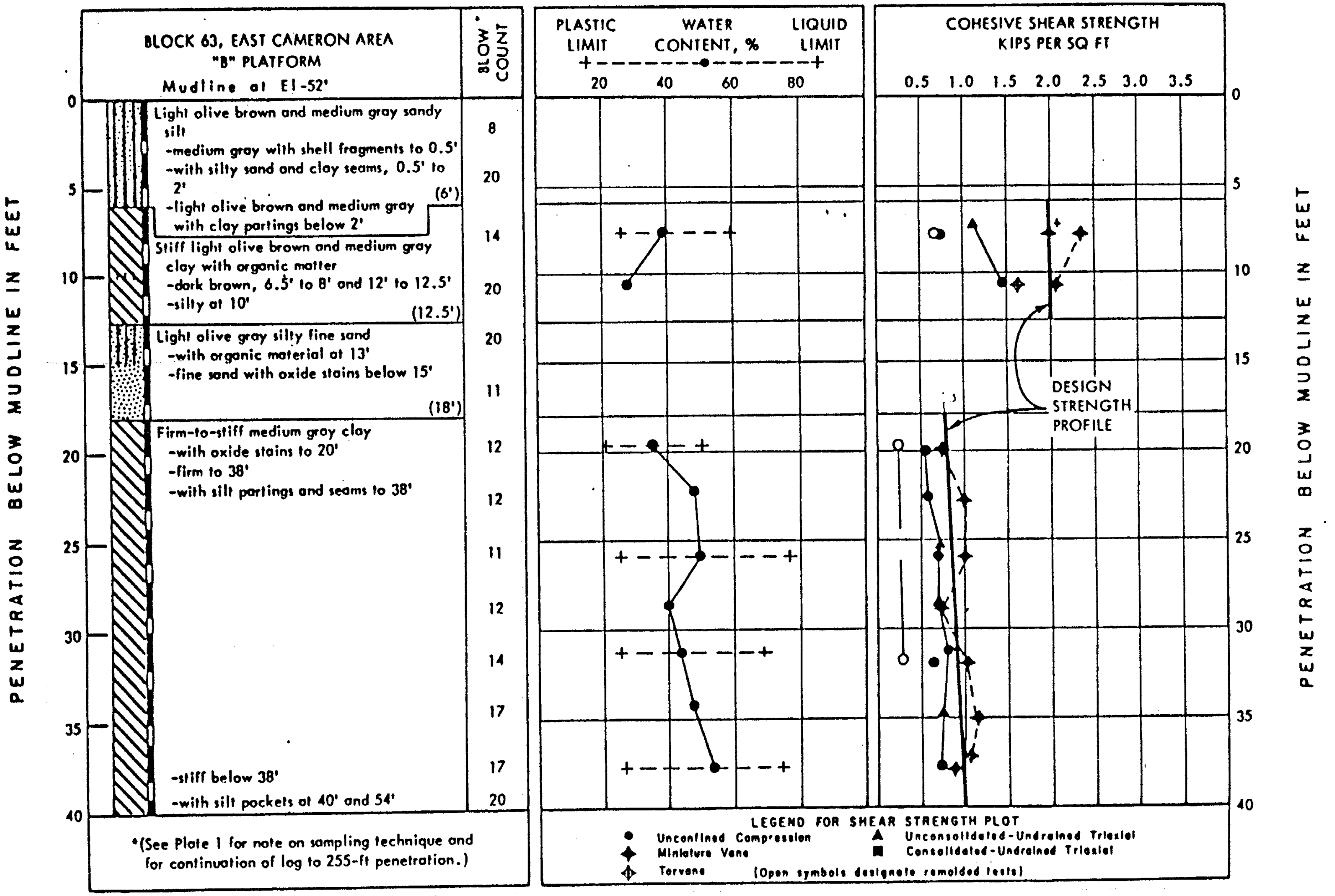
Grand Isle Area
Block 48



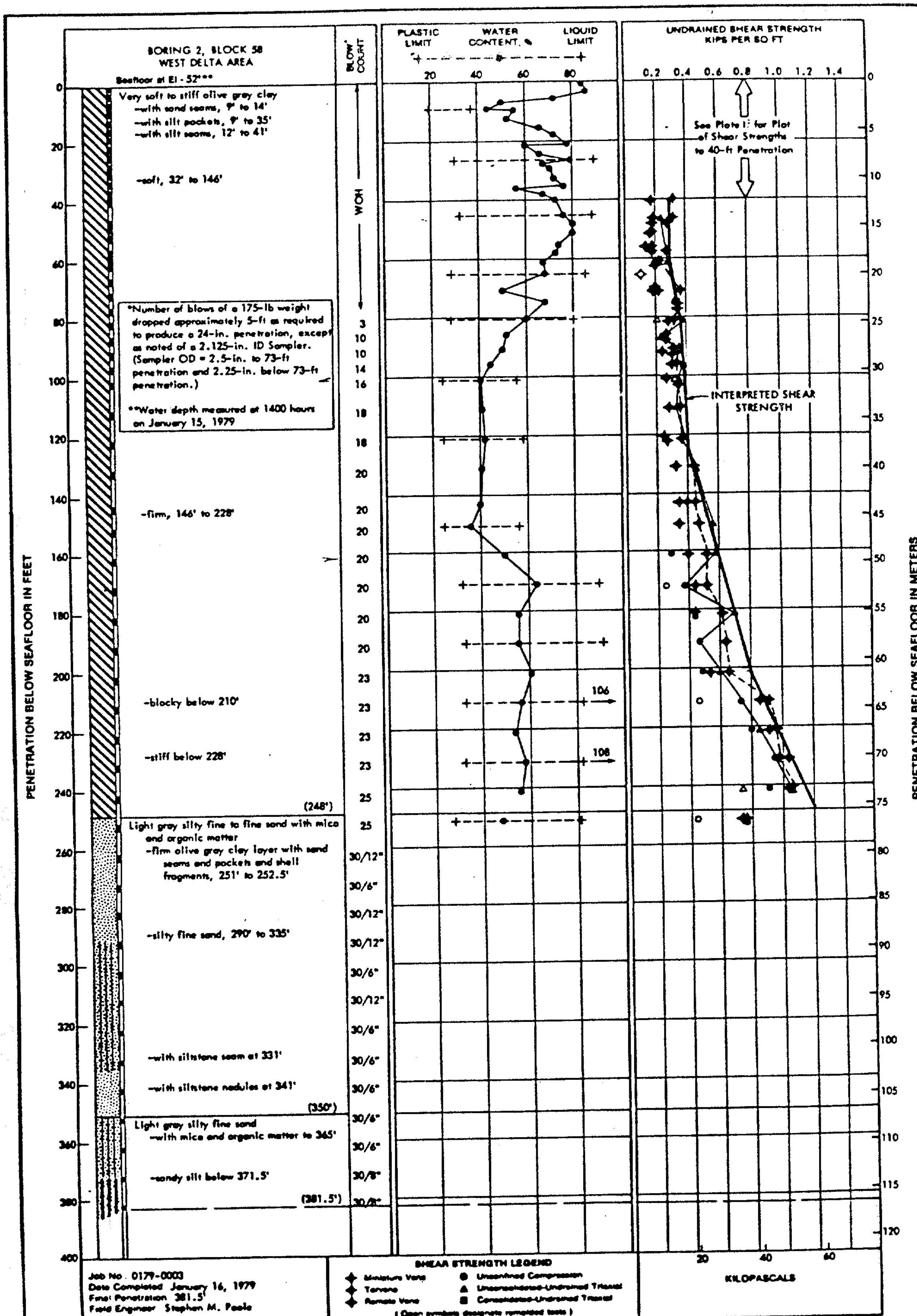
LOG OF BORING AND TEST RESULTS
TO 40-FT PENETRATION



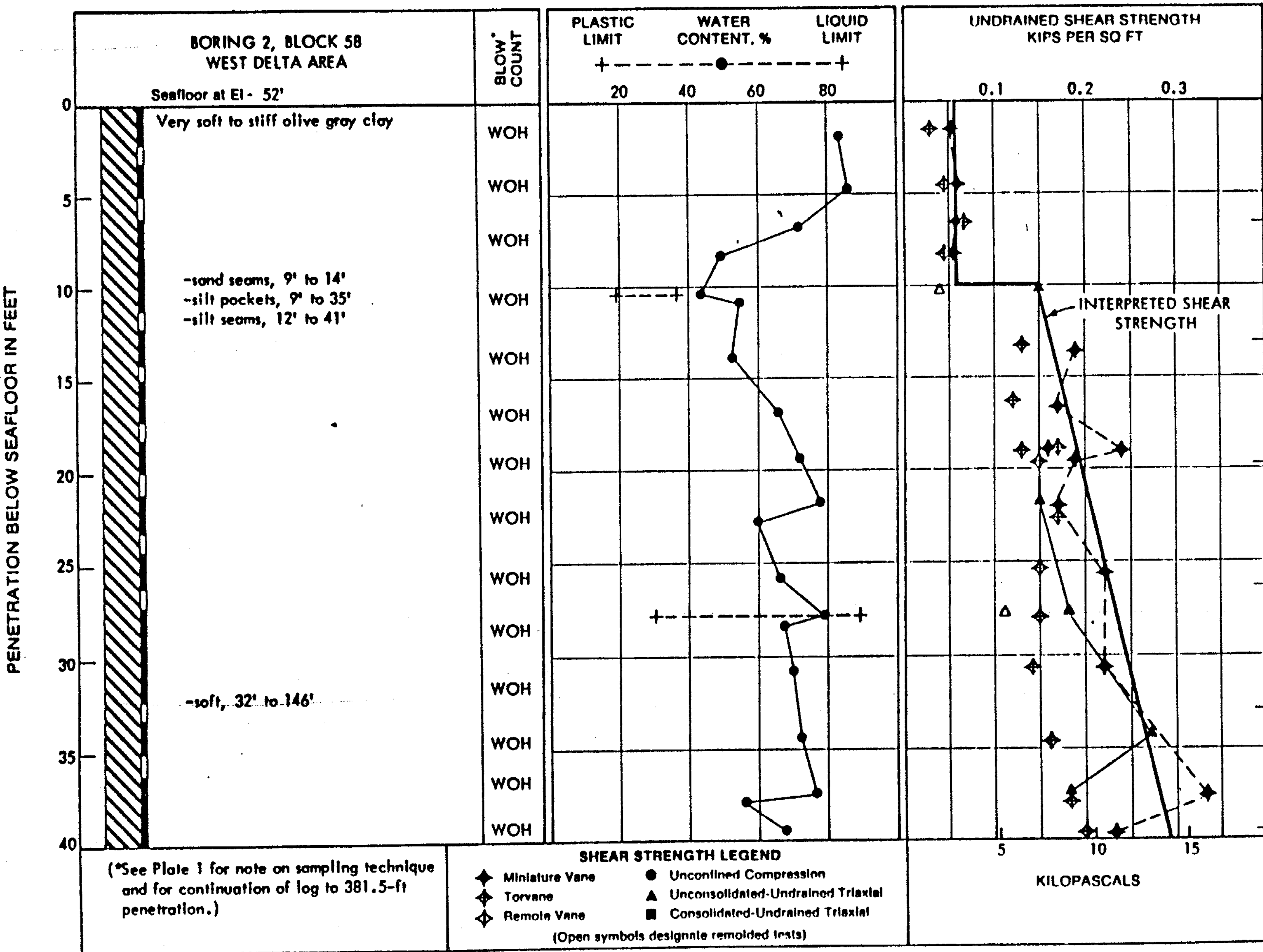
East Cameron Area
Block 63



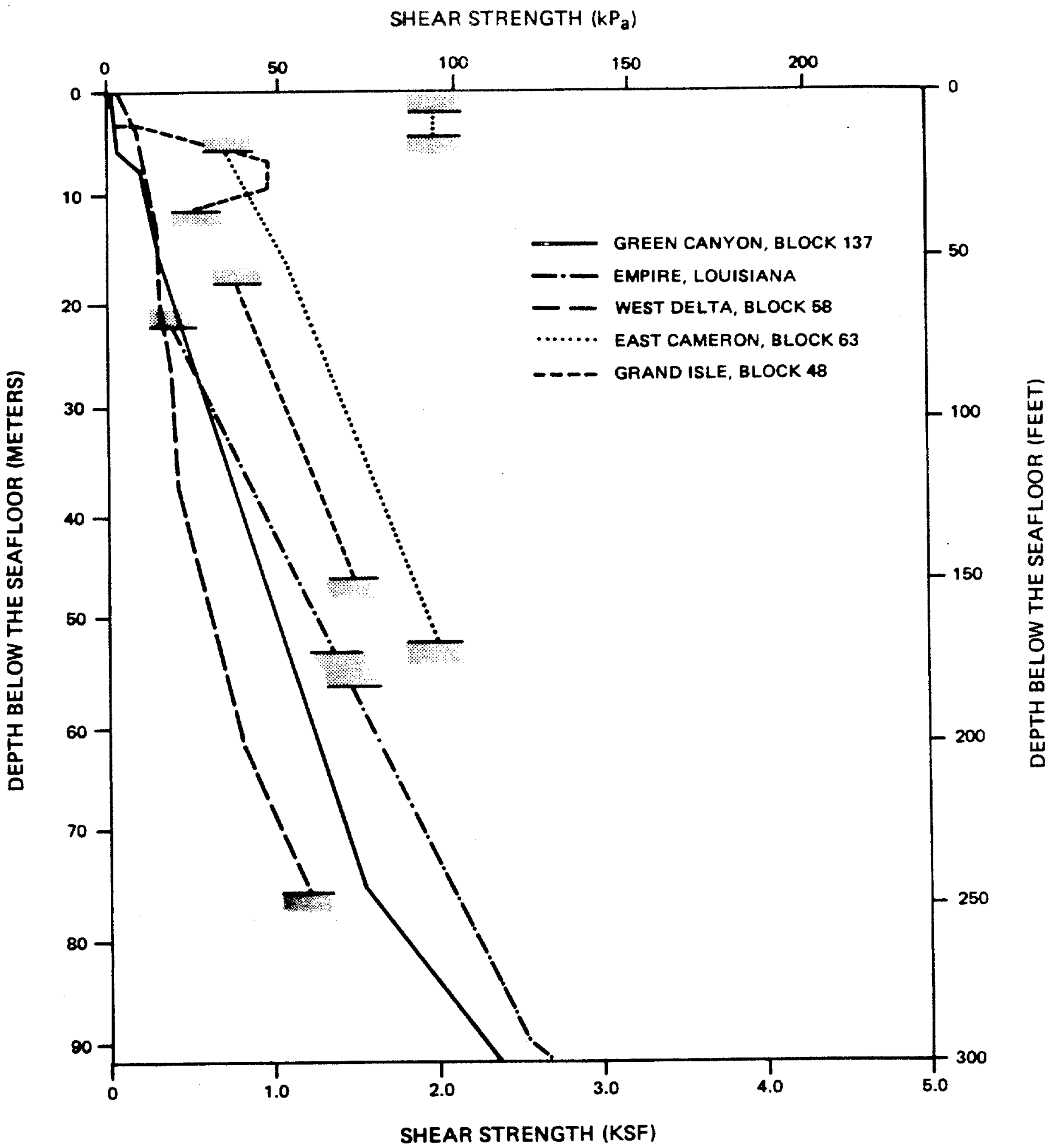
LOG OF BORING AND TEST RESULTS
TO 40-FT PENETRATION



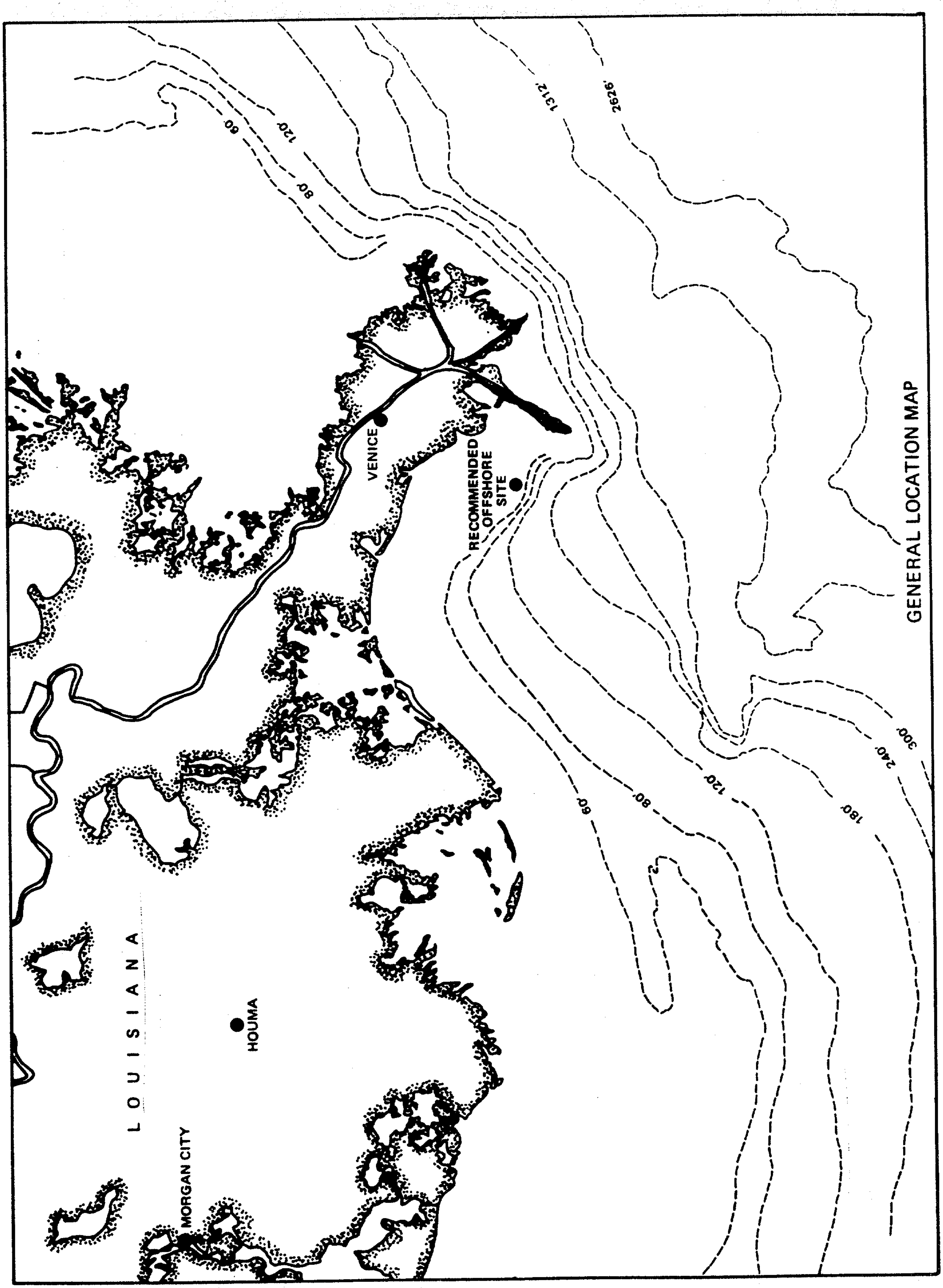
LOG AND TEST RESULTS
BORING 2, BLOCK 58
WEST DELTA AREA

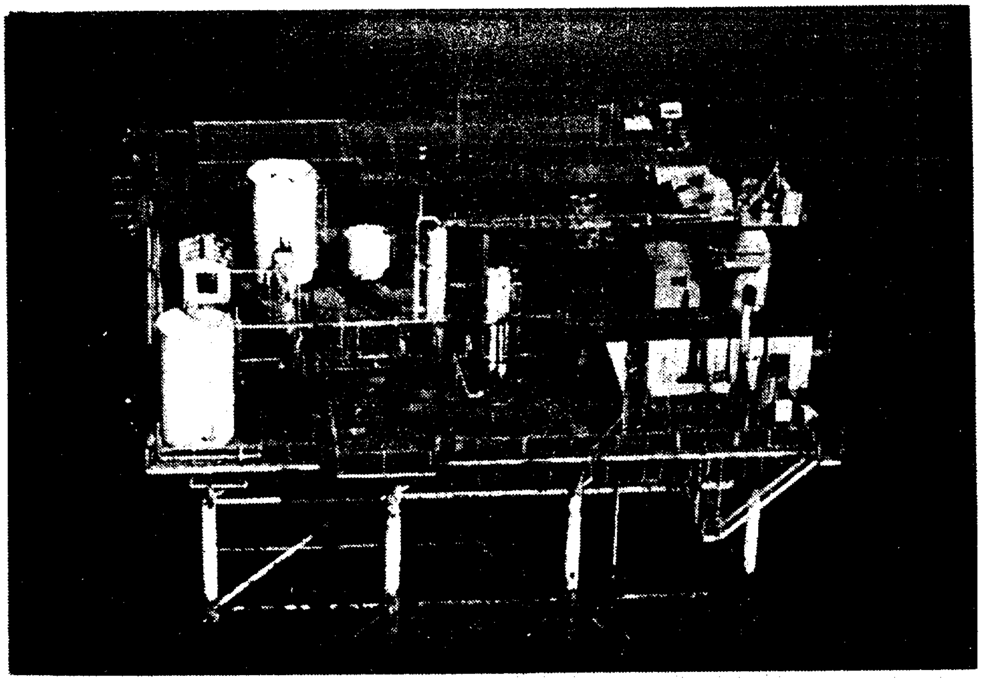


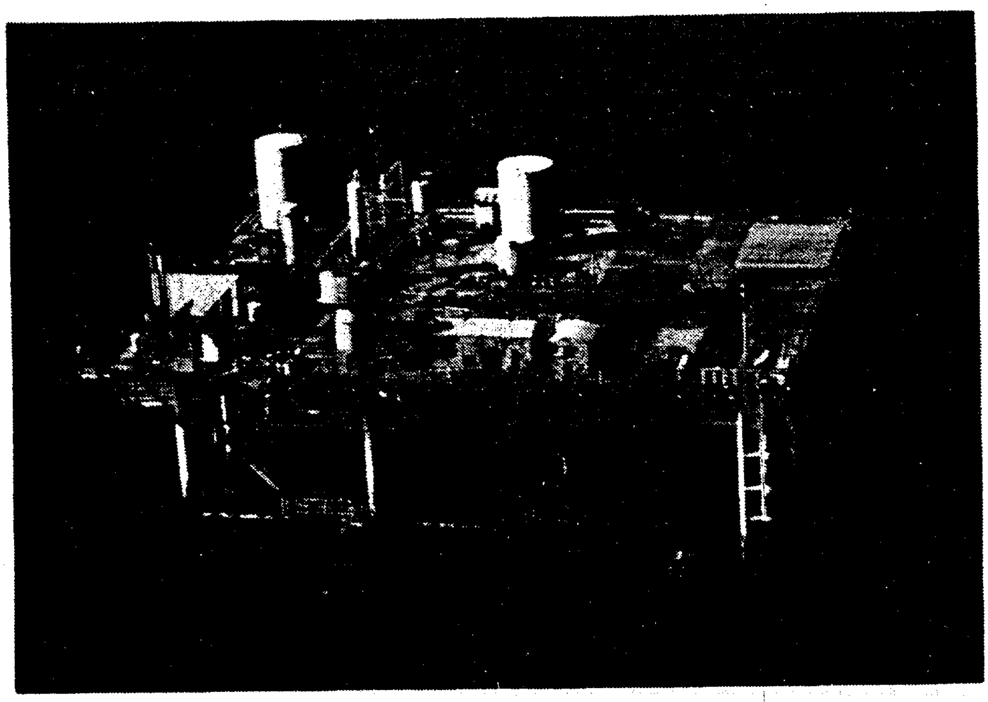
LOG AND TEST RESULTS TO 40-FT PENETRATION
BORING 2, BLOCK 58
WEST DELTA AREA



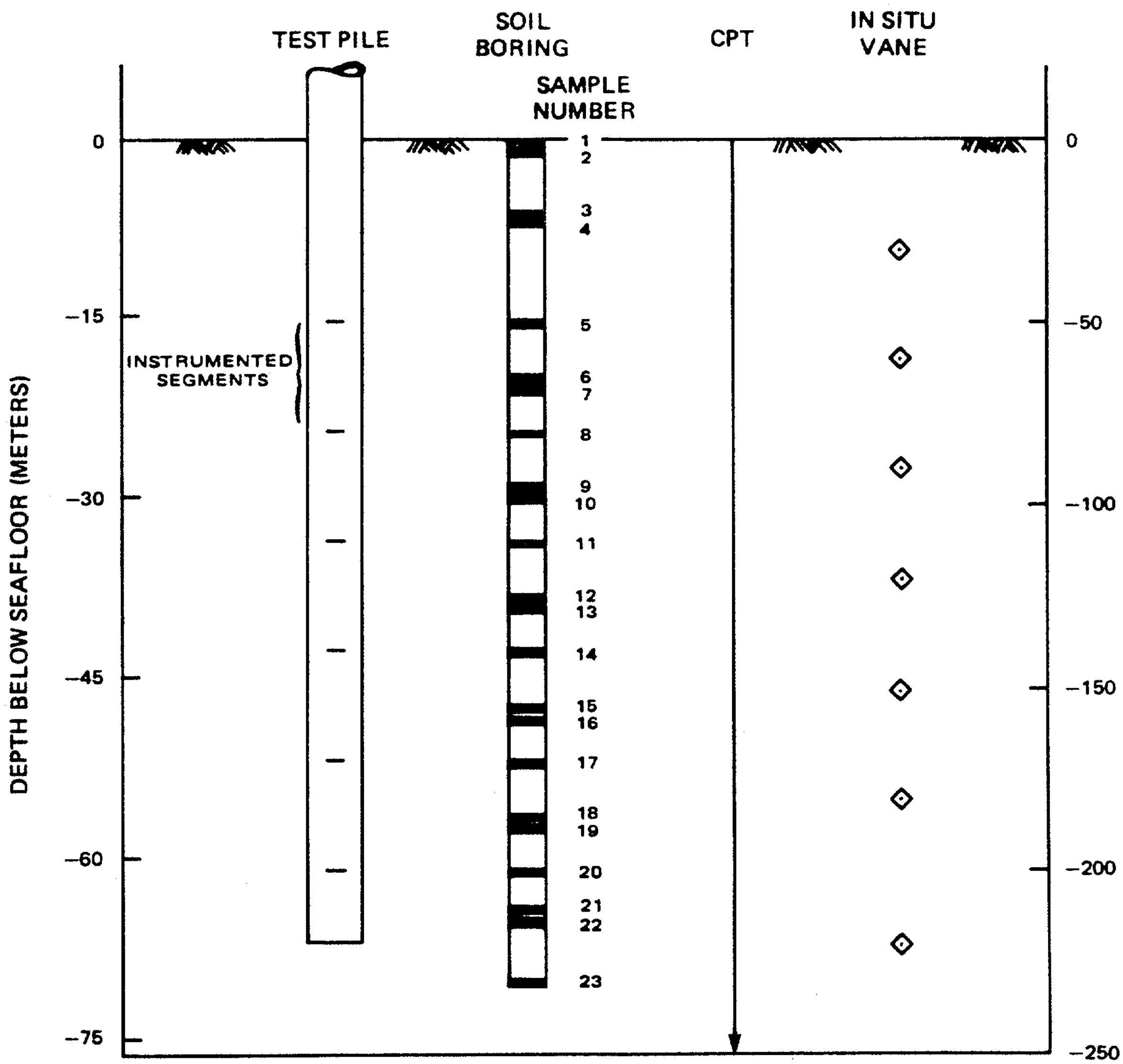
SHEAR STRENGTH PROFILE COMPARISON
GREEN CANYON AND CANDIDATE SITES


GENERAL LOCATION MAP
LOUISIANA
VENICE
RECOMMENDED OFFSHORE SITE
HOUMA
MORGAN CITY
60'
80'
120'
1312'
2626'
60'
80'
120'
180'
240'
300'





OFFSHORE CANDIDATE SITE
WEST DELTA, BLOCK 58



PLAN FOR SITE INVESTIGATION PROGRAM

SAMPLE NUMBER *(1)	DEPTH (FEET) (1 FT = 0.305 M)	LABORATORY TEST [3]					
		LL & PL	CONSOL, G_s	UU,[2] MV	$\overline{CIU}$	$\overline{CK_oU}$	$\overline{DSS}$
1	0 - 2	X		X			
2	3 - 5	X		X			
3	20 - 22	X		X		X	
4*	23 - 25						
5	50 - 52	X		X			X
6	65 - 67	X	X	X	X		
7*	68 - 70						
8	80 - 82	X		X		X	
9	95 - 97	X		X	X		
10*	98 - 100						
11	110 - 112	X		X			X
12	125 - 127	X	X	X	X		
13*	128 - 130						
14	140 - 142	X		X		X	
15	155 - 157	X		X	X		
16*	158 - 160						
17	170 - 172	X		X			X
18	185 - 187	X	X	X	X		
19*	188 - 190						
20	200 - 202	X		X		X	
21	210 - 212	X		X	X		
22*	213 - 215						
23	230 - 232	X	X	X			X
TOTALS		16	4	16	6	4	4

(1) SAMPLE TO BE SENT TO DET NORSKE VERITAS

(2) ALL UU TESTS INCLUDE MOISTURE CONTENT, DENSITY, POCKET PENETROMETER AND TORVANE

(3) ALL TUBES WILL BE X-RAYED PRIOR TO SAMPLE EXTRUSION IN THE LABORATORY

EXPLANATION

LL & PL = LIQUID AND PLASTIC LIMITS

UU = UNCONSOLIDATED UNDRAINED TRIAXIAL TEST

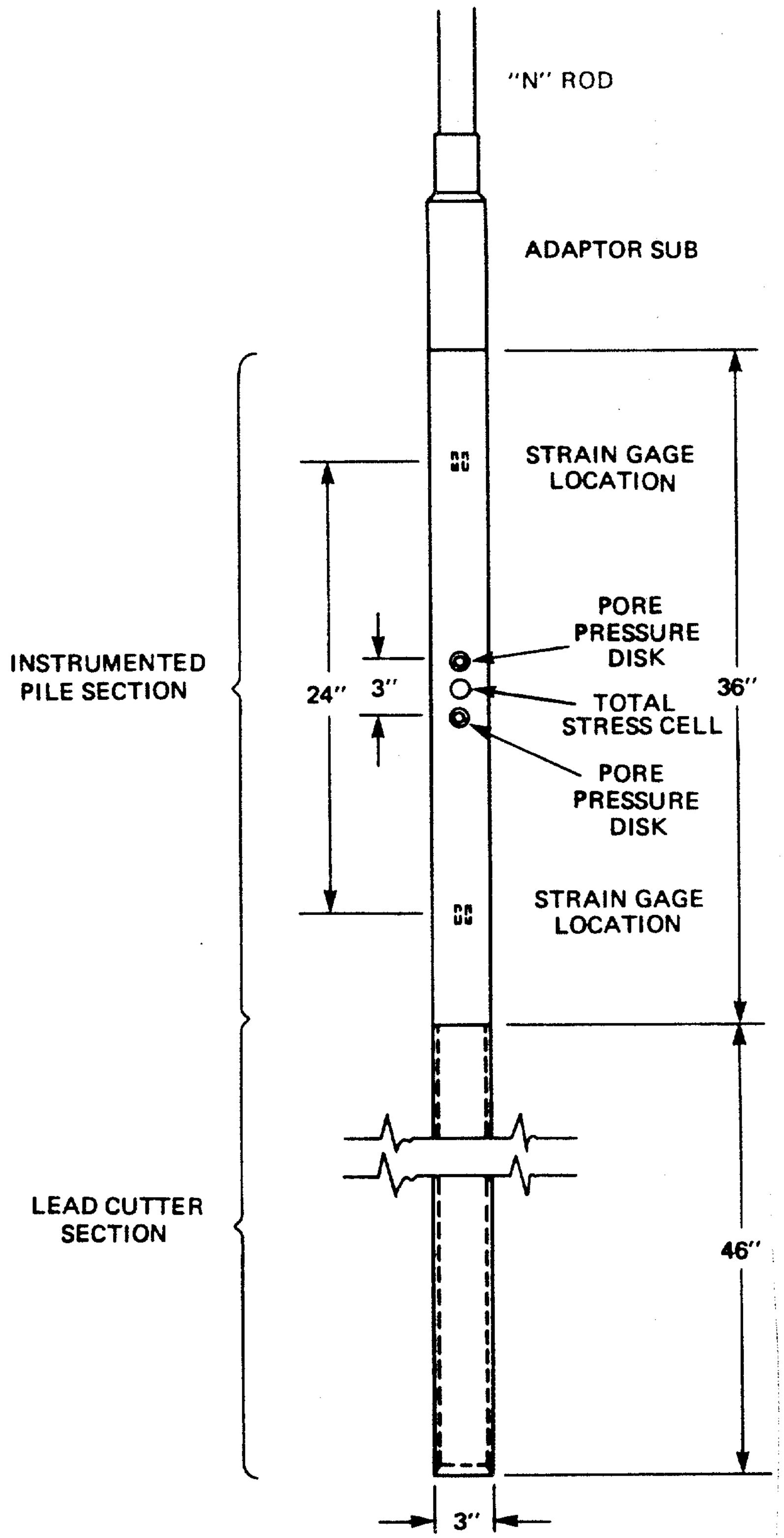
MV = MINIATURE VANE SHEAR TEST

$\overline{CIU}$ = CONSOLIDATED UNDRAINED TRIAXIAL TEST WITH PORE PRESSURE

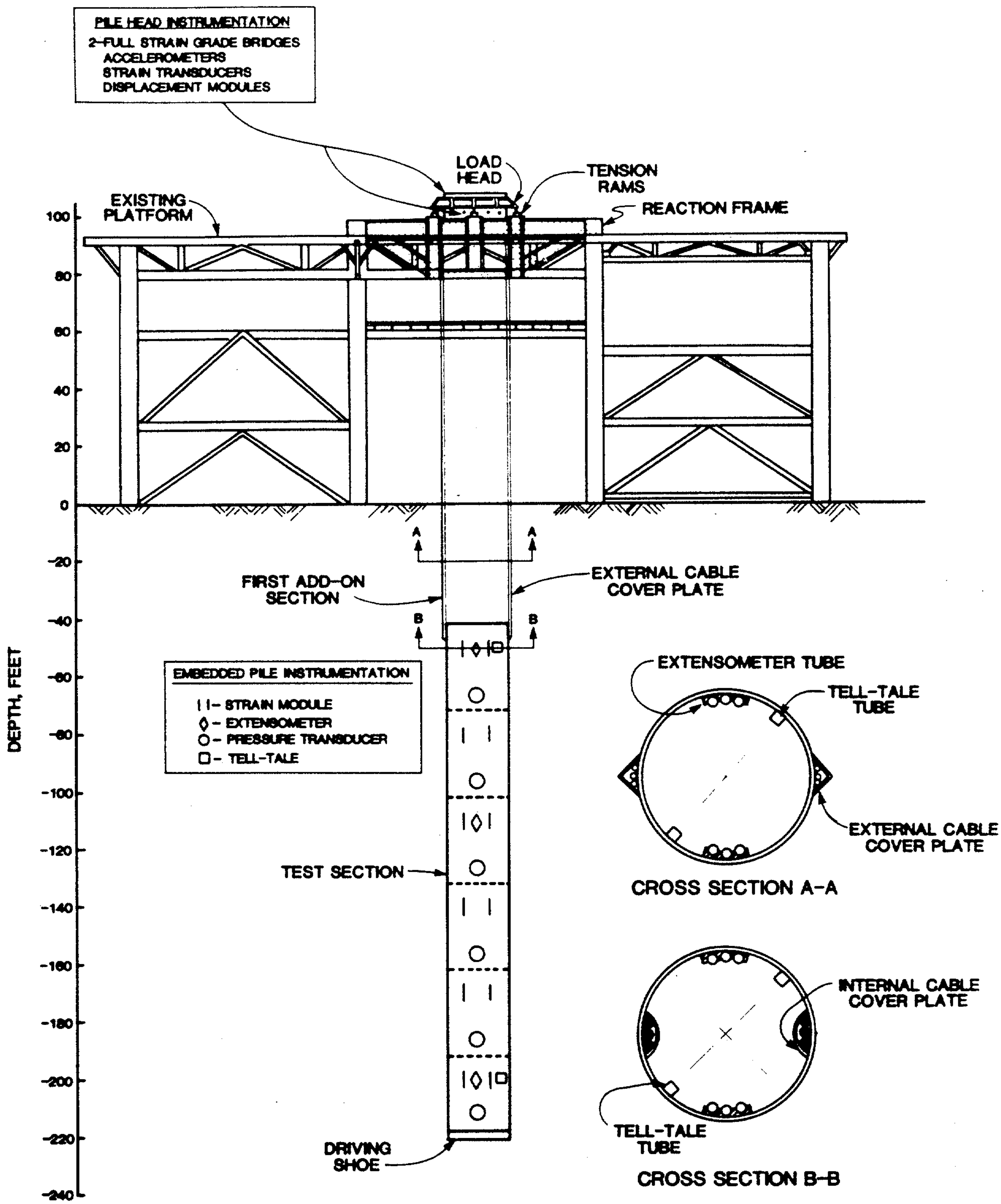
$\overline{CK_oU}$ = K_o - CONSOLIDATED UNDRAINED TRIAXIAL TEST WITH PORE PRESSURE

$\overline{DSS}$ = DIRECT SIMPLE SHEAR WITH PORE PRESSURE

LABORATORY TESTING PROGRAM

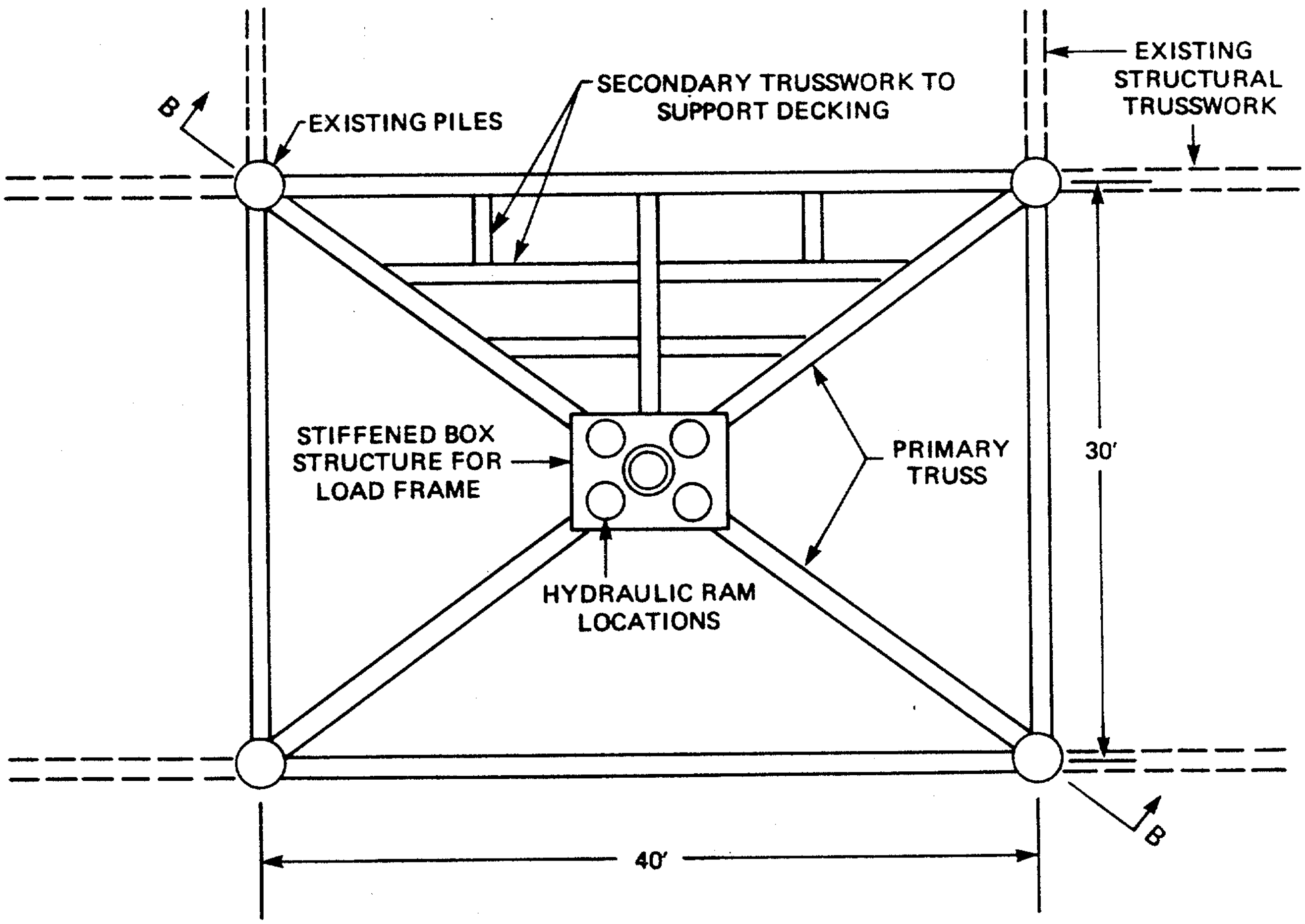


SMALL DIAMETER PILE SEGMENT

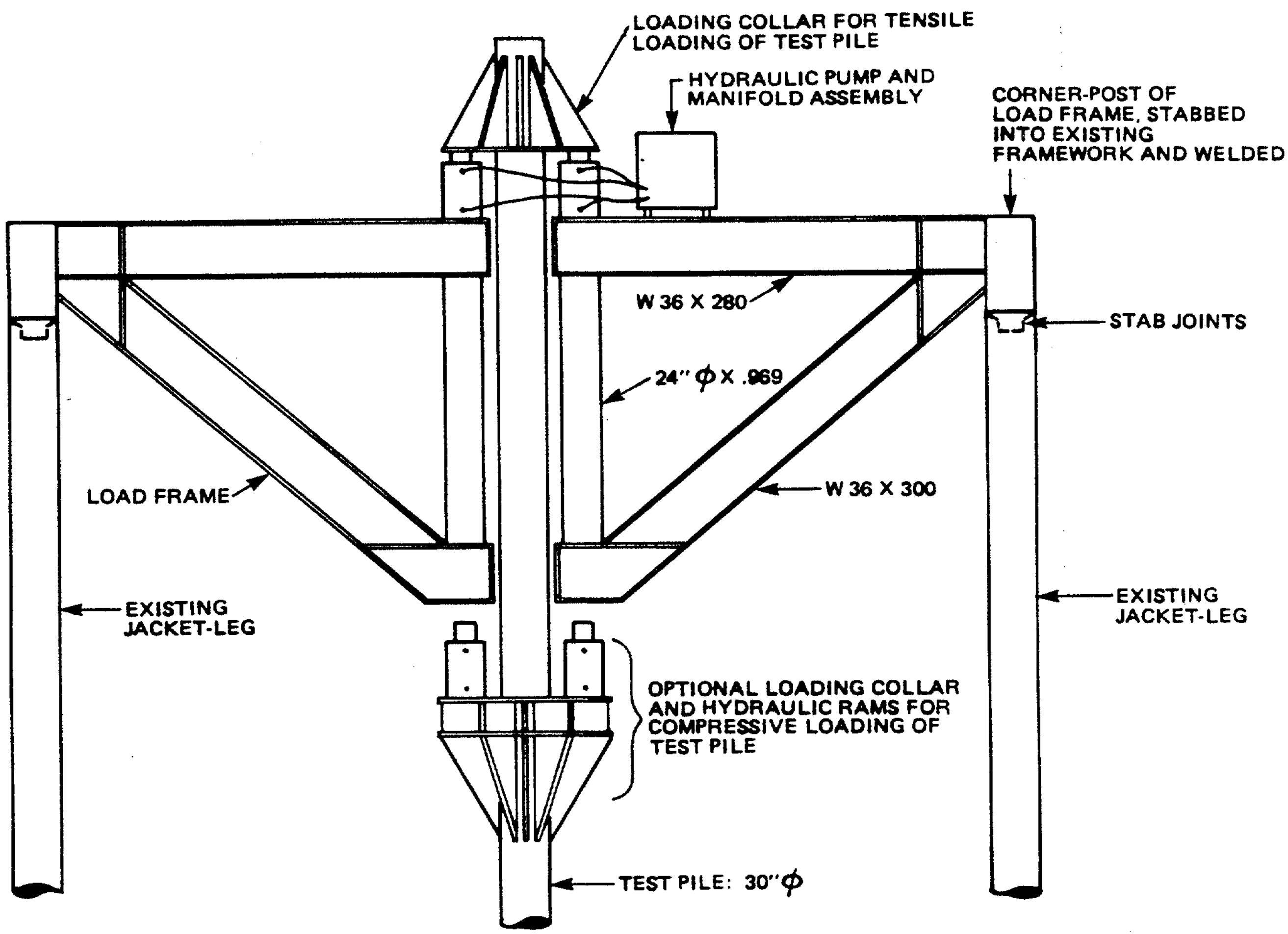


TEST SET-UP CONFIGURATION

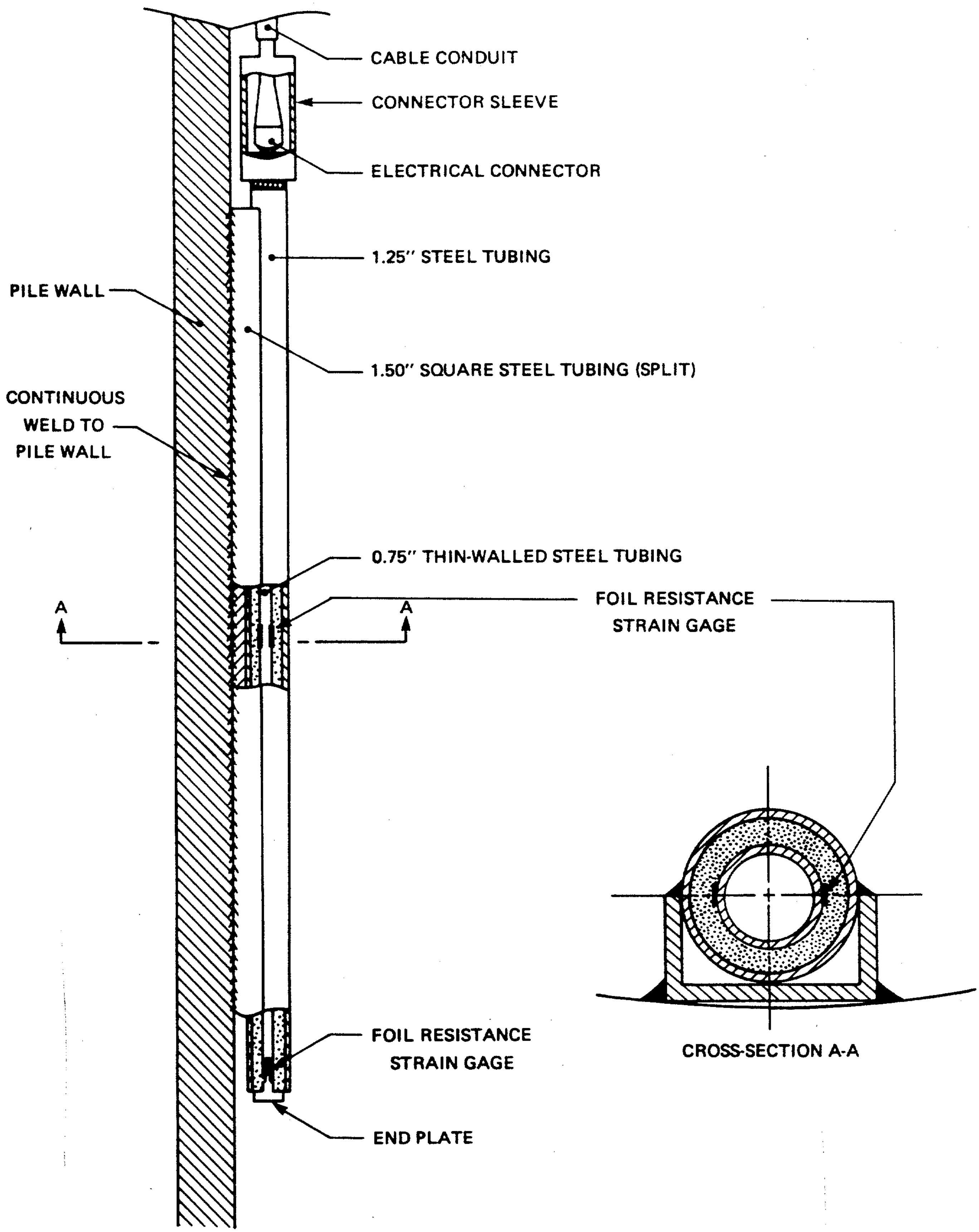
NOTE: TEST PILE NOT TO SCALE



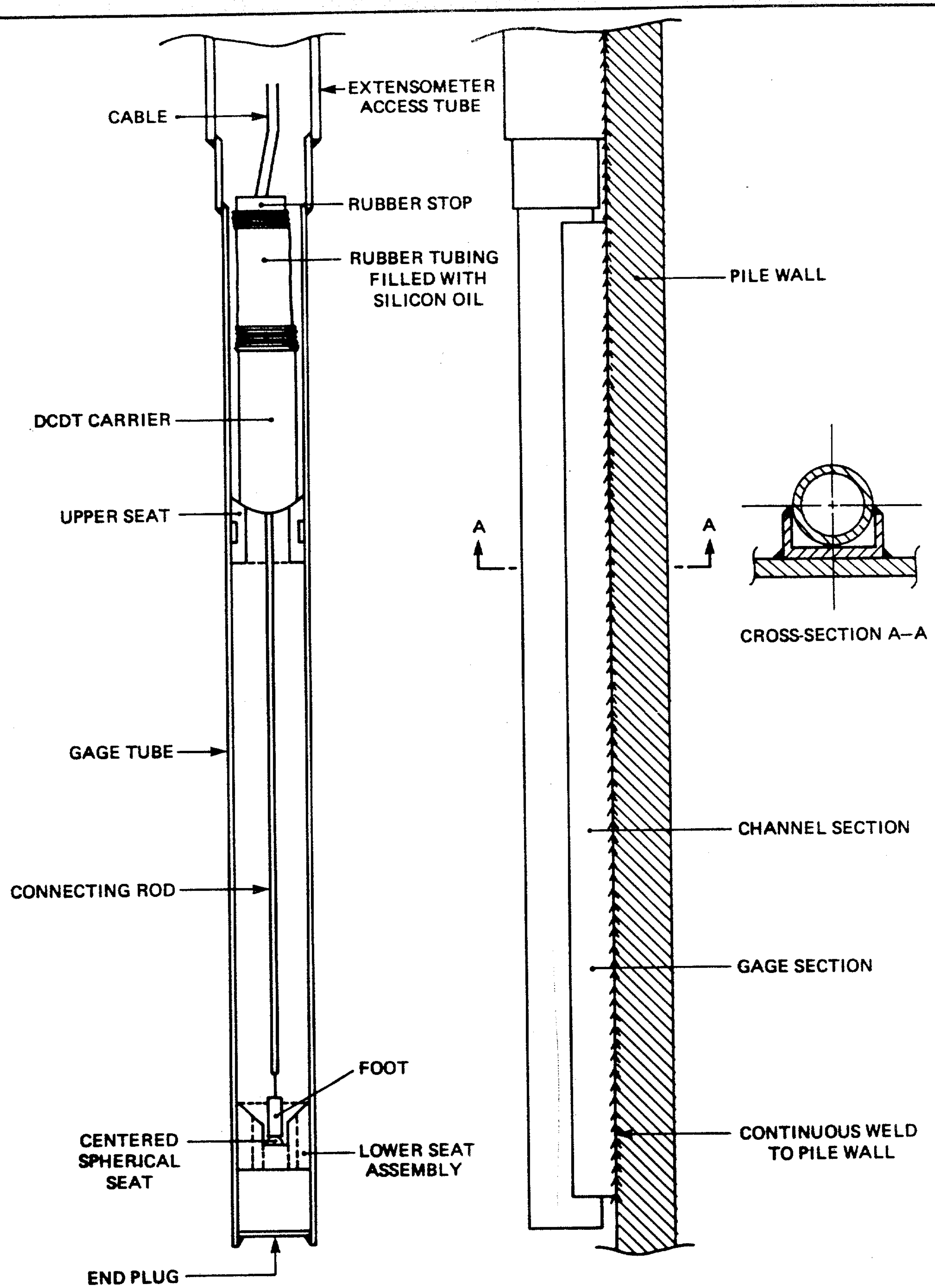
PLAN VIEW – LOAD FRAME



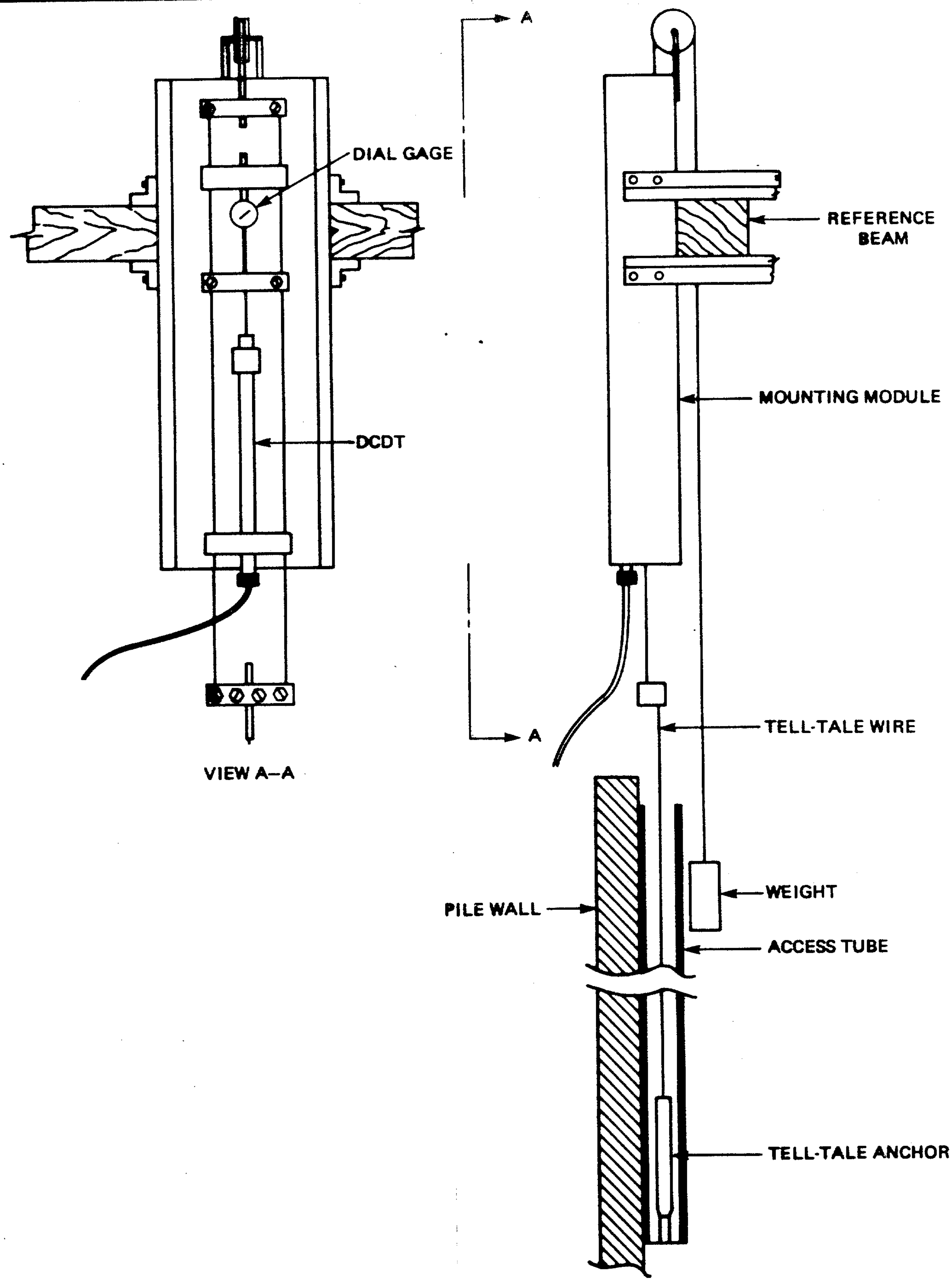
SCHEMATIC DIAGRAM OF LOAD FRAME, SECTION B–B



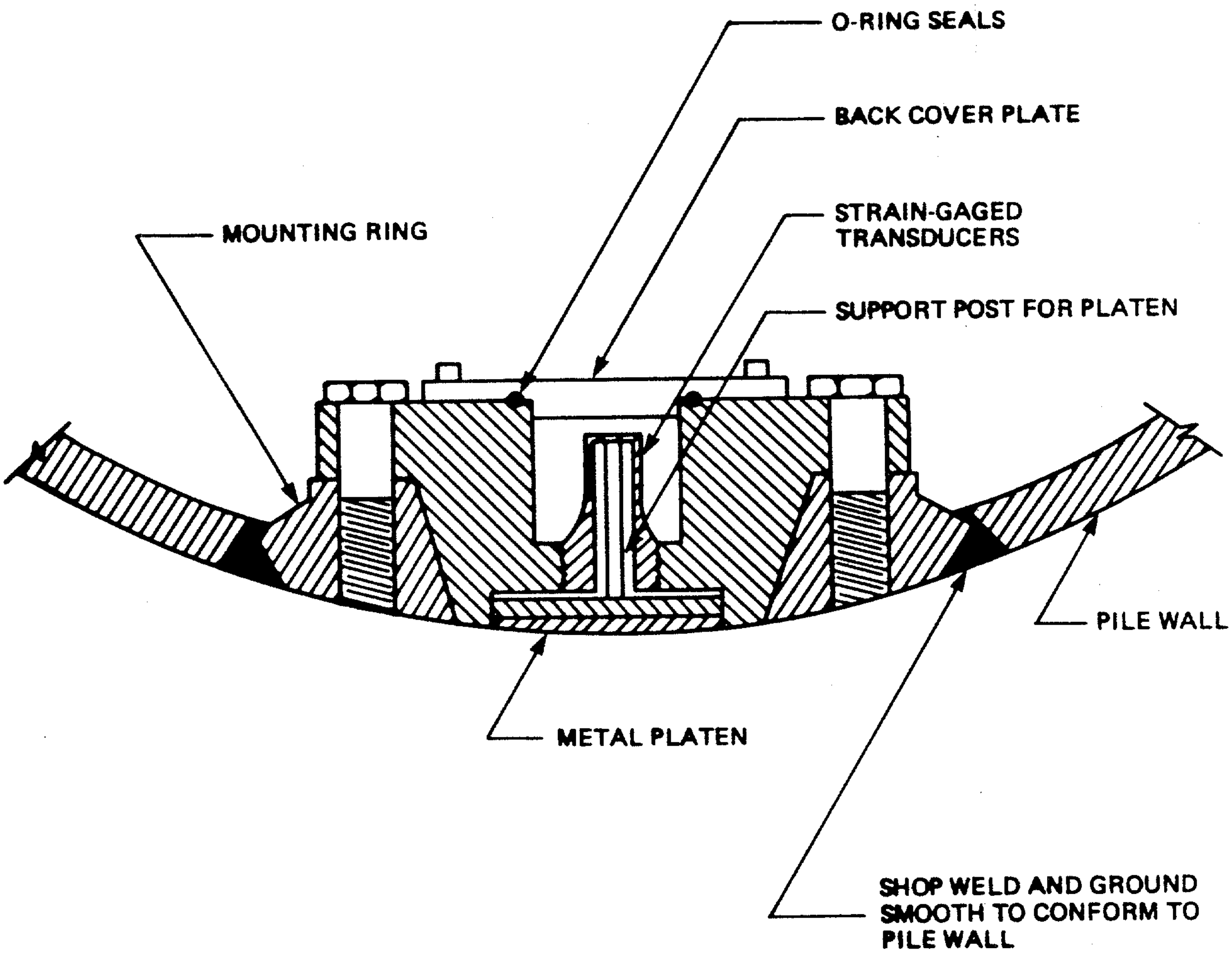
RESISTANCE STRAIN GAGE MODULE



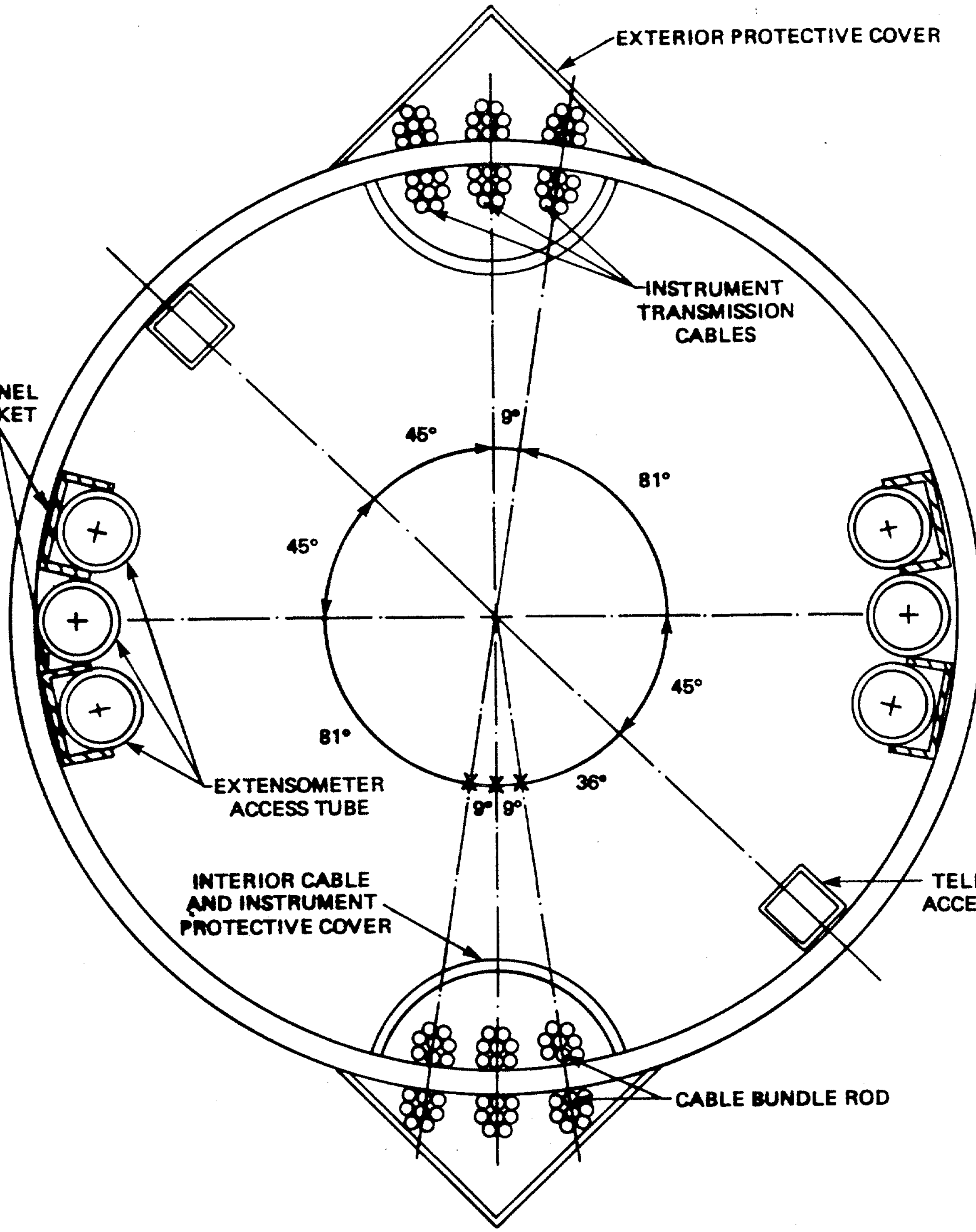
EXTENSOMETER UNIT



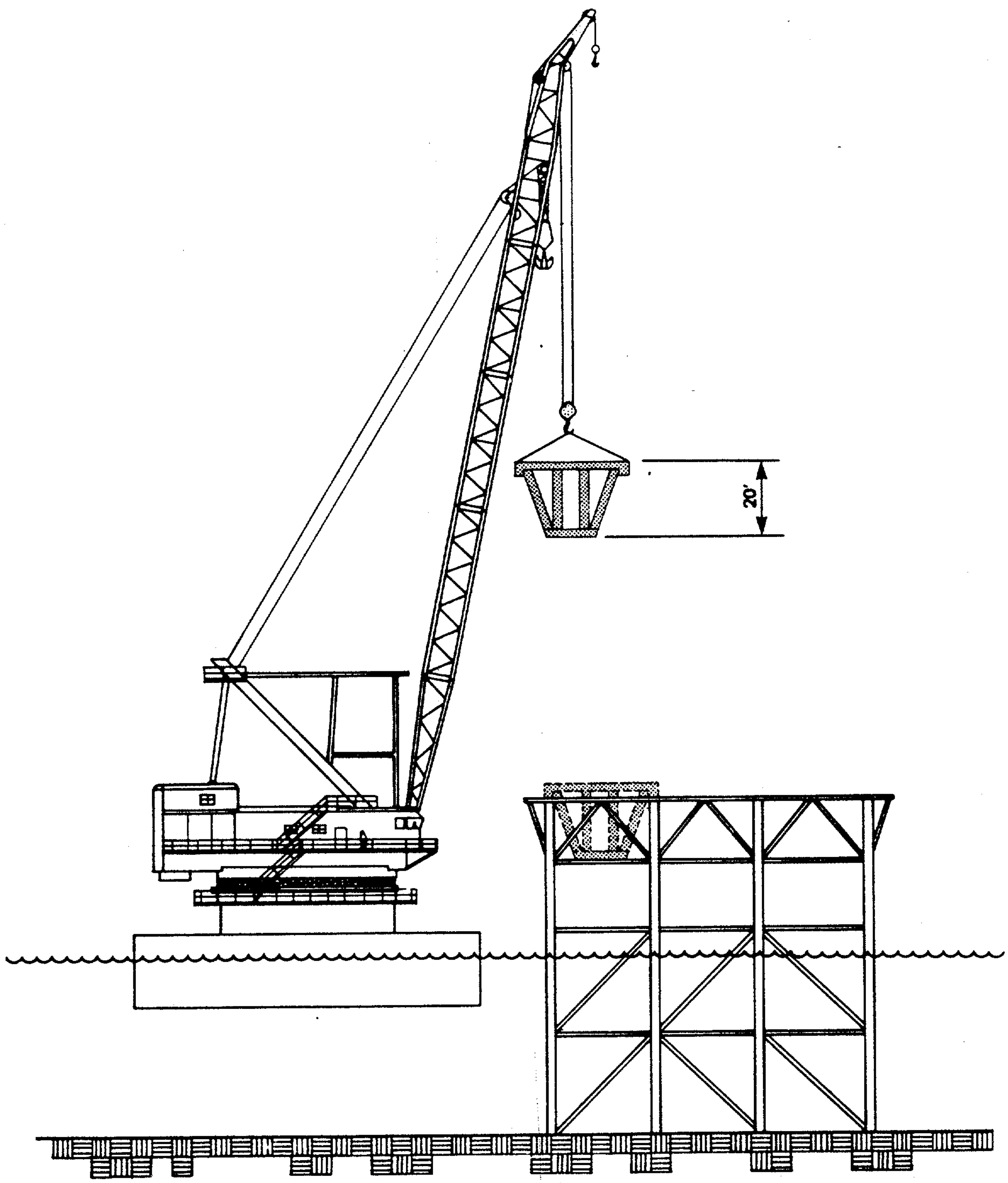
TELL-TALE ASSEMBLY



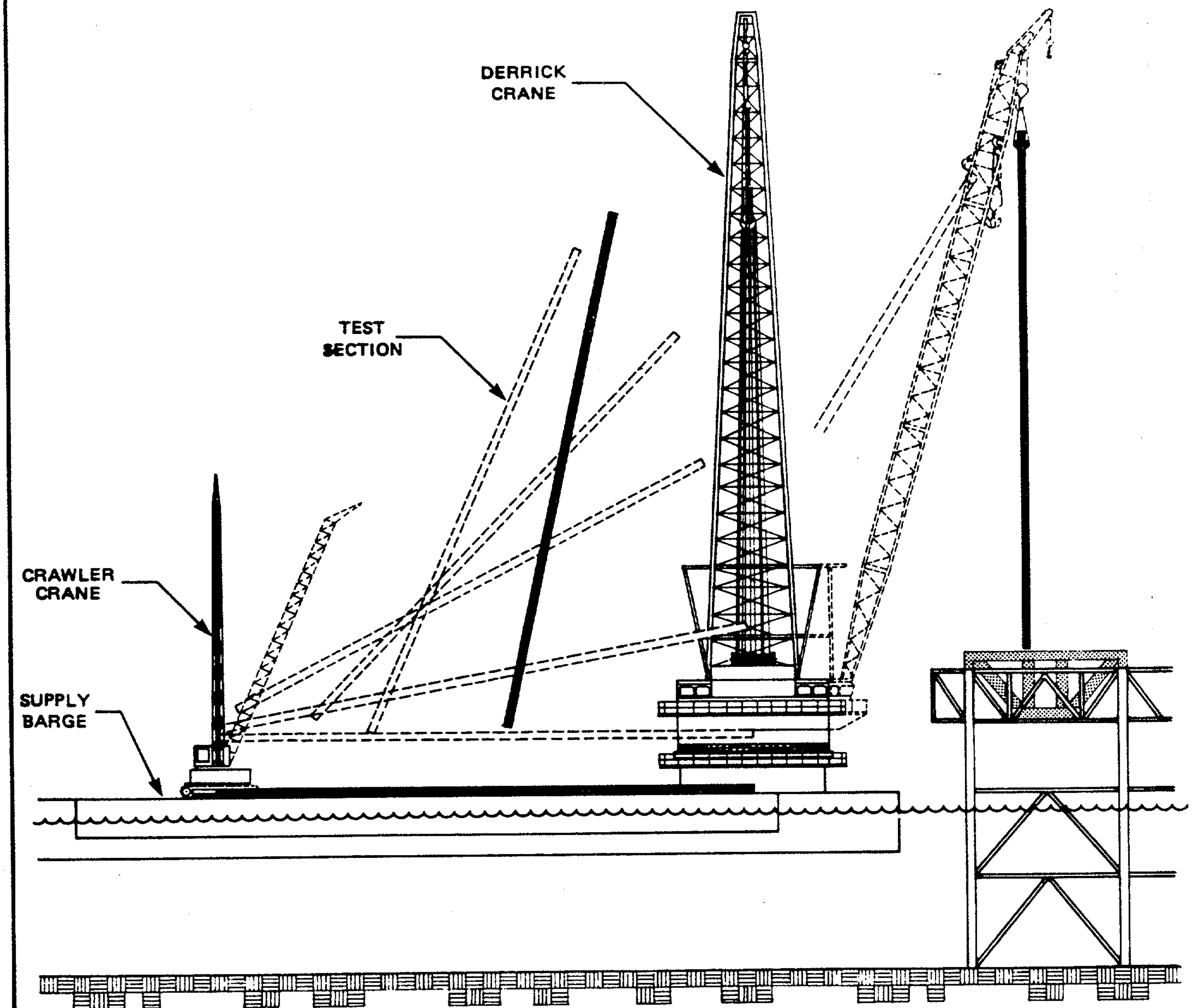
SOIL PRESSURE TRANSDUCER



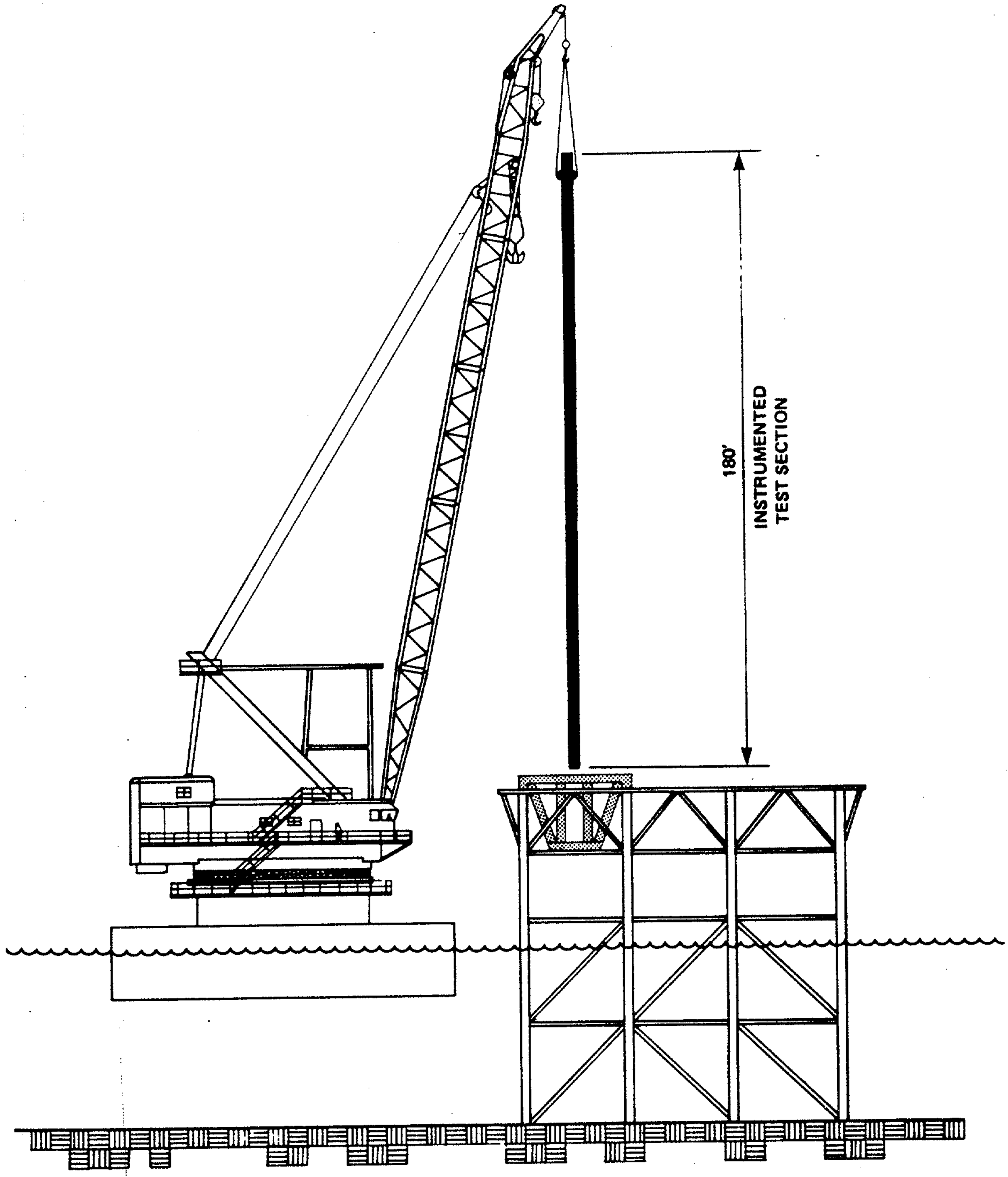
CROSS SECTION OF TEST PILE



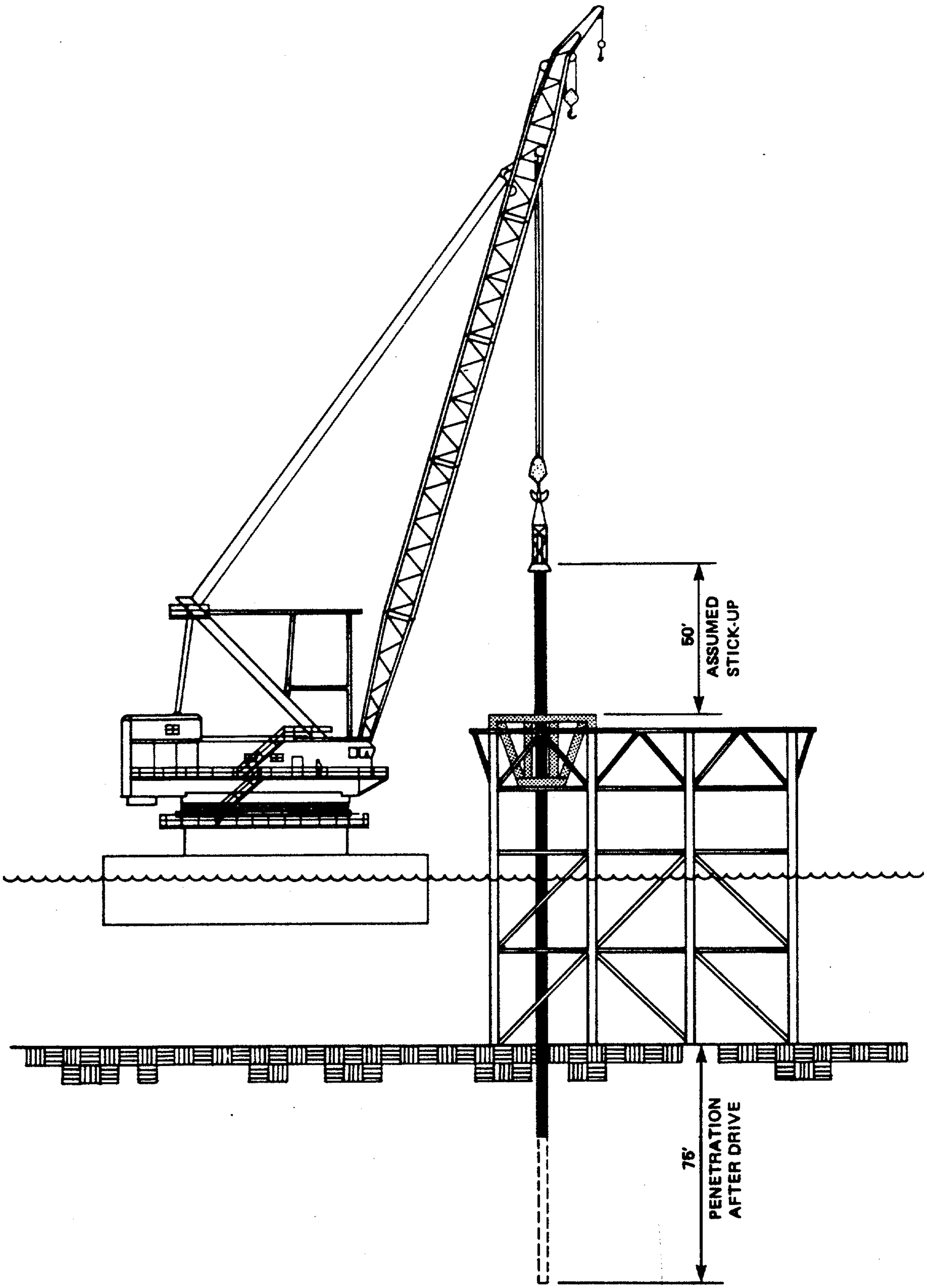
INSTALLATION OF LOAD FRAME



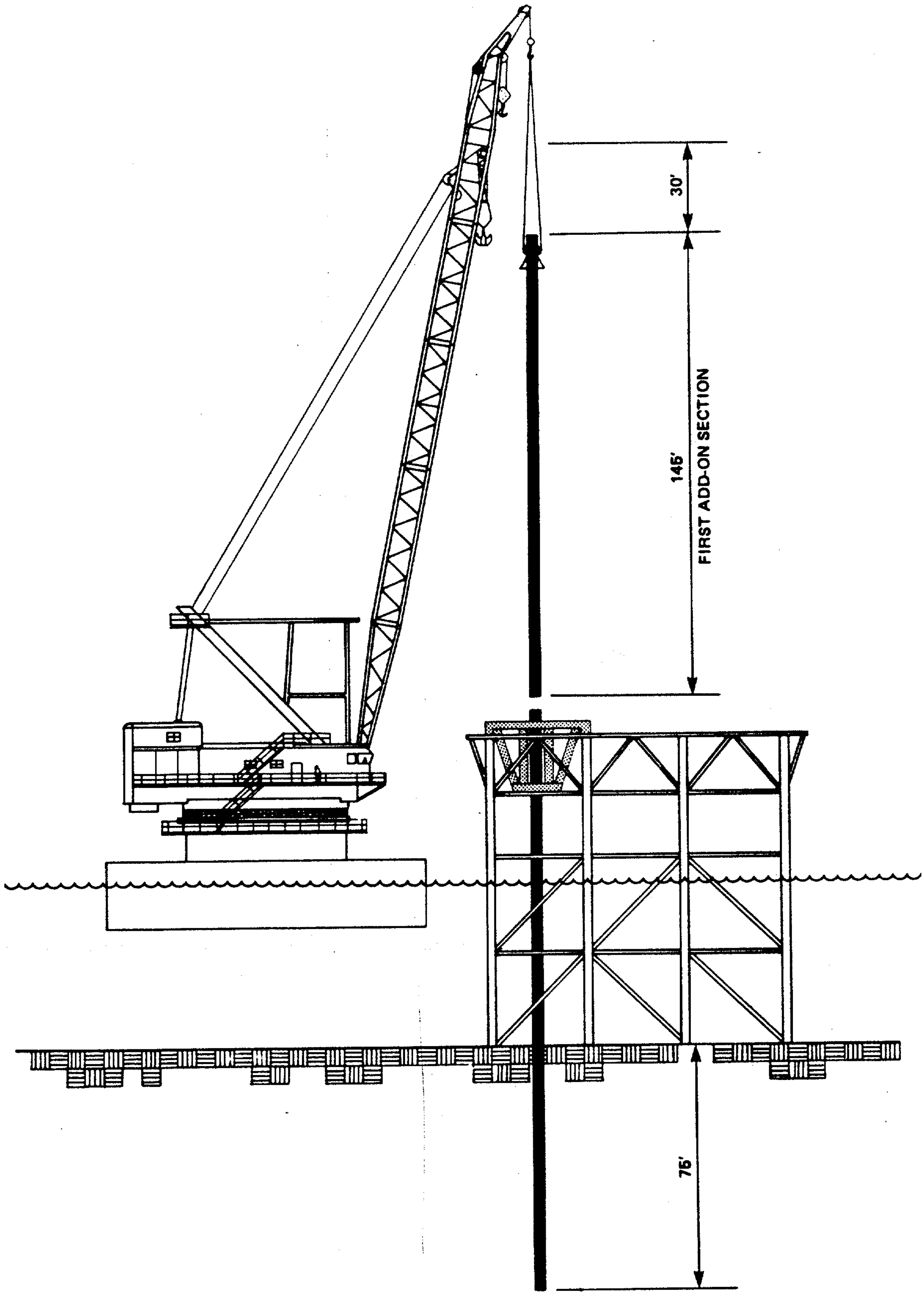
TEST SECTION PICK-UP



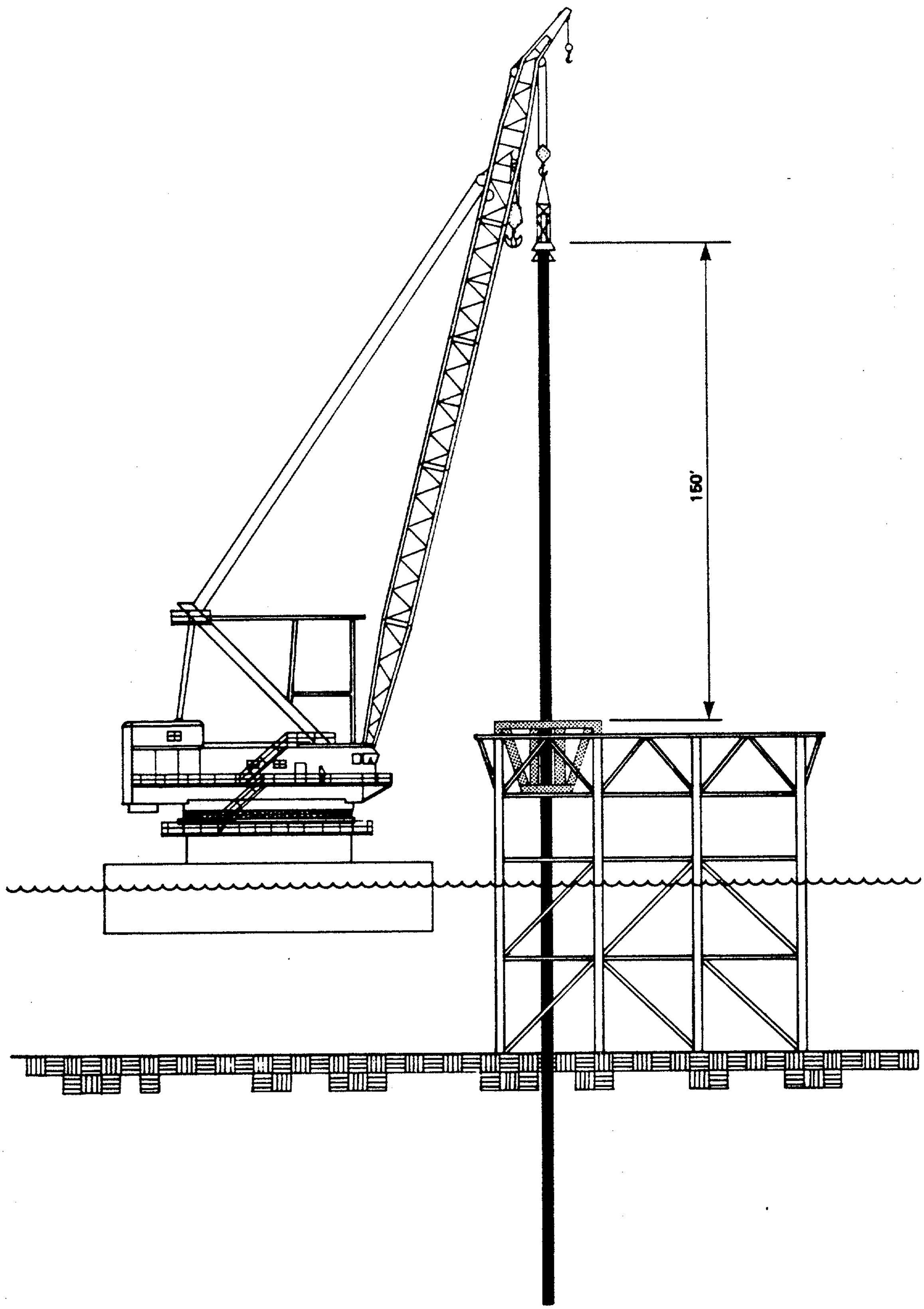
INSTALLATION OF TEST PILE



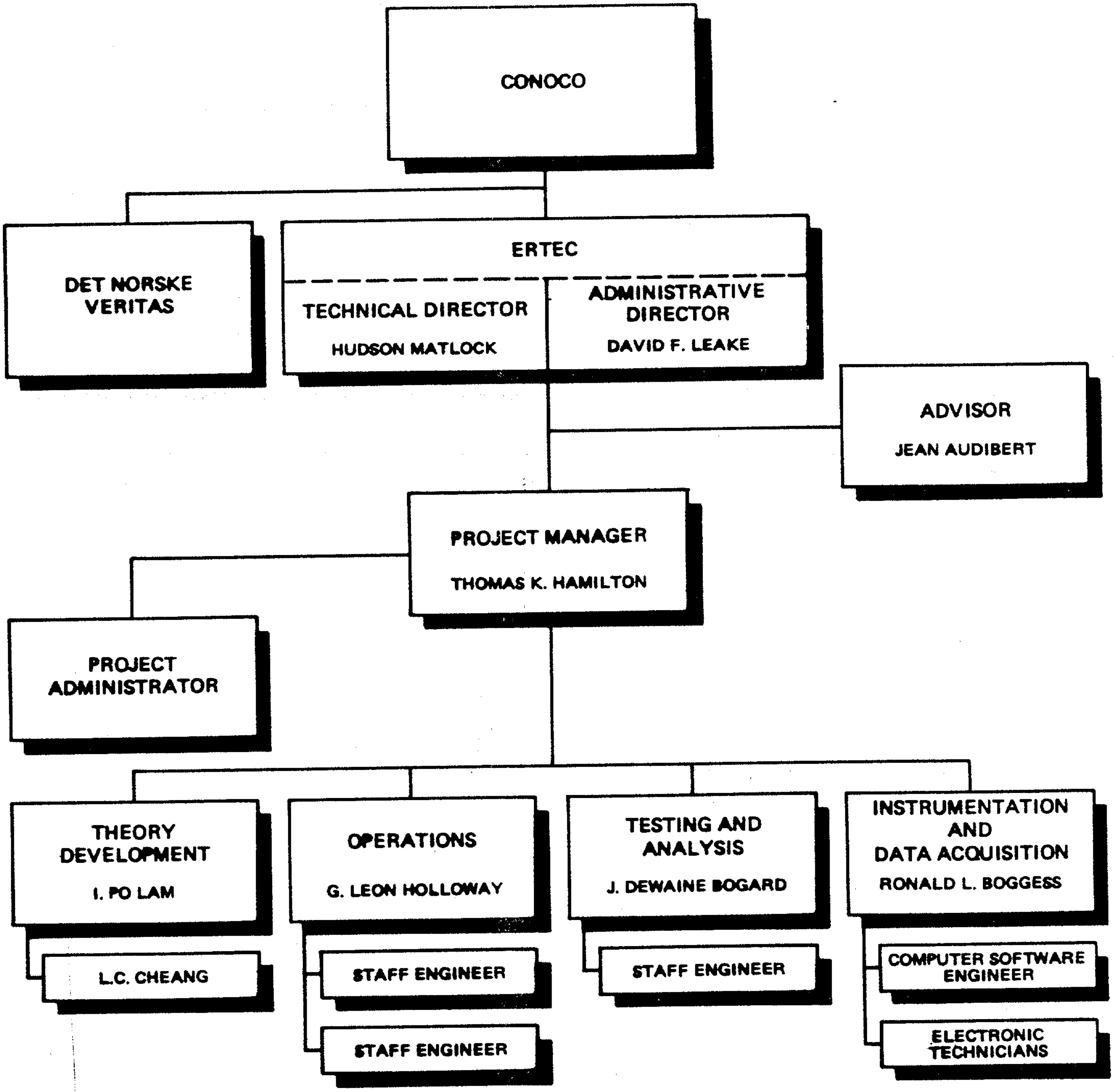
INSTALLATION OF TEST PILE



INSTALLATION OF TEST PILE



INSTALLATION OF TEST PILE



ORGANIZATIONAL CHART

PLATE 34

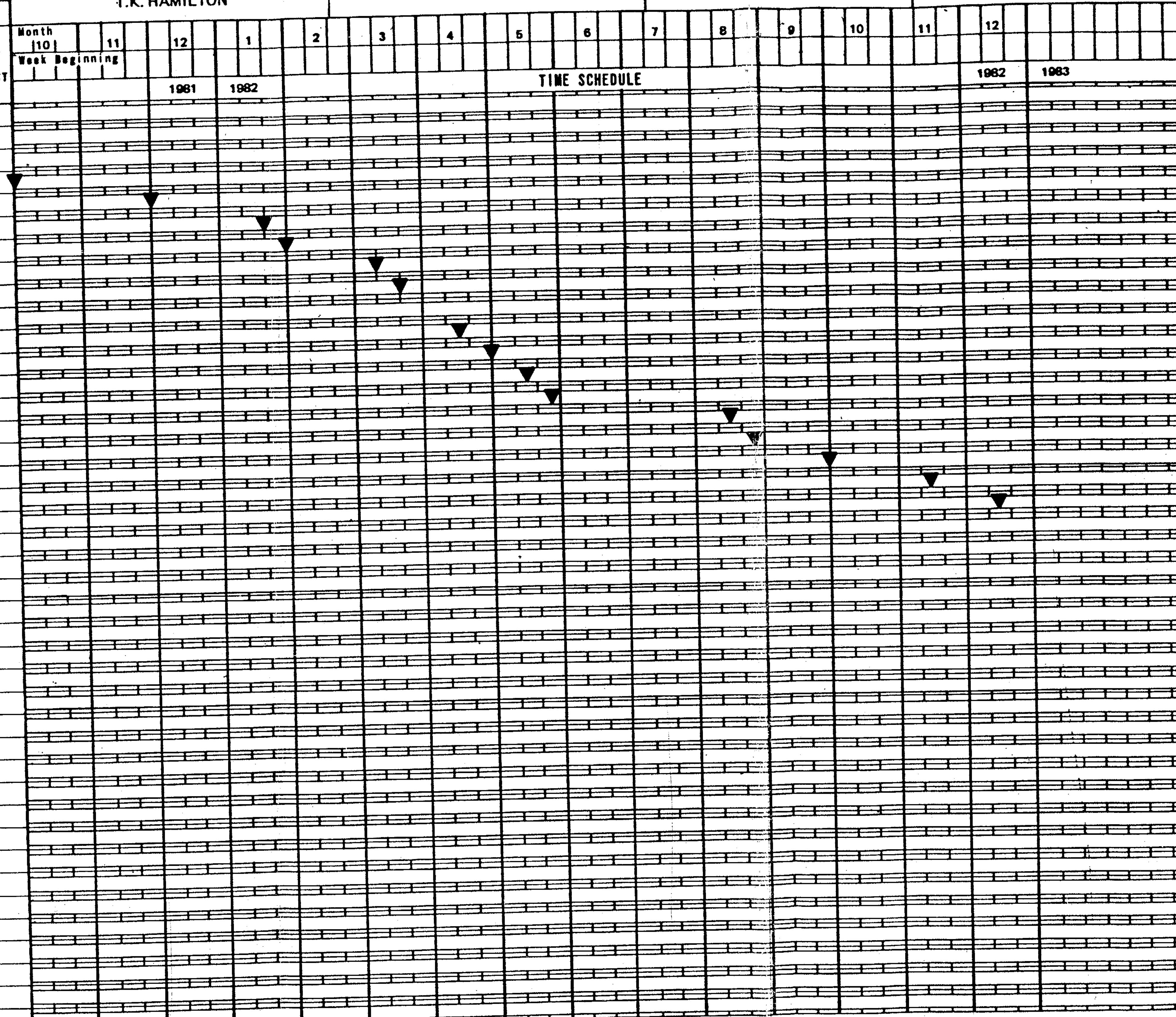
Ertec PROJECT MASTER PLANNING AND CONTROL SCHEDULE

FORM PM 101

PROJECT NAME AND NUMBER	TENSION PILE STUDY
Date Issued	7-30-81
Date Revised	
CUSTOMER NAME	CONOCO
PROJECT MANAGER	T.K. HAMILTON
PROJECT LOCATION	
SITE DESIGNATION	
Prepared by	
Revised by	
Approved by	
Revision Approval	
PAGE	1 OF 1
TITLE	SCHEDULE 1 MILESTONES

MILESTONES/FUNCTIONS

Phase	Task	Act	Item	TASK DESCRIPTION	BUDGETED HOURS/COST
				MILESTONES	
				AUTHORIZATION TO PROCEED	
				ALL SPECIFICATIONS TO CONOCO FOR BIDS	
				SITE INVESTIGATION COMPLETE	
				BEGIN PILE FABRICATION	
				DATA ACQUISITION SYSTEM COMPLETE	
				STRAIN GAGES AND EXTENSOMETERS AT FABRICATION YARD	
				PILE CALIBRATION COMPLETE	
				TEST PILE COMPLETE	
				PILE INSTALLATION AND TESTING COMPLETE	
				SMALL DIAMETER SEGMENT TEST COMPLETE	
				BEGIN MAJOR TEST SERIES	
				END MAJOR TEST SERIES	
				SITE SPECIFIC REPORT	
				RESULTS FROM THEORY DEVELOPMENT	
				FINAL REPORT	



TOTAL

SPECIAL TIME/SCHEDULE CONSTRAINTS

NOTES:

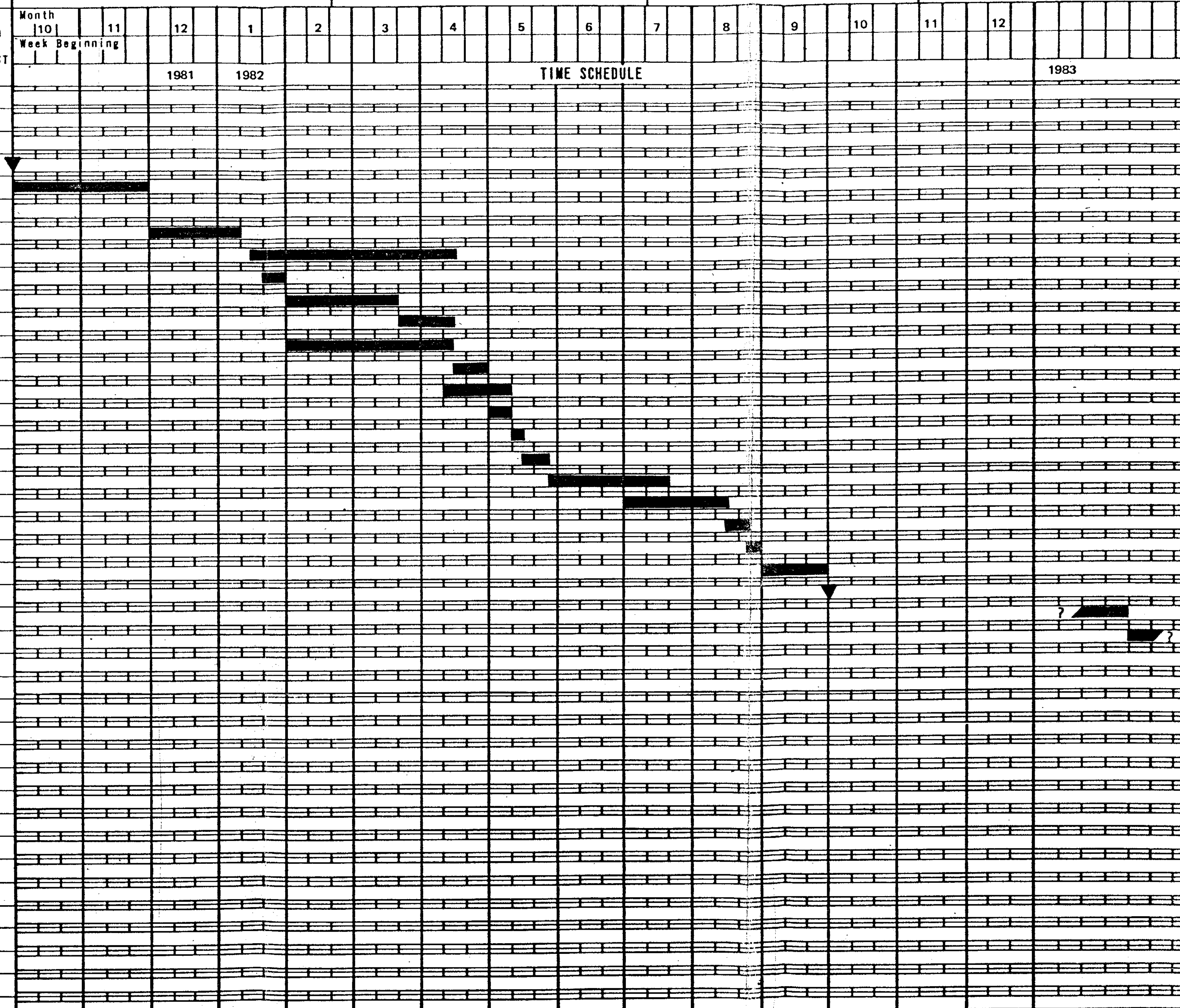
Ertec PROJECT MASTER PLANNING AND CONTROL SCHEDULE
FORM PM 101

CUSTOMER NAME: CONOCO
PROJECT LOCATION:
Prepared by:
Revised by:
Approved by:
Revision Approval:

TITLE: SCHEDULE 2 OPERATIONS

PROJECT NAME AND NUMBER: TENSION PILE STUDY
Date Issued: 7-30-81
Date Revised:
PROJECT MANAGER: G.L. HOLLOWAY
SITE DESIGNATION:

Phase	Task	Act	Item	MILESTONES/FUNCTIONS — TASK DESCRIPTION	BUDGETED HOURS/COST
				OPERATIONS	
				AUTHORIZATION TO PROCEED	
				PREPARE FABRICATION AND INSTALLATION SPECIFICATIONS FOR CONOCO	
				PLAN AND PERFORM SITE INVESTIGATION	
				LABORATORY TESTING	
				PREPARE FABRICATION YARD	
				PILE FABRICATION (INSTRUMENTS NOT REQUIRED)	
				STRAIN GAGE INSTALLATION/CALIBRATION	
				FABRICATE LOAD FRAME, LOAD HEAD, SCAFFOLD	
				COMPLETE FABRICATION/PREPARE FOR TRANSPORT	
				PREPARE PLATFORM	
				TRANSPORT TEST PILE AND LOAD FRAME	
				INSTALL LOAD FRAME, TEST PILE, AND FIRST TEST	
				PERFORM SMALL DIAMETER PILE SEGMENT TESTS	
				PREPARE REPORT ON FABRICATION AND INSTALLATION	
				PREPARE FOR MAJOR TEST SERIES	
				PERFORM MAJOR TEST SERIES	
				DEMOBILIZATION	
				PREPARE REPORT ON OPERATIONS	
				SITE SPECIFIC REPORT	
				PREPARE FOR FOLLOW-UP TEST	
				PERFORM FOLLOW-UP TEST	



NOTES:

TOTAL

SPECIAL TIME/SCHEDULE CONSTRAINTS

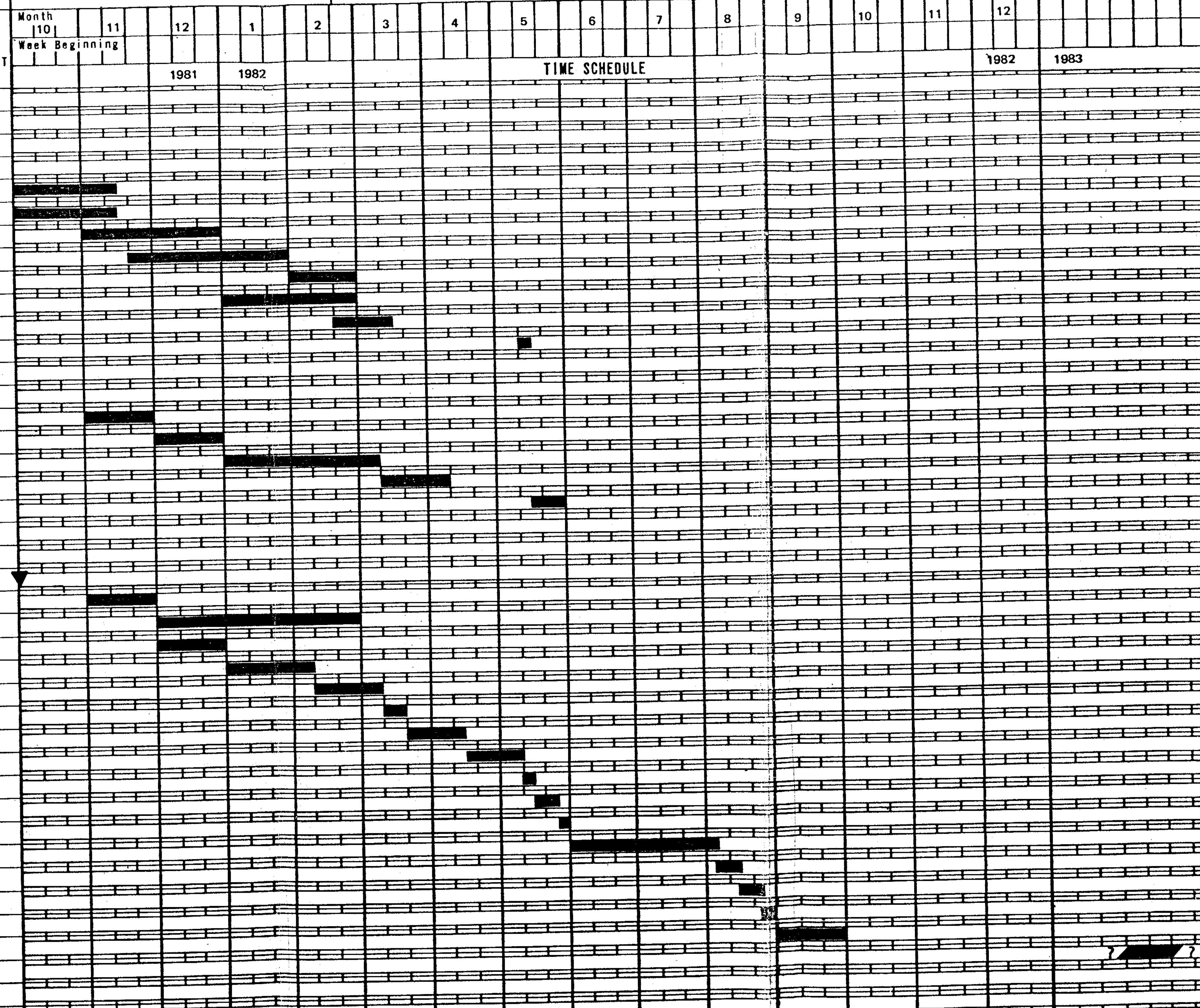
BOT-00174

Ertec PROJECT MASTER PLANNING AND CONTROL SCHEDULE
FORM PM 101

PROJECT NAME AND NUMBER	TENSION PILE STUDY
Date Issued	7-30-81
Date Revised	
CUSTOMER NAME	CONOCO
PROJECT MANAGER	R.L. BOGGESS
PROJECT LOCATION	
SITE DESIGNATION,	
Prepared by	
Revised by	
Approved by	
Revision Approval	
PAGE 1 OF 1	
TITLE	SCHEDULE 3 INSTRUMENTATION AND DATA ACQUISITION

MILESTONES/FUNCTIONS

Phase	Task	Act	Item	TASK DESCRIPTION	BUDGETED HOURS/COST
				INSTRUMENTATION AND DATA ACQUISITION	
				PILE INSTRUMENTS	
				DESIGN INSTRUMENTS	
				ORDER LONG LEAD TIME PARTS	
				PREPARE MACHINE DRAWINGS	
				MACHINE AND ASSEMBLE STRAIN GAGES	
				PROOF TEST AND CALIBRATE STRAIN GAGES	
				MACHINE AND ASSEMBLE PRESSURE UNITS	
				PROOF TEST AND CALIBRATE PRESSURE UNITS	
				PILE INSTALLATION AND TESTING	
				SMALL-DIAMETER PILE SEGMENT	
				DESIGN INSTRUMENT	
				PREPARE MACHINE DRAWINGS	
				MACHINE AND ASSEMBLE INSTRUMENT	
				INSTRUMENT CHECK-OUT	
				SEGMENT TEST	
				DATA ACQUISITION SYSTEM	
				ORDER DATA SYSTEM	
				DETERMINE SOFTWARE REQUIREMENTS	
				SOFTWARE DEVELOPMENT	
				DESIGN DATA PANELS	
				FABRICATE DATA PANELS	
				SET-UP DATA SYSTEM IN PORTABLE BUILDING	
				TRANSPORT TO FABRICATION YARD	
				FIELD CALIBRATION OF TEST PILE	
				TEST PILE MONITOR UNTIL INSTALLATION	
				PILE INSTALLATION AND TESTING	
				PILE SEGMENT TESTS	
				RETURN DATA SYSTEM TO HOUSTON	
				DATA PROCESSING IN HOUSTON	
				MOBILIZE DATA SYSTEM FOR MAJOR TEST	
				MAJOR TEST	
				DEMOBILIZE TO HOUSTON	
				DATA PROCESSING	
				FOLLOW-UP TEST	



NOTES:

TOTAL

SPECIAL TIME/SCHEDULE CONSTRAINTS

BDT-00174

Ertec PROJECT MASTER PLANNING AND CONTROL SCHEDULE

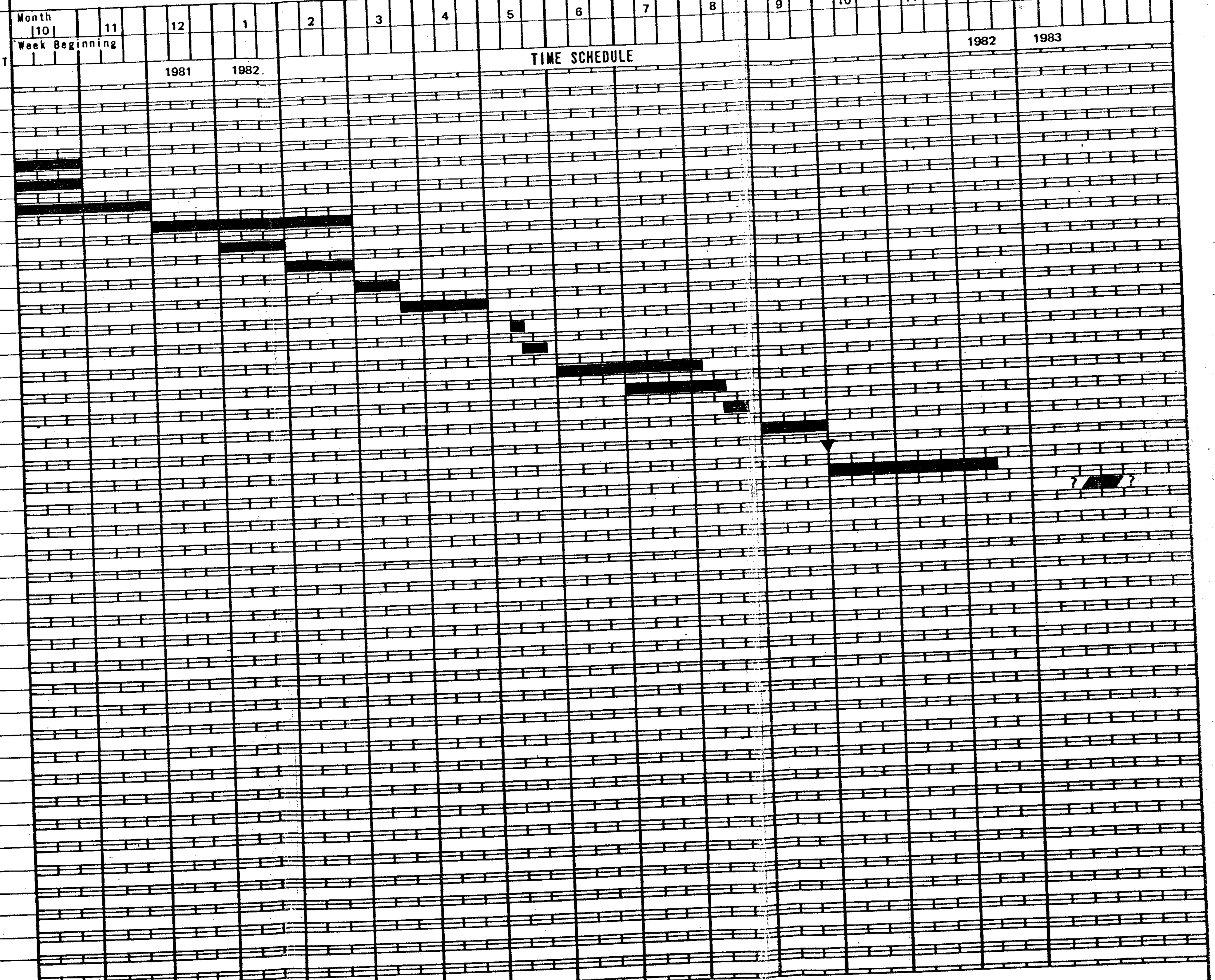
FORM PM 101

PROJECT NAME AND NUMBER	TENSION PILE STUDY
Date Issued	7-30-81
Date Revised	
CUSTOMER NAME	CONOCO
MANAGER	J.D. BOGARD
PROJECT LOCATION	
SITE DESIGNATION	
Prepared by	
Revised by	
Approved by	
Revision Approval	
PAGE	1 OF 1
TITLE	SCHEDULE 4 TESTING AND ANALYSIS

MILESTONES/FUNCTIONS

Phase	Task	Act	Item	TASK DESCRIPTION	BUDGETED HOURS/COST
				TESTING AND ANALYSIS	
				DETERMINE INSTRUMENT REQUIREMENTS	
				DETERMINE SOFTWARE REQUIREMENTS	
				CONSULT ON INSTRUMENT DESIGN	
				SOFTWARE DEVELOPMENT	
				PLAN INSTALLATION AND FIRST TEST	
				CALIBRATION AND SOFTWARE INTERFACING	
				PLAN TEST PILE INSTALLATION AND FIRST TEST	
				CALIBRATION OF TEST PILE	
				INSTALLATION OF PILE AND TESTING	
				SEGMENT TESTING	
				DATA PROCESSING AND ANALYSIS	
				PREPARE FOR MAJOR TEST	
				MAJOR TEST	
				DATA PROCESSING AND ANALYSIS	
				SITE SPECIFIC REPORT	
				ANALYSIS AND FINAL REPORT	
				FOLLOW-UP TEST	
				TOTAL	

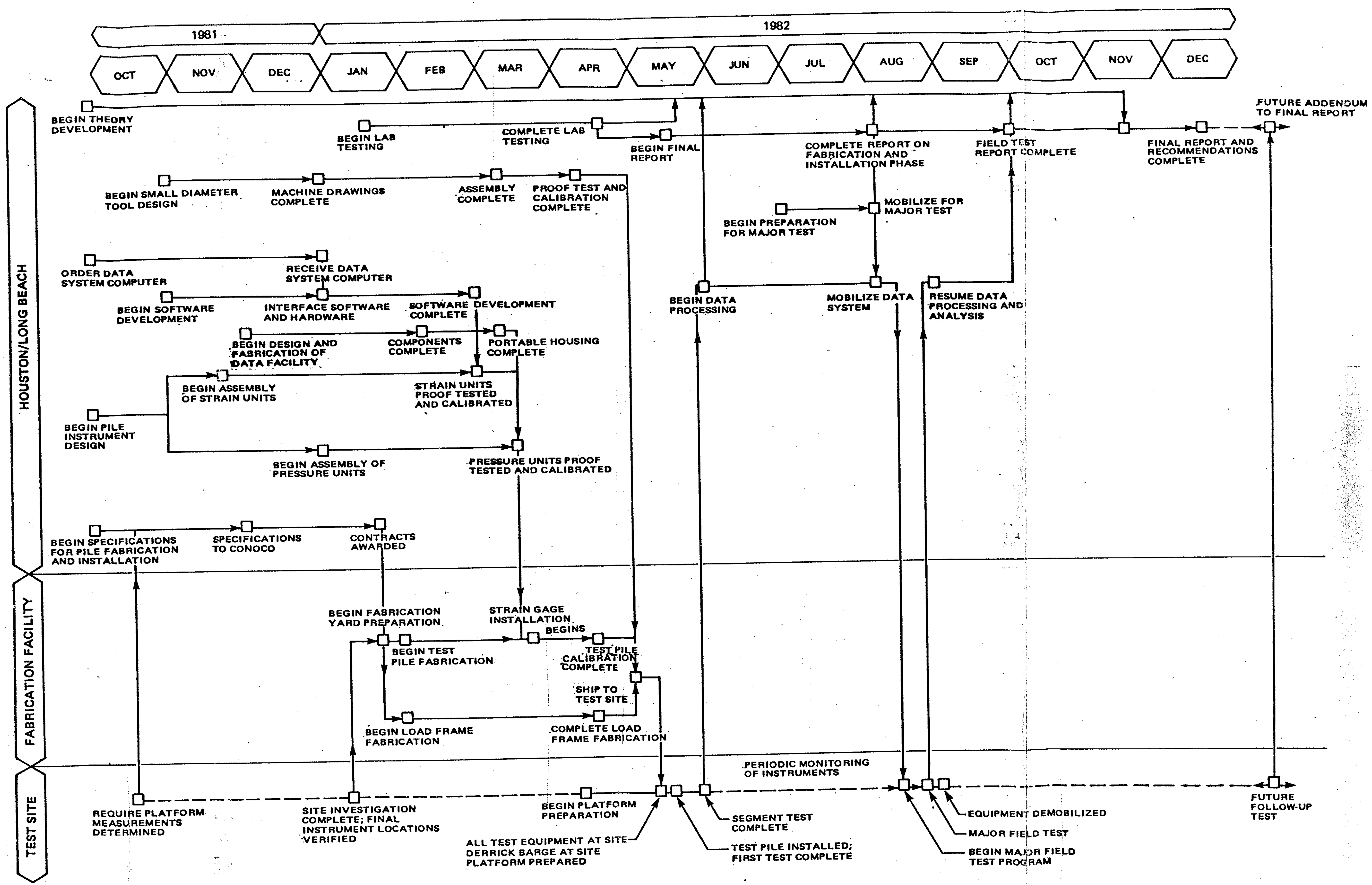
TIME SCHEDULE



SPECIAL TIME/SCHEDULE CONSTRAINTS

NOTES:

PLATE 38



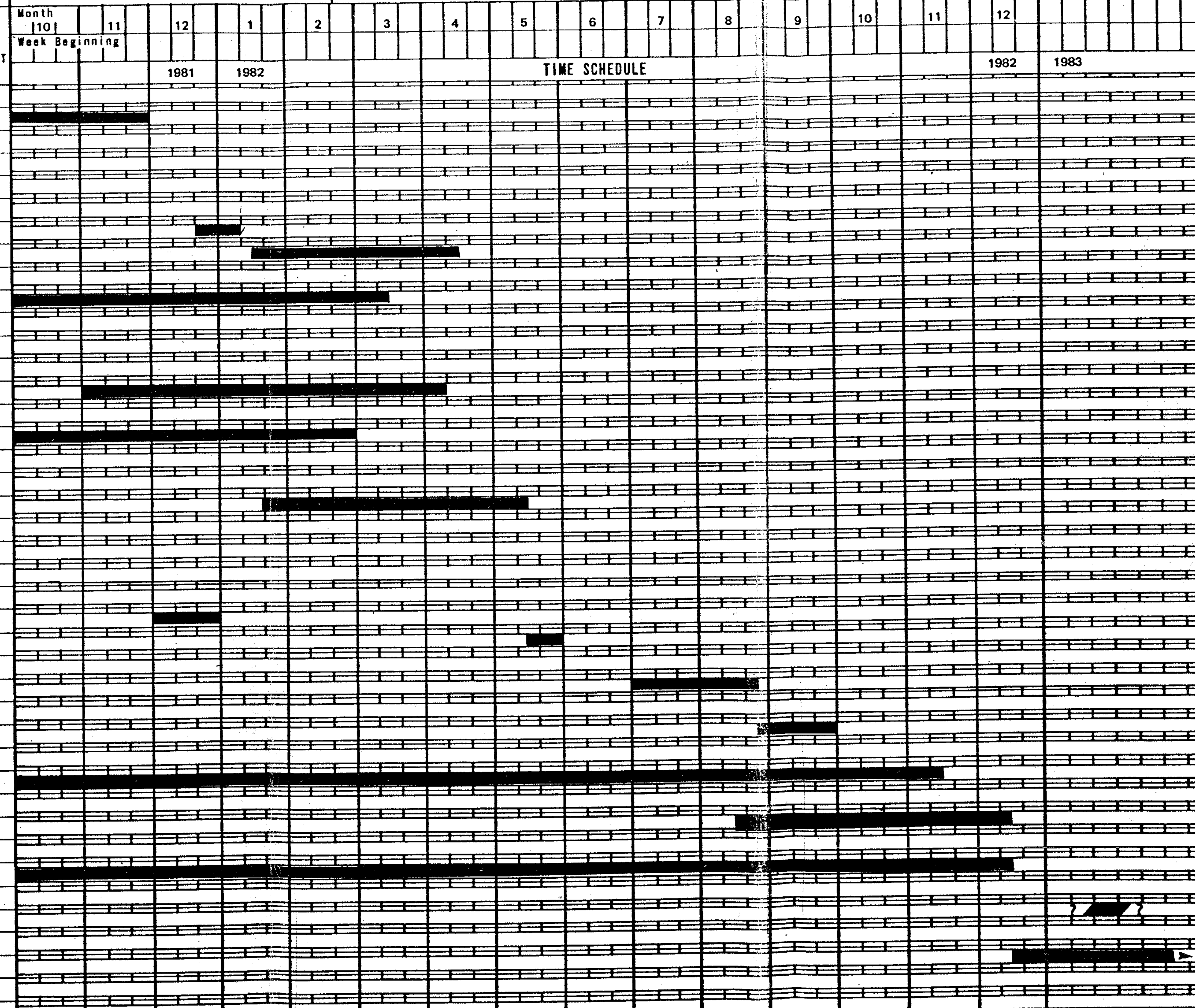
SCHEDULE 5 FLOW CHART FOR FIELD TEST PROGRAM

Ertec PROJECT MASTER PLANNING AND CONTROL SCHEDULE
FORM PM 101

CUSTOMER NAME	CONOCO
PROJECT LOCATION	
Prepared by	
Revised by	
Approved by	
Revision Approval	
PAGE	1 OF 1
TITLE	SCHEDULE 6 BUDGET TASKS
PROJECT NAME AND NUMBER	TENSION PILE STUDY
Date Issued	7-30-81
Date Revised	
PROJECT MANAGER	T.K. HAMILTON
SITE DESIGNATION	

MILESTONES/FUNCTIONS

Phase	Task	Act	Item	TASK DESCRIPTION	BUDGETED HOURS/COST
	1			PREPARATION OF DESIGN DRAWINGS AND SPECIFICATIONS FOR PHYSICAL TEST SYSTEM	
	2			SITE INVESTIGATION AND LABORATORY TESTING PROGRAM	
			1	SITE INVESTIGATION	
			2	LABORATORY TESTING	
	3			DESIGN, FABRICATION, TESTING AND CALIBRATION OF PILE INSTRUMENTS FOR LARGE-DIAMETER PILE	
	4			DESIGN MODIFICATIONS AND CALIBRATION OF SMALL DIAMETER PILE SEGMENT	
	5			DEVELOPMENT OF DATA ACQUISITION SYSTEM AND SOFTWARE	
	6			TEST PILE FABRICATION, INSTALLATION AND INITIAL TEST	
	7			PLANNING AND IMPLEMENTATION OF SMALL DIAMETER SEGMENT TEST	
			1	PLANNING	
			2	TESTING	
	8			PLANNING AND PERFORMING MAJOR FIELD TEST	
	9			DATA REDUCTION AND ANALYSIS	
	10			THEORY DEVELOPMENT	
	11			REPORT AND RECOMMENDATIONS	
	12			PROJECT ADMINISTRATION AND REVIEW	
	13			PLANNING AND PERFORMING FOLLOW-UP TEST	
	14			DESIGN SPECIFICATION FOR TENSION LEG PLATFORMS	
				TOTAL	



SPECIAL TIME/SCHEDULE CONSTRAINTS

NOTES:

PLATE 40

BOT-00174

APPENDIX I

BUDGET

SUMMARY PROJECT COSTS

Task 1 -	**Preparation of Design Drawings and Specifications for the Physical Test System**		
	A. Personnel (Ertec)		$40,680
	B. Travel Expenses		1,690
	C. Reproduction/Printing		300
	D. Structural Analysis/Shop Drawings		10,000*
		Subtotal	52,670
Task 2 -	**Site Investigation and Laboratory Testing Program**		
	A. Personnel		
	A.1 Ertec		8,280
	A.2 Conoco (welders, operators)		700*
	B. Travel Expenses		
	B.1 Onshore		1,930
	B.2 Offshore		1,200*
	C. Services and Equipment Rental		78,750*
	D. Laboratory Test Program		21,645
		Subtotal	112,505
Task 3 -	**Design, Fabrication, Testing, and Calibration of Instrumentation for Large-Diameter Pile**		
	A. Personnel (Ertec)		89,500
	B. Instrumentation		184,580
	C. Miscellaneous		14,000
		Subtotal	288,080
Task 4 -	**Design Modifications and Calibration of Small-Diameter Pile Segment**		
	A. Personnel (Ertec)		23,400
	B. Materials		8,050
	C. Services		13,800
		Subtotal	45,250
Task 5 -	**Development of Data Acquisition System and Software**		
	A. Personnel (Ertec)		44,250
	B. Data Acquisition		49,100
	C. Dynamic Recording Measurements		11,200
		Subtotal	104,550

* Cost Paid by Conoco

Task 6 - Test Pile Fabrication, Installation and Initial Test

A.	Personnel (Ertec)		121,550
B.	Travel Expenses		
	B.1 Onshore		25,000
	B.2 Offshore		10,650*
C.	Fabrication of Test Pile		168,000*
D.	Platform Modifications		33,750*
E.	Equipment Rental		417,300*
F.	Material		90,820*
G.	Mobilization		840
		Subtotal	867,910

Task 7 - Planning and Implementation of Small Diameter Segment Test

A.	Personnel		
	A.1 Ertec		34,800
	A.2 Conoco (welders, operators)		1,050*
B.	Travel Expenses		
	B.1 Onshore		2,530
	B.2 Offshore		9,000*
C.	Services and Equipment Rental		89,800*
		Subtotal	137,180

Task 8 - Planning and Performing Major Field Test

A.	Personnel		
	A.1 Ertec		89,230
	A.2 Conoco (welders, operators)		2,100*
B.	Travel Expenses		
	B.1 Onshore		6,795
	B.2 Offshore		16,800*
C.	Mobilization & Demobilization		7,000
D.	Misc. Supplies & Materials		2,000
		Subtotal	123,925

Task 9 - Data Reduction and Analysis

A.	Personnel (Ertec)		47,600
B.	Shipping		200
C.	Computer		3,000
D.	Misc. Expenses & Supplies		15,000
		Subtotal	65,800

* Costs paid by Conoco

Task 10 - Theory Development

A.	Personnel (Ertec)	55,200
B.	Travel Expenses	2,950
C.	Computer	20,000
	Subtotal	78,150

Task 11 - Report and Recommendations

A.	Personnel (Ertec)	97,360
B.	Reproduction/Printing	4,000
C.	Shipping	400
D.	Misc. Expenses & Supplies	2,000
	Subtotal	103,760

Task 12 - Project Administration and Review

A.	Personnel (Ertec)	79,200
B.	Sponsor Meetings	20,000
C.	Travel Expenses	14,500
D.	Miscellaneous	1,050
	Subtotal	114,750

Task 13 - Planning and Performing Follow-up Test

A.	Personnel	
	A.1 Ertec	74,030
	A.2 Conoco (welders, operators)	2,100*
B.	Travel Expenses	
	B.1 Onshore	5,045
	B.2 Offshore	14,000*
C.	Mobilization & Demobilization	7,000
D.	Equipmental Rental	20,000*
E.	Misc. Supplies and Materials	2,000
	Subtotal	124,175

Task 14 - Design Specifications for Tension Leg Platforms

A.	Personnel (Ertec)	98,900
B.	Travel Expenses	17,880
C.	Reproduction/Printing	5,000
D.	Shipping	1,000
E.	Sponsor Meetings	25,000
F.	Computer	15,000
	Subtotal	162,780

* Cost Paid by Conoco

SUMMARY PROJECT COSTS

Ertec Estimated Costs	1,415,465
Ertec Risk & Uncertainties (25%)	353,866
Estimated Conoco Direct Costs	966,020
Estimated Total Project Costs	$2,735,351

GENERAL PROJECT COSTS

TASK 1 - Preparation of Design Drawings and Specifications for the Physical Test System

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Project Engineer	$60/hr	180 hr	$10,800
A.2 Staff Engineer	$55/hr	420 hr	23,100
A.3 Draftsman	$30/hr	180 hr	5,400
A.4 Technical Typist	$23/hr	60 hr	1,380
		Subtotal	40,680
B. Travel Expenses			
B.1 Airfare	$135/trip	4 trips	540
B.2 Subsistence	$75/day	10 days	750
B.3 Transportation	$40/day	10 days	400
		Subtotal	1,690
C. Reproduction/Printing			300
		Subtotal	300
D. Structural Analysis/Shop Drawings			10,000
		Subtotal	10,000
		Total	$52,670

TASK 2 - Site Investigation and Laboratory Testing Program

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Project Engineer	$60/hr	72 hr	$ 4,320
A.2 Staff Engineer	$55/hr	72 hr	3,960
		Subtotal	8,280
B. Personnel (Paid by Conoco)			
B.1 Welder	$30/hr	10 hr	300
B.2 Operator	$40/hr	10 hr	400
		Subtotal	700
C. Travel Expenses			
C.1 Airfare (Long Beach/Houston)	$600/trip	2 trips	1,200
C.2 Subsistence (Onshore)	$75/day	6 days	450
C.3 Transportation	$40/day	7 days	280
C.4 Subsistence and Transportation (Offshore - Paid by Conoco)	$150/day	8 days	1,200
		Subtotal	3,130

		Rate	Quantity	Cost
D.	Services and Equipment Rental (Paid by Conoco)			
D.1	Drilling Engineer	$500/day	5 days	2,500
D.2	Drilling Crew	$3,600/day	5 days	18,000
D.3	Operators (CPT)	$1,200/day	5 days	6,000
D.4	Remote Vane	$600/day	5 days	3,000
D.5	CPT	$4,000/day	5 days	20,000
D.6	Drilling Rig	$1,200/day	5 days	6,000
D.7	Drilling, Sampling & Field Testing			6,000
D.8	Mobilization & Demobilization			6,500
D.9	Expendables (drilling mud, tubes, etc.)			4,000
D.10	Subsistence & Transportation (9)	$150/day	45 days	6,750
			Subtotal	78,750
E.	Laboratory Test Program			
E.1	Sample Shipment/Handling			4,000
E.2	X-Ray	$45/test	23 tests	1,035
E.3	Laboratory Tests			
E.3.1	Liquid & Plastic Limits	$50/test	16 tests	800
E.3.2	Miniature Vane Test	$30/test	16 tests	480
E.3.3	Consolidation	$550/test	4 tests	2,200
E.3.4	Specific Gravity	$30/test	4 tests	120
E.3.5	Grain Size (hydrometer)	$50/test	4 tests	200
E.3.6	Unconsolidated Undrained Triaxial Test	$110/test	16 tests	1,760
E.3.7	Consolidated Undrained Triaxial Test			
E.3.7.1	Isotropic	$285/test	6 tests	1,710
E.3.7.2	Anisotropic	$600/test	4 tests	2,400
E.3.8	Direct Simple Shear	$860/test	4 tests	3,440
E.4	Test Program Report			3,500
			Subtotal	21,645
			Total	$112,505

TASK 3 - Design, Fabrication, Testing, and Calibration of Instrumentation for Large-Diameter Pile

		Rate	Quantity	Cost
A.	Personnel (Ertec)			
A.1	Project Engineer	$60/hr	600 hr	$36,000
A.2	Staff Engineer	$55/hr	100 hr	5,500
A.3	Technician	$30/hr	1,400 hr	42,000
A.4	Draftsman	$30/hr	200 hr	6,000
			Subtotal	89,500

		Rate	Quantity	Cost
B.	Instrumentation (Material/Subcontractors Services)			
	B.1 Total Pressure Cell	$2,790/ea	14 ea	39,060
	B.2 Pore Pressure Cell	$3,900/ea	14 ea	54,600
	B.3 Strain Module	$2,650/ea	16 ea	42,400
	B.4 Extensometer	$2,510/ea	8 ea	20,080
	B.5 Tell-tale/Displacement Module	$1,800/ea	4 ea	7,200
	B.6 Extensometer Connectors	$3,540/ea	6 ea	21,240
			Subtotal	184,580
C.	Miscellaneous Materials, Supplies, and Equipment Rental			14,000
			Total	$288,080

TASK 4 - Design Modifications and Calibration of Small-Diameter Pile Segment

		Rate	Quantity	Cost
A.	Personnel (Ertec)			
	A.1 Project Engineer	$60/hr	150 hr	$ 9,000
	A.2 Staff Engineer	$55/hr	60 hr	3,300
	A.3 Technician	$30/hr	250 hr	7,500
	A.4 Draftsman	$30/hr	120 hr	3,600
			Subtotal	23,400
B.	Materials (DCDTS, Pressure Transducers, Strain Gages, etc.)			8,050
			Subtotal	8,050
C.	Services			
	C.1 Contract Labor			12,000
	C.2 Subcontractors Fee			1,800
			Subtotal	13,800
			Total	$45,250

TASK 5 - Development of Data Acquisition System and Software

		Rate	Quantity	Cost
A.	Personnel (Ertec)			
	A.1 Project Engineer	$60/hr	220 hr	$13,200
	A.2 Staff Engineer	$55/hr	510 hr	28,050
	A.3 Draftsman	$30/hr	40 hr	1,200
	A.4 Technician	$30/hr	60 hr	1,800
			Subtotal	44,250

	Rate	Quantity	Cost
B. Data Acquisition System			
B.1 Data Recording (Instrumentation)			
B.1.1 Computer/Console	$2,800/mo	12 mo	33,600
B.1.2 Lab/Printer/Plotter/ Control System	$3,100/mo	5 mo	15,500
		Subtotal	49,100
C. Dynamic Recording Measurements			
C.1 Pile Driving Analyzer and Operator	$1,400/day	6 day	8,400
C.2 Report on Dynamic Measurements			2,800
		Subtotal	11,200
		Total	$104,550

TASK 6 - Test Pile Fabrication, Installation, and Initial Test

	Rate	Quantity	Cost
A. Personnel - Field Supervision (Ertec)			
A.1 Fabrication/Calibration of Test Pile/Load Frame			
A.1.1 Project Engineer	$60/hr	450 hr	$27,000
A.1.2 Staff Engineer	$55/hr	950 hr	52,250
		Subtotal	79,250
A.2 Platform Modification/Preparation			
A.2.1 Staff Enginee	$55/hr	180 hr	9,900
		Subtotal	9,900
A.3 Installation of Load Frame/Test Pile/First Test			
A.3.1 Project Engineer	$60/hr	240 hr	14,400
A.3.2 Staff Engineer	$55/hr	240 hr	13,200
A.3.3 Technician	$30/hr	160 hr	4,800
		Subtotal	32,400
B. Travel Expenses			
B.1 Fabrication/Calibration of Test Pile/Load Frame			
B.1.1 Airfare (New Orleans/Houston)	$135/trip	15 trips	2,025
B.1.2 Subsistence (Onshore)	$75/day	190 days	14,250
B.1.3 Transportation	$40/day	160 days	6,400
		Subtotal	22,675

	Rate	Quantity	Cost
B.2 Platform Modification/Preparation			
B.2.1 Airfare (New Orleans/Houston)	$135/trip	1 trip	135
B.2.2 Subsistence (Onshore)	$75/day	4 days	300
B.2.3 Subsistence & transportation (Offshore - Paid by Conoco)	$150/day	15 days	2,250
		Subtotal	2,685
B.3 Installation of Load Frame/Test Pile/First Test			
B.3.1 Airfare (New Orleans/Houston)	$135/trip	6 trips	810
B.3.2 Subsistence (Onshore)	$75/day	8 days	600
B.3.3 Transportation	$40/day	12 days	480
B.3.4 Subsistence & transportation (Offshore - Paid by Conoco)	$150/day	56 days	8,400
		Subtotal	10,290
C. Fabrication of Test Pile (Paid by Conoco)			
C.1 Personnel (Estimate)			
C.1.1 Welders	$30/hr	3200 hr	96,000
C.1.2 Supervisors	$40/hr	800 hr	32,000
C.1.3 Operators	$40/hr	350 hr	14,000
C.1.4 Inspectors	$50/hr	200 hr	10,000
		Subtotal	152,000
C.2 Fabrication Yard (Estimate)			
C.2.1 Welding Supplies	$150/day	70 days	10,500
C.2.2 Crane	$100/day	20 days	2,000
C.2.3 Miscellaneous	$50/day	70 days	3,500
		Subtotal	16,000
D. Platform Modification/Preparation (Paid by Conoco)			
D.1 Personnel (Estimate)			
D.1.1 Welders	$30/hr	450 hr	13,500
D.1.2 Supervisors	$40/hr	150 hr	6,000
D.1.3 Operators	$40/hr	150 hr	6,000
		Subtotal	25,500
D.2 Material (Estimate)			
D.2.1 Material for platform modification			5,000
D.2.2 Welding Supplies	$150/day	15 days	2,250
D.2.3 Misc. material & supplies			1,000
		Subtotal	8,250

	Rate	Quantity	Cost
E. Installation of Load Frame/Test Pile/First Test (Paid by Conoco)			
E.1 Equipment Rental (Estimate)			
E.1.1 Derrick barge (500 ton)			
E.1.1.1 Rental	$60,000/day	3 days	180,000
E.1.1.2 Mobilization & Demobilization			80,000
E.1.1.3 Down Time (20%)			36,000
E.1.2 Work barge/tug	$6,500/day	7 days	45,500
E.1.3 Pile hammer (D62-12)			11,000
E.1.4 Hydraulic rams/system		6 mo	50,000
E.1.5 Storage buildings/office			
E.1.6.1 Building rental	$800/mo	6 mo	4,800
E.1.6.2 Mobilization/ Demobilization	$1,000	2	2,000
E.1.6 Generators	$1,600/mo	5 mo	8,000
		Subtotal	417,300
F. Material			
F.1 Test Pile (Paid by Conoco)			
F.1.1 Pile material	$104/ft	330 ft	34,320
F.1.2 Misc. steel (access tubes, channels, angles, etc.)			39,500
F.1.3 Steel for load head			6,000
F.2 Load Frame (Paid by Conoco)			
F.2.1 Additional steel for load frame			10,000
F.2.2 Wood & misc. material for decking			1,000
		Subtotal	90,820
G. Mobilization of Ertec Equipment (Houston to Fabrication Yard)	$.60/mi	1,400 mi	840
		Subtotal	840
		Total	$867,910

TASK 7 - Planning and Implementation of Small-Diameter Segment Test

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Project Engineer	$60/hr	240 hr	14,400
A.2 Staff Engineer	$55/hr	240 hr	13,200
A.3 Technician	$30/hr	240 hr	7,200
		Subtotal	34,800
B. Personnel (Paid by Conoco)			
B.1 Welder	$30/hr	15 hr	450
B.2 Operator	$40/hr	15 hr	600
		Subtotal	1,050

	Rate	Quantity	Cost
C. Travel Expenses			
C.1 Airfare (Long Beach/Houston)	$600/trip	12 trips	1,200
C.2 Subsistence (Onshore)	$75/day	6 days	450
C.3 Transportation	$40/day	22 days	880
C.4 Subsistence & transportation (Offshore - Paid by Conoco)	$150/day	60 days	9,000
		Subtotal	11,530
D. Services and Equipment Rental (Paid by Conoco)			
D.1 Drilling Crew	$3600/day	10 days	36,000
D.2 Drilling Engineer	$500/day	10 days	5,000
D.3 Equipment Rig	$1,200/day	12 days	14,400
D.4 Drilling and Sampling	$10/ft	600 ft	6000
D.5 Expendables (drilling mud, fuel,etc.)			8,400
D.6 Mobilization & Demobilization			6,500
D.7 Subsistance & Transportation (9)	$150/day	90 days	13,500
		Sub-Total	89,800
		Total	$137,180

TASK 8 - Planning and Performing Major Field Test

	Rate	Quantity	Cost
A. Planning phase			
A.1 Personnel (Ertec)			
A.1.1 Project Engineer	$60/hr	160 hr	$ 9,600
A.1.2 Staff Engineer	$55/hr	160 hr	8,800
A.1.3 Technician	$30/hr	120 hr	3,600
		Subtotal	22,000
A.2 Personnel (Ertec) (Monitor instrumentation between initial and major test)			
A.2.1 Project Engineer	$60/hr	36 hr	2,160
A.2.2 Technician	$30/hr	144 hr	4,320
		Subtotal	6,480
A.3 Travel Expenses (Monitor instrumentation between initial and major test)			
A.3.1 Airfare (New Orleans/ Houston)	$135/trip	15 trips	2,025
A.3.2 Subsistence	$40/day	15 days	600
A.3.3 Transportation (Offshore)	$400/trip	12 trips	4,800
		Subtotal	7,425

	Rate	Quantity	Cost
B. Testing Phase			
B.1.1 Project Engineer	$60/hr	450 hr	27,000
B.1.2 Staff Engineer	$55/hr	450 hr	24,750
B.1.3 Technician	$30/hr	300 hr	9,000
		Subtotal	60,750
B.2 Personnel			
B.2.1 Welder	$30/hr	30 hr	900
B.2.2 Operator	$40/hr	30 hr	1,200
		Subtotal	2,100
B.3 Travel Expenses			
B.3.1 Airfare (New Orleans/Houston)	$135/trip	6 trips	810
B.3.2 Subsistence (Onshore)	$75/day	24 days	1,800
B.3.3 Transportation	$40/day	39 days	1,560
B.3.4 Subsistence & transportation (Offshore-Paid by Conoco)	$150/day	80 days	12,000
		Subtotal	16,170
C. Mobilization and Demobilization of Equipment (Houston to Offshore Site)			7,000
		Subtotal	7,000
D. Miscellaneous Supplies and Materials			2,000
		Subtotal	2,000
		Total	$123,925

TASK 9 - Data Reduction and Analysis

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Project Engineer	$60/hr	500 hr	$30,000
A.2 Staff Engineer	$55/hr	320 hr	17,600
		Subtotal	47,600
B. Shipping (Air Courier) (Houston - Long Beach)			200
		Subtotal	200

	Rate	Quantity	Cost
C. Computer			15,000
		Subtotal	15,000
D. Miscellaneous Expenses and Supplies (Paper, Tapes, etc.)			3,000
		Subtotal	3,000
		Total	$65,800

TASK 10 - Theory Development

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Project Engineer	$60/hr	480 hr	$28,800
A.2 Staff Engineer	$55/hr	480 hr	26,400
		Subtotal	55,200
B. Travel Expenses			
B.1 Airfare (Long Beach/Houston)	$600/trip	3 trips	1,800
B.2 Subsistence (Onshore)	$75/day	10 days	750
B.3 Transportation	$40/day	10 days	400
		Subtotal	2,950
C. Computer			20,000
		Total	$78,150

TASK 11 - Report and Recommendations

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Project Engineer	$60/hr	480 hr	$28,800
A.2 Staff Engineer	$55/hr	960 hr	52,800
A.3 Draftsman	$30/hr	280 hr	8,400
A.4 Technical Typist	$23/hr	320 hr	7,360
		Subtotal	97,360
B. Reproduction/Printing			4,000
		Subtotal	4,000

	Rate	Quantity	Cost
C. Shipping (Air Courier) (Houston-Long Beach, and Norway)			400
		Subtotal	400
D. Miscellaneous Expense and Supplies (binders, photos, etc.)			2,000
		Subtotal	2,000
		Total	$103,760

TASK 12 - Project Administration and Review

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Principal	$95/hr	200 hr	$ 19,000
A.2 Associate Professional	$90/hr	180 hr	16,200
A.3 Project Professional	$60/hr	200 hr	12,000
A.4 Project Administrator	$40/hr	800 hr	32,000
		Subtotal	79,200
B. Sponsor Meetings (Project Staff)			20,000
		Subtotal	20,000
C. Travel Expenses			
C.1 Airfare			
C.1.1 Long Beach/Houston	$600/trip	5 trips	3,000
C.1.2 Oslo/Houston	$1,740/trip	5 trips	8,700
C.2 Subsistence (Onshore)	$100/day	20 days	2,000
C.3 Transportation	$40/day	20 days	800
		Subtotal	14,500
D. Miscellaneous			1,050
		Subtotal	1,050
		Total	$114,750

TASK 13 - Planning and Performing Follow-up Test

	Rate	Quantity	Cost
A. Planning Phase			
A.1 Personnel (Ertec)			
A.1.1 Project Engineer	$60/hr	80 hr	$ 4,800
A.1.2 Staff Engineer	$55/hr	80 hr	4,400
A.1.3 Technician	$30/hr	40 hr	1,200
		Subtotal	10,400
A.2 Personnel (Ertec) (Monitor instrumentations between test)			
A.2.1 Project Engineer	$60/hr	24 hr	1,440
A.2.2 Technician	$30/hr	48 hr	1,440
		Subtotal	2,880
A.3 Travel Expenses (Monitor instrumentations between test)			
A.3.1 Airfare (New Orleans/Houston)	$135/trip	5 trips	675
A.3.2 Subsistence (Onshore)	$40/day	5 days	200
A.3.3 Transportation (Offshore)	$400/day	5 days	2,000
		Subtotal	2,875
B. Testing Phase			
B.1 Personnel (Ertec)			
B.1.1 Project Engineer	$60/hr	450 hr	27,000
B.1.2 Staff Engineer	$55/hr	450 hr	24,750
B.1.3 Technician	$30/hr	300 hr	9,000
		Subtotal	60,750
B.2 Personnel (Paid by Conoco)			
B.2.1 Welder	$30/hr	30 hr	900
B.2.2 Operator	$40/hr	30 hr	1,200
		Subtotal	2,100
B.3 Travel Expense			
B.3.1 Airfare (New Orleans/Houston)	$135/trip	6 trips	810
B.3.2 Subsistence (Onshore)	$75/day	24 days	1,800
B.3.3 Transportation	$40/day	39 days	1,560
B.3.4 Subsistence & transportation (Offshore-Paid by Conoco)	$150/day	80 days	12,000
		Subtotal	16,170

	Rate	Quantity	Cost
C. Mobilization and Demobilization of Equipment			7,000
		Subtotal	7,000
D. Equipmental Rental (Paid by Conoco) (Rams, generators, etc.)			20,000
		Subtotal	20,000
E. Misc. Supplies and Materials			2,000
		Subtotal	2,000
		Total	$124,175

TASK 14 - Design Specifications for Tension Leg Platforms

	Rate	Quantity	Cost
A. Personnel (Ertec)			
A.1 Principal	$95/hr	120 hr	$ 11,400
A.2 Associate Professional	$90/hr	120 hr	10,800
A.3 Project Engineer	$65/hr	420 hr	27,300
A.4 Staff Engineer	$60/hr	520 hr	31,200
A.5 Draftsman	$35/hr	280 hr	9,800
A.6 Technical Typist	$28/hr	300 hr	8,400
		Subtotal	98,900
B. Travel Expenses			
B.1 Airfare			
B.1.1 Oslo/Houston	$1740/trip	6 trips	10,440
B.1.2 Long Beach/Houston	$600/trip	4 trips	2,400
B.2 Subsistence (Onshore)	$100/day	36 days	3,600
B.3 Transportation	$40/day	36 days	1,440
		Subtotal	17,880
C. Reproduction/Printing			5,000
		Subtotal	5,000
D. Shipping (Air Courier) (Houston-Long Beach, Norway)			1,000
		Subtotal	1,000
E. Sponsor Meetings			25,000
		Subtotal	25,000
F. Computer			15,000
		Subtotal	15,000
		Total	$162,780

APPENDIX II

REFERENCE SOURCE DOCUMENTS

REFERENCE SOURCE DOCUMENTS

1. Structural Drawings for Platform "A"
   West Delta Area, Block 58
   Drawing No. 00-07-1, Plan and Elevations for Tender Type Drilling Side Jacket and Decks
   Drawing No. C0-039-28, Elevations "A" and "D" and Deck Framing Plan After Conversion to Self-contained 16-Leg Platform
   Drawing No. C0-039-3A, Horizontal Bracing Plans
   Drawing No. (not shown), Original Equipment Layout for West Delta, Block 58 Platform "A"
   Sketch for Pile Make-up and Design Penetration

2. Platform completion report (Construction)
   Platform "A", West Delta, Block 58
   Well Data
   Pile Data
   Conductor Data
   Location Within West Delta Block
   General Construction Notes

3. Preliminary Geotechnical Information
   Boring 1, Block 137
   Green Canyon Area
   McClelland Engineers
   Job No. 0181-0181
   May 22, 1981

4. Soil and Foundation Investigation
   Block 48, Grand Isle Area
   "J" Structure
   McClelland Engineers, Inc.
   Report No. 72-251
   November 21, 1971

5. Soil and Foundation Investigation
   Block 63, East Cameron Area
   "B" Platform
   McClelland Engineers, Inc.
   Report No. 0276-048
   October 15, 1976

6. Well Site Survey of Viosca Knoll Blocks 864/908 Gulf of Mexico
   Intersea Research Corporation
   February 26, 1981

7. Deck Lifting Frame Drawings
   R-1, Deck Lifting Frame Plan, Sections and Details
   R-2, Deck Lifting Frame Sections and Details
   R-3, Lifting Frame Assembly Details of Types "A and "B" Lifting Eyes

8. Geotechnical Investigation
Boring 2, Block 58
West Delta Area
Gulf of Mexico
McClelland Engineers, Inc.
Report No. 0179-0003
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9. Foundation Investigation
Offshore Drilling Structure
West Delta Area, Block 58
McClelland Engineers, Inc.
Report No. 5692-5
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10. Ertec Memorandum
June 22, 1981
Meeting Notes on Operational
Aspects for offshore Pile Test

11. Engineering Geology and Geotechnical Considerations,
Upper continental Slope, Offshore Louisiana
McClelland Engineers, Inc.
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12. Advance Final Design Information
Boring 1, Block 137
Green Canyon, Gulf of Mexico
McClelland Engineers, Inc.
July 6, 1981

APPENDIX III

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REFERENCES

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APPENDIX IV

RESUMES

Ertec
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HUDSON MATLOCK
VICE PRESIDENT, RESEARCH AND DEVELOPMENT

EDUCATION

1947 The University of Texas, B.S., Civil Engineering

1950 The University of Texas, M.S., Civil Engineering

EXPERIENCE

1977-present **Ertec**
Vice President, Research and Development.

1948-1977 **The University of Texas, Department of Civil Engineering**
Instructor to Professor, Chairman, 1972-1976.

PROFESSIONAL SOCIETIES AND ACTIVITIES

Member, Program Committee, Offshore Technology Conference, representing the American Society of Civil Engineers, 1970-1972
Member of Panel on Certification of Offshore Structures, Marine Board, National Research Council, 1976
Member, Committee on Offshore Energy Technology, Marine Board, National Research Council 1977-1979
American Society of Civil Engineers
International Society for Soil Mechanics and Foundation Engineering
Society for Experimental Stress Analysis
Registered Professional Engineer, Texas
Texas Society of Professional Engineers
Tau Beta Pi
Chi Epsilon

SELECTED PUBLICATIONS AND PAPERS

"Non-Dimensional Solutions for Laterally Loaded Piles, with Soil Modulus Assumed Proportional to Depth," coauthor with Lymon C. Reese, Proceedings of the Eighth Texas Conference on Soil Mechanics and Foundation Engineering, Special Publication No. 29, Bureau of Engineering Research, The University of Texas, Austin, 1956, 41 pp.

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HUDSON MATLOCK
ADDENDUM TO RESUME

PUBLICATIONS AND PAPERS

"Correlations for Design of Laterally Loaded Piles in Soft Clay," 1970 Offshore Technology Conference, Houston, Preprints, Vol. 1, Paper 1204, pp. 577-593.

"Analytical Model for Ice-Structure Interaction," coauthor with William P. Dawkins and John J. Panak, Journal of the Engineering Mechanics Division, American Society of Civil Engineers, Vol. 97, EM4, Paper No. 8282, August 1971, pp. 1083-1092.

"A Nonlinear Analysis of a Soil Supported Frame," coauthor with Clifford O. Hays, 1972 Offshore Technology Conference, Houston, Preprints, Vol. 2, Paper No. 1699, pp. 737-752.

"A Slab Foundation Subjected to Complex Loadings," coauthor with John J. Panak and David W. Fowler, Journal of the American Concrete Institute, Proceedings, Vol. 69, No. 10, October 1972, pp. 630-636.

"A Discrete-Element Method for Transverse Vibrations of Beam-Columns Resting on Linearly Elastic or Inelastic Supports," coauthor with Jack H. C. Chan, 1973 Offshore Technology Conference, Houston, Preprints, Vol. 2, Paper No. 1841, pp. 205-218.

"Nonlinear Discrete Element Analysis of Frames," coauthor with Clifford O. Hays, Journal of the Structural Division, American Society of Civil Engineers, Vol. 99, ST10, Paper No. 10091, October 1973, pp. 2011-2030.

"Prediction of Axially-Loaded Pile Behavior Using Nonlinear Support," coauthor with Patrick L. Meyer and Darrel V. Holmquist, 1975 Offshore Technology Conference, Houston, Texas, Proceedings, Vol. 1, Paper No. 2186, pp. 375-388.

"Resistance-Displacement Relationships for Axially-Loaded Piles in Soft Clay," coauthor with Darrel V. Holmquist, 1976 Offshore Technology Conference, Houston, Texas, Proceedings, Vol. 2, Paper No. 2474, pp. 553-569.

Discussion of "Full-Scale Lateral Load Tests of Pile Groupings," by Jai B. Kim and Robert J. Brungraber (ASCE Proceedings Paper No. 11849), coauthor with Stephen H. C. Foo, Journal of the Geotechnical Division, Proceedings Paper No. 12585, American Society of Civil Engineers, Vol. GT 12, December 1976, pp. 1921-1922.

"Analysis of Driving of Foundation Piles," coauthor with Stephen H. C. Foo and Patrick L. Meyer, 1977 Offshore Technology Conference, Houston, Texas, Proceedings, Vol. 2, Paper No. 2842, pp. 281-290.

"A Computer Program for the Analysis of Beam-Columns Under Static Axial and Lateral Loads," coauthor with Dewaine Bogard, 1977 Offshore Technology Conference, Houston, Texas, Proceedings, Vol. 3, Paper No. 2953, pp. 581-588.

"Three-Dimensional Analysis of Framed Structures with Nonlinear Pile Foundations," coauthor with Larry M. Bryant, 1977 Offshore Technology Conference, Houston, Texas, Proceedings, Vol. 3, Paper No. 2955, pp. 599-606.

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1980–present
Ertec
Associate and Manager, Gulf States Region, with offices in Houston, Texas, responsible for serving those clients and projects located in the south-central United States.

1975–1980
Fugro Gulf, Inc., Consulting Engineers and Geologists
Initially employed as Project Engineer. Responsible for coordinating field work, laboratory test assignments, analysis of test results, evaluation of data and drafting of engineering reports. Involved primarily with land projects; however, as required, dealt with offshore soils projects such as pile design for offshore platforms.

In July 1977, progressed to Manager-Business Development responsible for marketing company services.

1974–1975
David L. Federer & Associates, Foundation and Soil Engineers
Chief Engineer and Manager of Operations in charge of office and field operations at branch office located in Indianapolis, Indiana, coordinating soils investigations and laboratory work and reviewing engineering reports.

1972–1974
Benton Engineering, Inc., Consulting Engineers in Applied Soil Mechanics
Progressed from Staff Engineer to Project Engineer. Responsible for soils investigations, laboratory test assignments, analysis of test results, and drafting of engineering reports prescribing recommendations for a variety of soil problems, including structural fill, bearing capacity, slope stability, pavement, retaining wall and pile design, and expansive soil treatment.

1963–1972
U.S. Navy
Lieutenant. After five years of duty as line officer, transferred to Civil Engineering Corps. Final duty station - Public Works Center, San Diego, as Assistant Operations Officer and Officer-in-Charge of Contracts, administering government contracts with total annual value of $2.5 million.

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1947 The University of Texas, B.S., Civil Engineering

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1948-1977 The University of Texas, Department of Civil Engineering
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Member, Program Committee, Offshore Technology Conference, representing the American Society of Civil Engineers, 1970-1972
Member of Panel on Certification of Offshore Structures, Marine Board, National Research Council, 1976
Member, Committee on Offshore Energy Technology, Marine Board, National Research Council 1977-1979
American Society of Civil Engineers
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"Three-Dimensional Analysis of Framed Structures with Nonlinear Pile Foundations," coauthor with Larry M. Bryant, 1977 Offshore Technology Conference, Houston, Texas, Proceedings, Vol. 3, Paper No. 2955, pp. 599-606.

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"Simulation of Lateral Pile Behavior Under Earthquake Motion," coauthor with Stephen H. C. Foo and Larry M. Bryant, Proceedings, Specialty Conference on Earthquake Engineering and Soil Dynamics, Geotechnical Division, American Society of Civil Engineers, Pasadena, California, 1978.

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"Evaluation of Concepts for Guyed Tower Foundations," coauthor with I. P. Lam and L. Cheang, Paper No. 4147, Proceedings, Thirteenth Annual Offshore Technology Conference, Houston, Texas, May 1981.

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EDUCATION

1963	U.S. Naval Academy, Annapolis, Maryland, B.S., General Engineering
1969	Georgia Institute of Technology, Atlanta, Georgia, B.S., Civil Engineering
1970	Georgia Institute of Technology, Atlanta, Georgia, M.S., Civil Engineering

EXPERIENCE

1980–present

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Associate and Manager, Gulf States Region, with offices in Houston, Texas, responsible for serving those clients and projects located in the south-central United States.

1975–1980

Fugro Gulf, Inc., Consulting Engineers and Geologists

Initially employed as Project Engineer. Responsible for coordinating field work, laboratory test assignments, analysis of test results, evaluation of data and drafting of engineering reports. Involved primarily with land projects; however, as required, dealt with offshore soils projects such as pile design for offshore platforms.

In July 1977, progressed to Manager-Business Development responsible for marketing company services.

1974–1975

David L. Federer & Associates, Foundation and Soil Engineers

Chief Engineer and Manager of Operations in charge of office and field operations at branch office located in Indianapolis, Indiana, coordinating soils investigations and laboratory work and reviewing engineering reports.

1972–1974

Benton Engineering, Inc., Consulting Engineers in Applied Soil Mechanics

Progressed from Staff Engineer to Project Engineer. Responsible for soils investigations, laboratory test assignments, analysis of test results, and drafting of engineering reports prescribing recommendations for a variety of soil problems, including structural fill, bearing capacity, slope stability, pavement, retaining wall and pile design, and expansive soil treatment.

1963–1972

U.S. Navy

Lieutenant. After five years of duty as line officer, transferred to Civil Engineering Corps. Final duty station - Public Works Center, San Diego, as Assistant Operations Officer and Officer-in-Charge of Contracts, administering government contracts with total annual value of $2.5 million.

PROFESSIONAL SOCIETIES AND ACTIVITIES

Registered Professional Engineer - Texas, California, Louisiana, and Indiana
American Society of Civil Engineers
American Society of Military Engineers
The Society for Marketing Professional Services

PUBLICATIONS AND PAPERS

"A Study of the Reliability of the Multi-Stage Triaxial Test," unpublished paper, Master's Degree Program, Georgia Institute of Technology, 1969.

JEAN M. E. AUDIBERT
ASSOCIATE AND MANAGER OF ENGINEERING

EDUCATION

1968 Ecole Nationale Supérieure d'Arts et Métiers, Paris, France; Diplôme d'Ingénieur, Engineering

1972 Duke University, Durham, N.C.; Ph.D., Civil Engineering

EXPERIENCE

1981-present Ertec Western, Inc.
Manager of Engineering and Associate. Responsible for overall supervision and coordination of engineers and scientists and for technical direction and management of projects including site investigations, soil characterization, foundation design, pipeline routing and engineering, and research and development studies, both onshore and offshore.

1977-1981 Woodward-Clyde Consultants; Houston, Texas.
Progressed from Project Engineer (1977-1978) to Senior Project Engineer (1979-1980) to Manager of Engineering of Offshore Services Division and Associate of the firm (1981).

While at Woodward-Clyde, developed extensive experience in platform foundation and pipeline projects, both for site specific designs and general State-of-the-Art technology development. Directed or worked in a major capacity in more than 30 pile-supported and jack-up platform projects located in the Gulf of Mexico, off the U. S. East and West Coasts, Lower Cook Inlet and Norton Sound, Alaska, off the coast of Chile and in the Gulf of Cadiz, Spain. Also directed the foundation design and analyses for the feasibility study of a guyed tower as a production platform in 1,000 feet of water for the Gulf of Mexico and directed the site investigation and foundation engineering for deep water template structures.

Served as the main investigator in studies of the State-of-Practice and State-of-the-Art for the design and analysis of foundations for offshore pile-supported and gravity structures. Participated in the direction of a technology development project to create new analyses procedures for pile-supported structures subjected to intense wave loadings and strong earthquake ground motions. Also directed State-of-the-Art reviews on Pile Group Foundations and on Pile Foundations in Calcareous Soils.

Since 1975, performed research in soil-pipeline interaction, and has applied the results to the design of pipelines subjected to seafloor instabilities. In 1979, was awarded the Collingwood Prize for this research by the American Society of Civil Engineers. Directed the geotechnical evaluation of the performance and behavior of 13-ft diameter offshore concrete intake conduits laid in the Persian Gulf and of an 11-ft diameter concrete ocean outfall crossing the Barrier Islands, in Nasaugh County, L.I. Also directed projects associated with the routing and design of offshore pipelines laid across mudslide areas off the Mississippi Delta.

1976 **Geotechnical Engineers, Inc. Winchester, Massachusetts.**
Assistant Project Manager. Participated in geotechnical studies associated with the Pilgrim II Nuclear Power Station, Plymouth, Massachusetts, the design of a tank farm foundation for the Mystic Oilfired Power Station, Everett, Massachusetts and the foundation studies for, and the design of, the Constance M. Fiske Dam, Framingham, Massachusetts.

1974-1975 **Stone & Webster Engineering Corporation, Boston, Massachusetts**
Lead Geotechnical Engineer. While with S&W gained extensive experience in onshore geotechnical engineering was in charge of all geotechnical aspects associated with nuclear power plant projects (North Anna Power Station, Mineral, Virginia; Beaver Valley Power Station, Shippingport, Pennsylvania; fossil fired power plants (proposed Pointe Coupee Power Station, Baton Rouge, Louisiana), refineries and tank farms (Paulsboro Refinery, Paulsboro, New Jersey). Participated in the performance inspection of the North Anna Main Dam, Louisa County, Virginia. Also served as a member of an advisory team to the Netherlands government on the foundation design and analysis for offshore concrete structures used in the closure of the Oosterscheldt.

1972-1973 **Universite Laval**, Quebec, Canada.
Visiting Research Associate at Laval University. Taught an introductory course on the finite element method, pursued studies on the wave equation method for pile driving, participated in research on embankments built on sensitive Canadian clays, supervised the construction of plane strain devices for the testing of clays and participated in various aspects of research on testing and sampling of quick clays.

1968-1972 **Duke University**
As a Research Associate, was involved in research studies on the behavior of sand under plane strain conditions, the evaluation of constitutive relationships to be used in finite element studies and the teaching of undergraduate soil laboratory courses.

PROFESSIONAL SOCIETIES AND ACTIVITIES

Professional Engineers: Massachusetts and Texas
Societe des Ingenieurs Arts et Metiers
International Society of Soil Mechanics and Foundation Engineering
American Society of Civil Engineers
Engineering Science Society
Chi Epsilon
1980 ASCE James Croes Medal
1979 ASCE Collingwood Prize
1978 Woodward-Clyde Consultants' Young Professional Award
1968-69 Fullwright Fellow

Publications

Over 25 publications in the areas of geotechnical engineering, marine foundations design, dynamic reponse of site foundations and pipeline-soil interaction.

THOMAS K. HAMILTON
PROJECT ENGINEER

EDUCATION

1970 Texas A & M University, College Station, Texas, B.S., Civil Engineering

1977 Texas A & M University, College Station, Texas, M.S., Civil Engineering

EXPERIENCE

1981–present

Ertec

Project Engineer. Responsible for field investigations, laboratory studies, and geotechnical engineering. Other duties include marketing, program development, and participation in special research and development and sponsored projects.

1977–1981

Fugro Gulf, Inc., Consulting Engineers and Geologists

Staff Engineer to Project Engineer. Initially assigned to supervise geotechnical field investigations for onshore and offshore projects; responsibilities included formulation of laboratory testing programs and performance of engineering analyses to develop foundation design parameters. On select projects, employed advanced in-situ testing tools. Other duties included operational management of cone penetrometer (CPT) equipment and interpretation of CPT test results. Later assigned to Technical Services Group responsible for special geotechnical projects. Major assignment in this group was Project Manager for all phases of an instrumented large-scale pile load test for a major oil company. Requirements included site selection and validation, design of test pile and test system, fabrication and installation of test pile, performance of three-phase test program, data reduction and analysis, and report preparation.

1975–1977

Texas A & M University, College Station, Texas

Research Assistant. Assigned to project for USGS to examine self-burial capabilities of offshore pipelines. Responsibilities included offshore surveying and data interpretation, laboratory model testing and analysis, computer simulations, and report writing. Also performed independent consulting including contract laboratory testing and engineering analysis for special projects; e.g., sheet-pile bulkhead failure.

1970–1975

United States Air Force

Captain. Served as jet transport pilot in global operations. Responsibilities included command of aircraft and crew. Also served as instructor pilot and flight examiner.

PROFESSIONAL SOCIETIES AND ACTIVITIES

American Society of Civil Engineers, Associate Member
Registered Professional Engineer in Texas, No. 49212

SHORT COURSES AND SYMPOSIUMS

Offshore Geologic Hazards Short Course, Houston, 1978

Symposium on Site Exploration in Soft Ground Using In-Situ Techniques, Washington, D.C., 1978

Workshop on Pore Pressures in Submarine Sediments, Miami, 1979

PUBLICATIONS AND PAPERS

"The Validity of Analytical Methods for Predicting Self-Burial of Offshore Pipelines," unpublished Master's Thesis, Texas A & M University, August 1977.

Ertec
The Earth Technology Corporation

IGNATIUS P. LAM
PROJECT ENGINEER

EDUCATION

1976 California Institute of Technology, Pasadena, California, Engineering Degree in Civil Engineering.

1974 California Institute of Technology, M.S. in Civil Engineering.

1973 Ohio State University, Columbus, Ohio, B.S., Civil Engineering.

EXPERIENCE

1976–present **Ertec**
Project Engineer for Research and Development. Provides technical consultation on analytical and computation aspects of engineering. Updates and develops new computer programs for in-house usage. Organizes in-house research activities including professional publications. Supervises small teams of engineering staff in developing new methodologies on special analytical jobs. Actively involved in areas of offshore structures, soil-pile interactions, and constitutive modeling of soils.

Staff Engineer for Soil Dynamics Group (1976-79). Performed analytical and computer analyses as well as report writing. Participated in setting up and maintenance of in-house computer library. Assisted and provided consultation on computer analyses to other engineering groups. Areas of study included: slope stability; ground-water seepage; settlements; computer graphics; soil dynamics aspects such as earthquake site response, soil-structure interactions, and offshore pile responses; and earthquake engineering problems such as response spectra and artificial strong ground motion generations.

1974–1976 **California Institute of Technology**
Research Assistant involved in testing of sampler and footpad of Viking project for the Jet Propulsion Laboratory, Pasadena, California.

PROFESSIONAL SOCIETIES AND ACTIVITIES

Registered Professional Engineer, California, 1979
American Society of Civil Engineers, Member
Seismological Society of America, Member
International Society for Soil Mechanics and Foundation Engineering

PUBLICATIONS AND PAPERS

"Stress-Strain Laws for Cyclic Loading: From Theory to Practice," Proceedings, Symposium on Implementation of Computer Procedures and Stress-Strain Laws in Geotechnical Engineering at Chicago, Illinois, August 1981, coauthor with G. R. Martin.

"Evaluation of Concepts for Guyed Tower Foundations," Proceedings, 1981 Offshore Technology Conference, Houston, Texas, Vol. 4, Paper No. 4147, pp. 319-330, coauthor with H. Matlock and L. C. C. Cheang.

"Soil-Pile Interaction in Liquefiable Cohesionless Soils During Earthquake Loading," Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, Vol. 2, April 1981, coauthor with H. Matlock, G. R. Martin, and C. F. Tsai.

"A Parametric Study of an Effective Stress Liquefaction Model," Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, Vol. 2, April 1981, coauthor with G. R. Martin, S. L. McCaskie, and C. F. Tsai.

"Design of Pile Foundations," Proceedings, International Symposium on Marine Soil Mechanics, Mexico City, February 1980, coauthor with H. Matlock.

"Pore Pressure Dissipation During Offshore Cyclic Loading," Journal of the Geotechnical Engineering Division, ASCE, September 1980, coauthor with G. R. Martin and C. F. Tsai.

"Seismic Response of Cohesive Marine Soils," Journal of the Geotechnical Engineering Division, ASCE, September 1980, coauthor with G. R. Martin and C. F. Tsai.

"Seismic Response of Soft Offshore Soils - A Parametric Study," Proceedings, Second U.S. National Conference on Earthquake Engineering at Stanford, California, August 1979, coauthor with G. R. Martin, C. F. Tsai, and D. G. Anderson.

"Seismic Response of Cohesive Marine Soils," Symposium on Soil Dynamics in the Marine Environment, ASCE National Convention, Boston, Mass., April 1979, coauthor with C. F. Tsai and G. R. Martin.

"Dissipation of Pore Pressures During Offshore Cyclic Loading," Symposium on Soil Dynamics in the Marine Environment, ASCE National Convention, Boston, Mass., April 1979, coauthor with G. R. Martin and C. F. Tsai.

"SPASM 8 - A Dynamic Beam Column Program for Seismic Pile Analysis with Support Motions," Documentation Report prepared for Chevron Oil Field Research Company, La Habra, California, January 1979, coauthor with H. Matlock, S. H. C. Foo, and C. F. Tsai.

"Determination of Site Dependent Spectra Using Non-Linear Analysis," Proceedings, Second International Conference on Microzonation, San Francisco, California, November 1978, coauthor with C. F. Tsai and G. R. Martin.

"Edge Function Method Applied to Plates on Spring Foundations," Engineer's Thesis, California Institute of Technology, 1976.

IGNATIUS P. LAM
PROJECT ENGINEER

EDUCATION

1976 California Institute of Technology, Pasadena, California, Engineering Degree in Civil Engineering.

1974 California Institute of Technology, M.S. in Civil Engineering.

1973 Ohio State University, Columbus, Ohio, B.S., Civil Engineering.

EXPERIENCE

1976–present **Ertec**
Project Engineer for Research and Development. Provides technical consultation on analytical and computation aspects of engineering. Updates and develops new computer programs for in-house usage. Organizes in-house research activities including professional publications. Supervises small teams of engineering staff in developing new methodologies on special analytical jobs. Actively involved in areas of offshore structures, soil-pile interactions, and constitutive modeling of soils.

Staff Engineer for Soil Dynamics Group (1976-79). Performed analytical and computer analyses as well as report writing. Participated in setting up and maintenance of in-house computer library. Assisted and provided consultation on computer analyses to other engineering groups. Areas of study included: slope stability; ground-water seepage; settlements; computer graphics; soil dynamics aspects such as earthquake site response, soil-structure interactions, and offshore pile responses; and earthquake engineering problems such as response spectra and artificial strong ground motion generations.

1974–1976 **California Institute of Technology**
Research Assistant involved in testing of sampler and footpad of Viking project for the Jet Propulsion Laboratory, Pasadena, California.

PROFESSIONAL SOCIETIES AND ACTIVITIES

Registered Professional Engineer, California, 1979
American Society of Civil Engineers, Member
Seismological Society of America, Member
International Society for Soil Mechanics and Foundation Engineering

PUBLICATIONS AND PAPERS

"Stress-Strain Laws for Cyclic Loading: From Theory to Practice," Proceedings, Symposium on Implementation of Computer Procedures and Stress-Strain Laws in Geotechnical Engineering at Chicago, Illinois, August 1981, coauthor with G. R. Martin.

"Evaluation of Concepts for Guyed Tower Foundations," Proceedings, 1981 Offshore Technology Conference, Houston, Texas, Vol. 4, Paper No. 4147, pp. 319-330, coauthor with H. Matlock and L. C. C. Cheang.

"Soil-Pile Interaction in Liquefiable Cohesionless Soils During Earthquake Loading," Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, Vol. 2, April 1981, coauthor with H. Matlock, G. R. Martin, and C. F. Tsai.

"A Parametric Study of an Effective Stress Liquefaction Model," Proceedings, International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, Vol. 2, April 1981, coauthor with G. R. Martin, S. L. McCaskie, and C. F. Tsai.

"Design of Pile Foundations," Proceedings, International Symposium on Marine Soil Mechanics, Mexico City, February 1980, coauthor with H. Matlock.

"Pore Pressure Dissipation During Offshore Cyclic Loading," Journal of the Geotechnical Engineering Division, ASCE, September 1980, coauthor with G. R. Martin and C. F. Tsai.

"Seismic Response of Cohesive Marine Soils," Journal of the Geotechnical Engineering Division, ASCE, September 1980, coauthor with G. R. Martin and C. F. Tsai.

"Seismic Response of Soft Offshore Soils - A Parametric Study," Proceedings, Second U.S. National Conference on Earthquake Engineering at Stanford, California, August 1979, coauthor with G. R. Martin, C. F. Tsai, and D. G. Anderson.

"Seismic Response of Cohesive Marine Soils," Symposium on Soil Dynamics in the Marine Environment, ASCE National Convention, Boston, Mass., April 1979, coauthor with C. F. Tsai and G. R. Martin.

"Dissipation of Pore Pressures During Offshore Cyclic Loading," Symposium on Soil Dynamics in the Marine Environment, ASCE National Convention, Boston, Mass., April 1979, coauthor with G. R. Martin and C. F. Tsai.

"SPASM 8 - A Dynamic Beam Column Program for Seismic Pile Analysis with Support Motions," Documentation Report prepared for Chevron Oil Field Research Company, La Habra, California, January 1979, coauthor with H. Matlock, S. H. C. Foo, and C. F. Tsai.

"Determination of Site Dependent Spectra Using Non-Linear Analysis," Proceedings, Second International Conference on Microzonation, San Francisco, California, November 1978, coauthor with C. F. Tsai and G. R. Martin.

"Edge Function Method Applied to Plates on Spring Foundations," Engineer's Thesis, California Institute of Technology, 1976.

G. LEON HOLLOWAY
STAFF ENGINEER

EDUCATION

1977 Texas A & M University, College Station, Texas, B.S., Civil Engineering

1978 Texas A & M University, College Station, Texas, M.S., Civil Engineering

EXPERIENCE

1981–present **Ertec**
Staff Engineer. Responsibilities include field investigations, laboratory studies, engineering analysis, and report preparation. Other duties include coordination of activities for operational projects, proposals preparation, and marketing.

1978–1981 **Fugro Gulf, Inc.**
Staff Engineer to Senior Staff Engineer. Responsible for evaluation and reporting of geotechnical aspects for the design of offshore structures. Duties included the supervision of site investigations worldwide, planning laboratory test programs, engineering analyses and design, data analysis pertaining to large-scale pile load tests, report and proposal preparation, and training new engineers in offshore drilling techniques and operations.

Coordinated field geotechnical engineering operations and investigations for work in both the Bay of Campeche and the West Coast of Africa. Supervised pile driving operations for a major tanker terminal in the Red Sea off Saudi Arabia and a state-of-the-art investigation in foundation conditions along the entire Venezuelan coastline.

Designed foundations for offshore structures in the Gulf of Mexico, Red Sea, Baltimore Canyon area, Venezuela, Brazilian and West African coasts.

Recently supervised the planning, construction, and testing of a large-scale pile test near Iwaki, Japan.

Responsible for site investigation, evaluation, and reporting of mobile drilling rig leg penetrations in the Gulf of Mexico, Bay of Campeche, and Venezuela.

1977–1978 **Texas Transportation Institute**
Research Assistant. Involved in experimental and analytical studies to develop a new design criteria for laterally loaded drilled shafts in cohesive soils.

1977–1978 **Texas A & M University, Department of Civil Engineering**
Short Course Instructor. Served as an individual and group instructor for the use and application of the wave equation (pile driving).

1976–1977 **American Society of Civil Engineers**
Student Worker. Worked directly with the Executive Director for the Texas Section, ASCE, in coordinating the printing and mailing of the TEXAS CIVIL ENGINEER magazine.

EXPERIENCE (Cont.)

1976 Texas A & M University, Department of Civil Engineering

Student Research Assistant. Responsible for data collection and interpretation of problems dealing with drawdown of wells along the Texas Gulf Coast. Example problems and illustrative pictorials were also made for short course which was taught throughout Texas.

PROFESSIONAL SOCIETIES AND ACTIVITIES

American Society of Civil Engineers
Chi Epsilion - National Civil Engineering Honorary Fraternity
Tau Beta Pi - National Engineering Honorary Fraternity
Phi Kappa Phi - National Scholastic Honor Society
Phi Eta Sigma - Freshman Engineering Honor Fraternity

PUBLICATIONS AND PAPERS

"Design of Drilled Shafts in Clay for Supporting Precast Panel Retaining Walls," with H. M. Coyle, R. E. Burtoskewitz, and W. G. Sarver, Research Report No. 211-2, Texas Transportation Institute, Texas A & M University, October 1978.

J. DEWAINE BOGARD
PROJECT ENGINEER

EDUCATION

1970 The University of Texas at Austin, B.S. in Civil Engineering

1979 The University of Texas at Austin, M.S. in Civil Engineering

EXPERIENCE

1981–present **Ertec**
Project Engineer. Responsible for field investigations, laboratory studies, and geotechnical engineering. Duties include marketing, business development, and Research and Development and special projects.

1979–1981 **Fugro Gulf, Inc., Consulting Engineers and Geologists**
Project Engineer. Responsibilities included the planning, design, instrumentation, and fabrication of two large-scale axial test piles; the performance of the load tests; collection and analysis of data; and the preparation of reports. Other duties included the consultation with staff engineers on nonstandard pile foundation design problems, including the analysis of group pile test data and pile drivability studies.

1975–1979 **The University of Texas at Austin**
Research Assistant. Responsibilities included the performance of laboratory studies of axially-loaded pile models, development of instrumentation for field studies of expansive clays, and the development of computer solutions for axially and laterally loaded beam columns. Duties included the planning, design, and instrumentation of pile models to measure shear transfer, pore pressure, and displacement; the development of instrumentation to measure negative pore pressures in partially saturated clay soils; the collection and analysis of data from laboratory and field tests; and the preparation of reports and technical papers.

1970–1975 **Hudson Matlock, Consulting Engineer**
Research Engineer. Responsibilities included the planning, design, and fabrication of laboratory models for studies of cyclic load behavior in a confined soft clay; computer studies of the dynamic lateral behavior of piles during pile driving; and the design of instrumentation for installation in existing foundation piles. Duties included the instrumentation and fabrication of laboratory models, the collection of data during static and cyclic load tests, the analysis of data, and report preparation.

1967–1970 **The University of Texas at Austin**
Technical Staff Assistant. Responsibilities included the maintenance of laboratory equipment and instruments used in the strength of materials and experimental mechanics laboratory courses; the preparation of instrumented and noninstrumented specimens for laboratory experiments; and assistance in teaching a laboratory course in experimental mechanics.

EXPERIENCE (Cont.)

1966- 1967 Matlock, Hudson, Dawkins, and Panak, Consulting Engineers
Engineering Technician. Responsibilities included participation in field tests of the lateral-load behavior of piles and pile groups and laboratory studies of the lateral-load behavior of skirt-plates in soft clay soils. Duties involved instrumentation and calibration of models, the performance of static and cyclic tests, and the collection and reduction of data.

PUBLICATIONS AND PAPERS

"Lateral Load Behavior of Piles and Pile Groups Under Surcharge," with H. Matlock, unpublished report to Chevron Oil Field Research Company, Austin, Texas, 1973.

"Pile-Model Scale Effects and Cyclic Vane Shear Tests," with H. Matlock, an unpublished report to Chevron Oil Field Research Company, Austin, Texas, 1975.

"Observation of an Expansive Clay Under Controlled Conditions," with J. P. Stevens, P. N. Brotcke, and H. Matlock, Research Report 118-9F, Center for Highway Research, The University of Texas at Austin, 1976.

"A Computer Program for the Analysis of Beam-Columns Under Static Axial and Lateral Loads," 1977 Offshore Technology Conference, Houston, Paper No. 2953.

"A Model Study of Axially Loaded Pile Segments, Including Pore Pressure Measurements," with H. Matlock, a report to the American Petroleum Institute, Austin, Texas, 1979.

"Field Tests of the Lateral-Load Behavior of Pile Groups in Soft Clay," with H. Matlock, W. B. Ingram, and A. E. Kelley, 1980 Offshore Technology Conference, Houston, Texas, Paper No. 3871.

RONALD LEE BOGGESS
RESEARCH ENGINEER

EDUCATION

1972 Texas A & M University, College Station, Texas, B.S. in Mechanical Engineering

EXPERIENCE

1981–present **Ertec**
Research Engineer. Responsibilities include technical leadership of Houston-based Research and Development group in establishing and maintaining state-of-the-art instrumentation and equipment capabilities and providing systematic monitoring of data quality; and research search design and development of specialized tools and equipment. Other duties include assisting with marketing efforts, proposal preparation, and technical presentations.

1978–1981 **Fugro Gulf, Inc., Consulting Engineers and Geologists**
Research Engineer. Responsible for electromechanical direction and technical planning for various research and development projects as well as commercial projects.

1972–1978 **Texas A & M University, Civil Engineering Department, and Texas Transportation Institute (TTI)**
Engineering Research Associate (1976–78). Responsibilities included all phases of research from proposal to final report. Research included: Pavement evaluation - the development of nonstandard methods for nondestructive testing. Storm-related mudslides - instrumenting a region of the Mississippi Delta with piezometers to monitor pore pressure during storms. Fatigue and thermal cracking of asphaltic concrete - the construction of a machine that simulates the cyclic thermal stress condition in flexible pavement overlays.

Electronic Technician II (1972-1976). Half-time Civil Engineering Department duties consisted of setting up new soil test equipment for graduate as well as undergraduate soils lab course. Equipment included direct shear, consolidation and triaxial compression, Atterberg limits, vane shear, permeability, flow net and capillarity. Other duties included assisting professors in teaching the lab portion of the course as well as planning experiment schedules, maintaining equipment, ordering expendable and capital equipment, and ensuring generally smooth operation of the laboratory facility for both classroom and research use.

Half-time TTI pavement design division duties consisted of experimental design, instrumentation, and computer analysis of experimental data. Experiments consisted of dynamic modulus measurement of base course material and study of methods available to detect and objectively record pavement cracking while traveling at or near highway speeds. Instruments developed included a noninterconnected electromagnetic displacement transducer with an accuracy better than ± 0.0005 inch at a spacing of 2 inches.

EXPERIENCE (Cont.)

1969–1972 **Texas A & M University, Terramechanics Laboratory**
Electronic Technician. Responsible for instrumentation at the Terramechanics Lab. Also responsible for gathering data on tests performed, including soil testing to ensure target consistency (i.e., density, moisture content, shear strength). Work dealt with penetration of soil with instrumented projectiles. Data acquisition systems were electronics, still photography, and high speed movies.

1967–1969 **J. W. Hall, Consulting Engineers**
Designer-Draftsman. Designed air-conditioning and plumbing.

1966 **Watkins-Johnson**
Mechanical Designer. Designed mechanical packages for prototype systems. Hired originally as an electronic technician, but the responsibility of the division was shifted to mechanical design. Designed mechanical packages for prototype microwave systems.

PROFESSIONAL SOCIETIES AND ACTIVITIES

American Society of Mechanical Engineers
Texas Professional Photographers Association
Texas Society of Professional Engineers
Registered Professional Engineer, Texas

PUBLICATIONS AND PAPERS

"Characteristics of Expansive Clay and Roughness of Pavements," coauthor with R. L. Lytton and J. W. Spotts, presented at the Transportation Research Board, 54th Annual Meeting, 1975.

"The Duomorph - A Complex Modulus Transducer," coauthor with J. Noel and Dr. Saylak, presented to the Instrument Society of America, Albuquerque, New Mexico, 1978.

Ertec
The Earth Technology Corporation

LINO CHOI-CHI CHEANG
STAFF ENGINEER

EDUCATION

1978 The University of Texas, Austin, Texas, B.S., Civil Engineering

1979 The University of Texas, Austin, Texas, M.S., Civil Engineering

EXPERIENCE

1981–present **Ertec**
Staff Engineer. Duties include computer development and application on soil-pile interaction problems and organization of in-house research activities.

1979–1981 **Fugro Gulf, Inc., Consulting Engineers and Geologists**, Houston, Texas
Staff Engineer. Responsibilities included supervision of offshore site investigation from drilling vessel and jack-up rig. Other duties included driveability study and nonstandard foundation design problems such as pile group, guyed tower platform, and jack-up rig leg penetration.

1977–1979 **The University of Texas, Civil Engineering Research**, Austin, Texas
Research Assistant. Responsibilities included the design, fabrication, and instrumentation of model test piles for pile group study. Also computer application to develop soil models to analyze dynamic and cyclic response of pile foundations.

PROFESSIONAL SOCIETIES AND ACTIVITIES

American Society of Civil Engineers

PUBLICATIONS AND PAPERS

"Evaluation of Concepts for Guyed Tower Foundations," with H. Matlock and I. P. Lam, *Proceedings*, Offshore Technology Conference, Houston, Texas, May 1981, OTC 4147.

"Example of Soil-Pile Coupling Under Seismic Loading," with H. Matlock and S. H. C. Foo, *Proceedings*, Offshore Technology Conference, Houston, Texas, May 1981, OTC 3310.