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PENETRATION OF FREE-FALLING OBJECTS
INTO DEEP-SEA SEDIMENTS

by

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Penetration of Free-Falling Objects
Into Deep-sea Sediments

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I. INTRODUCTION

A. PURPOSE OF INVESTIGATION

Various types of objects will be lost which fall through the water column and impact on the ocean bottom as man continues to move more freely on the surface and through the oceans. Such objects can range from small and very expensive instrument packages to fleet submarines. It is important to know exactly how far they have penetrated into the bottom during search operations since complete penetration below the surface of the sediments may require a search by other than visual or acoustic methods.

The velocity and free fall attitude of an object that has been located and photographed on the bottom may be estimated from the penetration distance if the physical and mechanical properties of the sediment are known. The impact velocity and attitude could be potentially useful in reconstructing the event and also for determining the amount of energy transferred to the sediment and radiated from the point of impact.

The recovery method and force necessary to break a lost object free of the bottom during a salvage operation will depend to some degree upon how far the object has penetrated into the bottom sediments.

The fields of soil mechanics and foundation engineering have been concerned mainly with static situations including the prediction of the very slow settlement that a structure undergoes as it is erected. The weight is thus applied to the soil in progressively greater amounts. Deep ocean bottom installations may be preassembled, floated to their site, and allowed to free-fall to a position on the bottom. The free-fall method of implantment is potentially useful for ocean structures since it decouples the structure from the influence of surface motion and tethering lines. Prediction of an accurate initial penetration depth upon contact, therefore, becomes a critical design factor.

An indication of the sediment's mechanical and physical properties can be obtained by observing probes of known physical configuration as they penetrate the bottom since penetration depth depends on sediment strength.

B. SCOPE OF INVESTIGATION

The purpose of this investigation was to develop a method to predict the penetration depth of objects dropped into a simulated deep-sea sediment. Experimental data was available to test and verify the analytical method that was developed. The full scale experiment employed large, heavy objects and it was necessary to let the objects fall through air to allow them to reach a velocity at impact equal to the highest expected terminal velocity of free-fall through sea water for very dense objects. In addition, dropping the objects in air eliminated free fall stability problems as the impact attitude was effectively controlled and the effects of angular momentum on the impact were minimized. The sediment used in the experiment was of re-worked continental origin characterized by low shear strength and high water content typical of deep-sea and pelagic deposits.

The initial boundaries and limitations that were imposed on the study were designed to simplify the complexities of the problem to permit the mechanics to be understood, and to retain the ultimate objective of practical application of the method at sea. The conditions are summarized below.

1. The impact velocity at the top of the sediment column was in the range from zero to 20 feet-per-second. Zero velocity at the top of the sediment column involved releasing the object at the sediment surface and its acceleration through the soft upper layers before coming to rest. The upper limit of 20 feet per second was believed to be a realistic terminal velocity in sea water for most objects.

2. Free fall was assumed, or gravity was the only downward force acting on the object.

3. The object shapes were limited to simple geometries with established hydrodynamic properties from theoretical calculations or empirical tests. Configurations designed to penetrate, such as a coring tool with a long barrel and large mass on one end were not considered.

4. The sediments were taken to be cohesive, with no angle of internal friction. They were also assumed to be low strength, less than four pounds per square inch, and to have high water contents typical of marine sediments.

5. The study did not include the effects of any settlement after initial penetration.

6. The minimum factors necessary to predict penetration depth were considered to be: the impact velocity; geometry and mass of the object; and the shear strength profile and density of the sediment.

C. HISTORICAL BACKGROUND

The loss of the U.S.S. THRESHER and the problems involved in the location of the hull which had penetrated deeply into very soft sediments served to emphasize the fact that little was known about physical phenomena associated with deep-sea sediments and the mechanism of penetration. This disaster prompted the original full scale experiments carried out by the Naval Civil Engineering Laboratory and used to verify the method developed in this study. The THRESHER disaster also pointed out the difficulties involved in sampling sediments at deep ocean water depths and using only a few samples tested in a laboratory to predict as precisely as possible the sediment's dynamic behavior in-situ. This study is only a step toward understanding all the variables and their relationship to each other.

The following is a review of the state-of-knowledge before the investigation and the technical background. The variables involved and the development of other penetration equations are discussed.

1. State-of-Knowledge

The problem of earth penetration by projectiles is a classical one of terminal ballistics and an immense amount of both theoretical and experimental literature exists on the subject. Empirical attempts to determine the thickness of earth embankments needed to protect soldiers were made as early as 1742 [Young, 1969]. In recent years the free-fall penetration problem has been studied to provide protection against artillery, to estimate forces acting on a structure during earth impact such as would be required by orbiting nuclear power plants that would have to remain intact during re-entry and landing on earth, and to determine physical soil properties remotely by an acceleration-time record transmitted from a projectile penetrometer. The studies have involved the fields of engineering, mechanics, fluid mechanics, geology, soil mechanics, aerodynamics, wave propagation, as well as other disciplines. They were concerned with the problem of a body falling with high velocity through air and impacting on hard continental soils. Bibliographies of prior investigations are available [Schmid, 1969 and Young, 1969]. Dynamic studies in the field of soil mechanics on land are still in their infancy. Whether they can be extended to structures and the penetration problems in the deep oceans probably will remain a question for some time into the future for four basic reasons.

First, the velocity of an object free-falling through water will be much less than the velocity of a similar object in air. At very low velocities, from zero to 10 feet per second, the inertia of the object may not be important compared to other factors. In water the added mass of entrained fluid must be accounted for, but probably would be ignored in air.

Second, continental soils are quite different from deep-sea sediments. Sediments in the ocean basins typically have very small grain sizes, often clay sizes of .005 mm and smaller. The rate of sedimentation is measured fractions of millimeters per year with very old layered material found relatively close to the top of the sediment column. Deep-sea sediments are completely saturated with interstititial pore water often accounting for half their bulk volume. The pore water is not the pure water commonly found on land, but the chemically complicated sea water which causes flocculation of some sediment particles and the presence of authigenic minerals near the sea-sediment interface. Lower in the sediment column, diagensis and cementation between particles occur forming a loose fabric often with the porosity being relatively constant with depth. The effects of the low 2 degree centigrade temperature and high 6,000 pounds-per-square-inch pressure encountered at the median ocean depth create an entirely different environment than found on the continents. The degree of reworking by benthic organisms may also be important in determining the mechanical characteristics of the upper layers of the sediments.

Third, when measuring the mechanical properties of the sediments, the amount of disturbance that the sample undergoes as a result of the sampling process, handling and preparation for testing, temperature and pressure changes, and organic growth or decomposition is difficult to precisely estimate and may vary from one sampling and testing technique to another [Richards, 1961].

Fourth, if the sediments in the upper layers are treated as a suspension of particles in a fluid, which may be a valid approach to sediment dynamics if the water content is over 100 percent, then another problem arises. The fluid dynamics of non-newtonian materials have been researched for conduit flows such as slurries in pipelines, but very few investigations of external flow about a body [Pazwash and Robertson, 1969], and unsteady flow at a boundary have been made.

2. Prior Investigations

There are only a few records of objects that have been lost and recovered. The instances where things have been recovered or photographed to document and determine the penetration depth together with adequate data about the mechanical properties of the sediment are virtually non-existent. The same lack of data exists in reports written about the few cases where penetration was investigated. The reports typically set forth equations with empirical constants and contain no information about the controlling sediment parameters.

Much literature and empirical information is available about pile driving. The forcing of a long piling into soft sediments is, however, quite different from the free-fall penetration problem.

D. TECHNICAL BACKGROUND

All of the variables were studied, then the development of the previous penetration equations was researched before an attempt was made to solve the penetration problem. A review of the known variables for which data exists was made to develop a method that would be of use at the present time using available data and techniques.

1. <u>The Variables Involved</u>

Penetration may be a function of more than 20 different variables and may be described by the following equation:

$$f\,(V_o,\ M,\ A,\ z,\ e,\ r,\ S,\ E,\ \nu,\ \rho_s,\ T,\ \phi,\ w,\ s,\ \xi,\ \mu_w, \mu_s,\ c,\ k,\ \gamma,\ \delta,\ \rho_w,\ a_s,\ h) = o \qquad (1)$$

where,

V_o = impact velocity

M = mass of the object

A = cross sectional area of the object

z = depth of penetration

r = surface roughness of the object

S = object shape

e = void ratio of the sediment

E = Young's modulus of the sediment

ν = Poisson's ratio of the sediment

ρ_s = density of the sediment

T = time for penetration to occur

ϕ = mineralogic and chemical composition of the sediment

μ_s = viscosity of the sediment

c = shear strength of the sediment

k = permeability of the sediment

s = sensitivity of the sediment

w = water content of the sediment

γ = dilation of the sediment

δ = grain size of the sediment

ξ = post depositional changes of the sediment

ρ_w = density of the water

μ_w = viscosity of the water

h = water depth

a_s = adhesion of the sediment to the object

Such a list is self explanatory and is not exclusive. Some of the above properties are related to others, and the parameters may thus be reduced in number by a dimensional analysis [Liu, 1969]. Some of the properties, however, are not amenable to a mathematical analysis, for example the grain size distribution and the grain's morphology and orientation in the sediment fabric. A phenomological approach to the problem may, therefore, be required [Muga, 1966]. To put all of the variables into a system of equations may be an impossible task, and for this reason the prediction of penetration into deep-sea sediments may remain somewhat of an art and not susceptible to an exact solution for some years.

The deep-sea sediment particles accumulated over millions of years occur in many types which reflect unique depositional conditions of the earth's history. The mechanical properties vary widely, as subsequent to deposition the sediments may have undergone secondary cementation, diagenesis, recrystallization, and a degree of reworking by animals in the top important layers [Smith, 1969]. Some problems involved in learning more about deep-sea sediments are set forth in the following paragraphs.

The details of the sea-sediment interface and upper sediment layers in the depths of the ocean are only grossly known the world over. In the most studied ocean, the North Atlantic, Keller [1967], estimates one core has been analyzed for sediment mechanical properties for every 30,000 square miles of ocean floor. Less data is available in the Pacific. The variation of the ocean bottom's nature and the high cost of about 1,000 dollars per foot of core recovery and analysis will limit any great expansion of knowledge.

Much input to the design of foundations on land is based on past local experience incorporated into local building codes. On land, tests can be conducted and equations developed that fit special circumstances in certain areas at considerably less expense than in the oceans. Also a past history exists for land areas of interest, whereas comparatively little has been known of deep-sea sediments until very recent times. Although the horizontal area variability of deep-sea sediments may be less than that of continental sediments, to empirically categorize the seventy percent of the earth's surface covered by water and anticipate a return in less than the number of years that have elapsed since structures have been built on land would be folly.

2. The Development of Previous Penetration Equations

A review of the development of penetration equations emphasizes the importance of the various constants that act to control the penetration depth. The discussion that follows combines the outlines given by Schmid [1969], and

Young [1969]. First and most basic from Newton's second law,

$$F(t) = M\ddot{x}(t) \tag{2}$$

it can be shown that penetration depth is determined if velocity is known as a function of time. In general this is not the case for unsteady motion at a boundary.

Other classical equations are also based on Newton's second law where resistance to penetration is a function of the instantaneous velocity, V;

$$-M\ddot{x} = C_1 + f_1\ (V) + f_2\ (V^2) + \ldots\ f_n\ (V^n) \tag{3}$$

which postulates that during the first phase of penetration, at high velocity, the motion is governed by resistive forces proportional to velocity to some power, and at the final stages of penetration the resistance is independent of velocity. If the functions, $f_1, f_2, \cdots f_n$, are taken to be constants and the highest power of n assumed to be 2, then equation (3) simplifies to;

$$-M\ddot{x} = \alpha + \beta V + \gamma V^2 \tag{4}$$

where at high velocities the forces controlling penetration are proportional to V^2 or analogous to drag force in fluid flow. At moderate velocities resistance will be proportional to the first power of V, analogous to viscous resistance, and at the last stage, proportional to a constant force independent of velocity. According to how the constants in equation (4) are treated, the following classical equations can be derived after integrating twice with the initial conditions,

$V = V_o$ at $t = o$, and final conditions, $V = o$ at $t = T$.

Robins-Euler $$z = \frac{M V_o^2}{2 \alpha}$$ (constant resisting force) (5)

Poncelet $$z = \frac{M}{2\gamma} \ln \left(1 + \frac{\gamma V_o^2}{\alpha}\right)$$ (resisting forces constant and similar to fluid drag) (6)

Resal $$z = \frac{M}{\gamma} \ln \left(1 + \frac{\gamma V_o}{\alpha}\right)^2$$ (resisting forces similar to fluid viscosity and fluid drag) (7)

The question relative to the use of the above equations rests with the constants, α, β, γ, which are determined by the geometry and mass of the object and the type of medium being penetrated. Schmid [1969] discussed several empirical penetration equations from the literature which are variations of the above classical equations. The constants were determined from high velocity impacts on continental soils.

Thomason and others [1968] used Poncelet's equation to determine the amount of charge required for an explosive anchor system.

$$z = \frac{p}{2\ gib} \ln \left(1 + \frac{b}{a} V_o^2\right) \qquad (8)$$

where

$p = \frac{W}{A} = \frac{\text{weight of projectile}}{\text{normal frontal area}}$

a = constant related to the shatter strength of the medium (for "mud" a = 320 psi)

b = an inertial coefficient for the material

i = a form factor, usually 1.0

Evaluation of a and b is a problem and unfortunately a comparison of predicted and actual penetration was not given. However, the penetration depth's dependence on high velocity was illustrated.

Young [1969] presented a semi-empirical solution to the penetration problem derived from 160 full scale tests on continental soils with impact velocities ranging from 100 to 1,000 feet-per-second. Penetration was treated as three phases: (1) impact, (2) moving through the soil, and (3) coming to rest. The phenomena of entry is not the same as moving through the soil, but the surface effect of entry was found to be negligible after the object had penetrated three body diameters. The basic form of Young's equation was:

$$z = f_1 \ (S) \ f_2 \ (A) \ f_3 \ (W) \ f_4 \ (V_o) \ f_5 \ (N) \qquad (9)$$

where

S = a shape parameter of the object

A = cross sectional area of the object

W = weight of the object

V_o = impact velocity

N = constant dependent on soil properties averaged over penetration distance

Two equations were determined for two ranges of velocity, one for less than 200 feet per second and one for greater than 200 feet per second. The low velocity equation was:

$$z = 0.53 \ (N) \ (S) \ (\frac{W}{A}) \ln \ (1 + 2 \times 10^{-5} \ V_o^2) \qquad (10)$$

and nomograms were given for easy solution. All Young's data fitted within $\pm$ 20% deviation. Again it should be noted that the soil property constant, N, could vary by a factor from 1 to 50 and "was arbitrarily assigned by those knowledgeable in the field".

If penetration is treated as being resisted by viscous forces only, the following results according to Schmid [1969];

$$M\ddot{X} = A\,V(t) \tag{11}$$

which has as its solution

$$x = \frac{V_o}{\alpha}\left(1 - e^{-\alpha t}\right) \tag{12}$$

where

$$\alpha = \frac{A\mu}{M} \tag{13}$$

When t goes to infinity, the maximum penetration becomes:

$$z = \frac{V_o}{\alpha} \tag{14}$$

but again resolving the viscous parameter of the sediment, μ, and establishing a realistic time, t, become difficult.

Soils do not behave as isotropic, linearly elastic materials, except possibly at very small strains [D'Appolonia and Lambe, 1970]. Penetration into a material causes the elastic limit of the material to be exceeded and theories of elasticity cannot be applied directly to the problem. Theories of elasticity and plasticity applied to problems of deformation assume idealized stress strain laws which are not well suited to soils and more basically ignore the important dimension of time, and assume that the state of strain is instantaneous.

Various viscoelastic models, Figure 1, with combinations of Kelvin and Maxwell models, of a sediment can be assembled and solved by Laplace or Fourier transforms, if time dependence is linear.

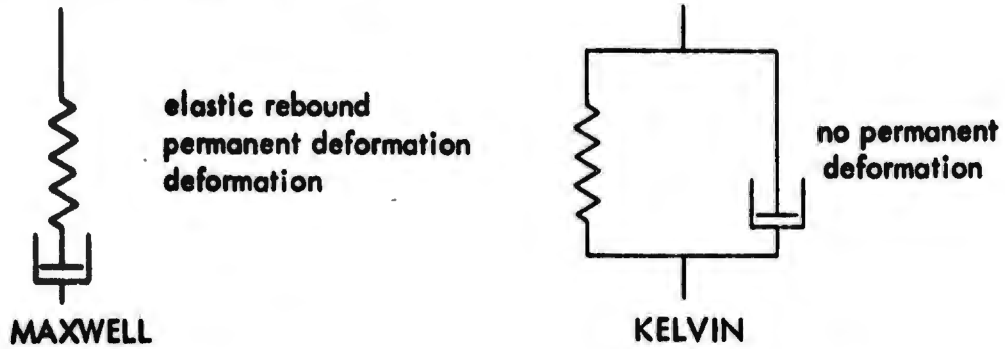


Figure I. KELVIN AND MAXWELL VISCOELASTIC MODELS

However the problem of determining the necessary soil parameters is non-trivial, and to get a unique solution, several sets of parameters are required [Schmid, 1966].

Modern advances in rheology and the continued development of the finite element method with appropriate yield criteria such as developed by Noh and Wilkins in 1964, and outlined by Schmid [1969], and the analysis of the initial settlement problem by D'Appolonia and Lambe, [1970], may be useful but again the problem of relating all parameters and determining the stress-strain behavior and yield criteria of a rheologically complicated material such as deep-sea sediments, may remain elusive for the near future.

In very weak, high water content, deep-ocean sediments, the penetration problem is somewhat similar to the problem of ship slamming. Studies of ship slamming and unsteady hydrodynamic impacts at a water surface have mainly been concerned with peak pressure, velocity-time relationships as a function of the form of a structure as it penetrates a fluid boundary and not penetration depth. Extensive literature and model test records exist [Ochi, 1962].

A method to estimate the impact velocity from the observed penetration depth was developed by Mandl and Givens [1964] after an aircraft was lost and crashed into soft clays in northern Canada. The method developed and explicity solved an equation of motion for a sphere and cylinder penetrating at high velocities into a Leda clay

$$-(m' + M)\ddot{X} = Mg - F - D \qquad (15)$$

where

F = the static strength of the clay, a function of penetration depth only

D = a drag force considered a function of penetration depth, velocity and time

Experimental tests of high velocity impacts into clay, (greater than 800 feet per second) confirmed that the method overpredicted penetration depth. The over-prediction was expected since viscous dissipation and elastic wave initiation were ignored.

After a detailed examination of mathematical methods available for analysis of unsteady motions of an object crossing an air-water interface, Moran [1965], concluded that none of them could yield a uniformly valid approximation to the solution of surface crossing and that the best hope for obtaining a reliable estimate was with numerical analysis.

3. <u>Known Variables for Which Data Exists</u>

Since all of the methods reviewed rely totally on the ability of the selected variables and constants to correctly parameterize the penetration problem, it was necessary to review what is known about the variables. The physical properties of the object are assumed to be known but the description of the sediment strength is subject to the interpretation of empirical tests or, in some instances, phenomenological observations. Even though deep-sea sediments are very different from continental soils, a review of what has been learned about the mechanical behavior of fine-grained clays on land and what is known about deep-sea sediments is necessary to assemble a workable solution. Also the problems of sampling and testing at sea cannot be ignored.

Information about the following parameters; density, water content, void ratio, shear strength, and sensitivity, which describe the mechanical behavior of deep-sea sediments, either exist in the literature or may be easily determined through laboratory tests which have been standarized and soon may be routinely performed at sea on oceanographic vessels.

The bulk density of deep-sea sediments is determined from routine measurement of the weight of a known volume of sediment. Typical values range from 74 to 125 pounds per cubic foot with the most common sediments in the range from 78 to 109 pounds per cubic foot [Keller, 1967]. The bulk densities of North Pacific sediments are generally lower than those of the North Atlantic.

The void ratio and porosity are a measure of the volume of sediment in a sample compared to the volume of voids, which are filled with sea water in the case of deep-sea sediments. They are also a measure of particle point to point contacts and bonds [Schmid, 1969]. The measurement is easily made with a pycnometer that measures that volume of a known weight of oven-dried sediment.

Sensitivity, the ratio of the original undisturbed shear strength to a remolded and disturbed shear strength, is important to the penetration problem since the object moves through disturbed sediment during penetration. Its importance is hard to estimate since most samples are disturbed to some degree. Mitchell and Houston [1969] indicate that in the range of sensitivity from 1 to 8, typical of deep-sea sediments, the mechanism that causes sensitivity is chemical cementation, which is not well understood by soil mechanists but obviously important.

For a cohesive sediment, the strength is a measure of the sediment's ability to resist mechanical deformation. Large masses of cohesive soils generally fail along a surface and hence the strength of a cohesive soil is defined as shear strength. For purely cohesive sediments undergoing large deformations, particle to particle interactions which would cause an "angle of internal friction" and increase in the strength of the sediment are generally assumed not to exist. However, as more sophisticated testing techniques are developed, this may prove to be an erroneous assumption.

Typical values of shear strengths were given by Keller [1967] to range from .25 to 2.5 pounds-per-square-inch, with the most common range between .5 and 1.5 pounds-per-square-inch. The North Atlantic basin sediments have slightly higher strengths than the North Pacific. The presence of carbonates will increase shear strength, but few carbonates are found below 12,000 feet. In the Gulf of Mexico, Bryant and others [1967], found shear strengths of silty clay turbidites of the abyssal plains to range from .3 to 1.1 pounds-per-square-inch with the pelagic sediments of the continental slopes having strengths up to 5.9 pounds-per-square-inch.

Richards [1967] predicted that a reduction of in-situ strength would be caused by sampling and laboratory testing and that the reduction might be proportional to the grain size, the amount of gases in solution, and temperature increases that cause increased bacterial action. However, samples tested in-situ at 300 meters with a vane device correlated well with tests from cores taken from the same area a year earlier and tested with a fall cone and laboratory vane [Richards, 1967]. Recent experience indicates this may have been an isolated instance of agreement.

Laboratory tests to determine the effects of temperature and pressure on shear strength and consolidation have been carried out with greatly disturbed, remolded samples [Vey and Nelson, 1966]. The results were somewhat inconclusive due to the small number of samples and difficulties in instrumentation. The results indicated that there was a decrease in direct shear strength with increased environmental pressure for a fine grained sediment with high void ratio. The vane shear tests with increased environmental pressure showed an increase in shear strength for plastic sediments and a decrease in shear strength for less plastic sediments.

In 1969 the first in-situ shear strength tests of ocean sediments which later were correlated with laboratory tests of core samples were carried out by Inderbitzen [1970].

In general sensitive clays have low values of strain at failure [Houston and Mitchell, 1969] and this contributes to the problem of determining the shear strength of very weak, saturated, and sometimes flocculated sediment in the upper few feet of the ocean bottom. Shear strength is measured by a variety of instruments: direct shear, triaxial shear, unconfined compression, vane shear, fall cone, and cone penetrometers. Each method has its own techniques and some are more applicable to typical deep-sea sediments than others.

The very weak, high water content, upper layers of sediment that are critical in the penetration problem are often lost or disturbed in the sampling process and must often be physically contained during laboratory testing. This precludes the use of an unconfined compression test or any test that requires trimming the sample before testing. The vane shear and fall cone tests can be done on a sample in its original container and the vane shear has the added advantage of easy adaptation to in-situ testing. Kravitz [1970] compared the results of Wykham-Farrance vane, Torvane, and fall cone tests on weak sediments and found that the results from the fall cone were more repeatable than the Wykham-Farrance vane or the Torvane which showed least repeatability. These results may have been expected since an important factor in vane shear testing is the rate of loading and the separation of static and dynamic resistance [Housel, 1959].

The vane test's advantages are: First, it can be conducted in-situ and a strength-depth profile is easily obtained where all other methods require reentry of a hole, which may be very difficult in the deep ocean, or discrete sampling which disturbs the sediments. Second, it is a simple inexpensive technique when compared to sampling and laboratory testing. Third, it does not require a system of weights or free-falling objects to cause the soil to fail and therefore has the potential to be used at sea on a rolling, pitching ship.

The vane test limitations can be summarized as: First, it can only be used in uniform, saturated, cohesive sediment. Second, when done in-situ it does not obtain a sample for evaluation. Third, it imposes a failure surface which may not be the weakest surface or relevant to the problem being studied.

Eden [1966] found that the vane will yield higher strengths with more consistent results in sensitive clay with shear strengths less than ten pounds per square inch when compared to a fall cone. This is in conflict with the more recent tests of Kravitz and emphasizes the problems in testing. Kravitz made statistically significant tests on a laboratory prepared montmorillonite sample and Eden tested natural clays.

Shear strength values from a vane were found to be 15% higher than those obtained by an unconfined compression test on Gulf of Mexico slope sediments [Morelock, 1969]. This may be partially balanced by the findings of Inderbitzen [1970] who found that laboratory vane measurements were 22% lower than in-situ measurements made from DEEP QUEST at a depth of 3,500 feet. This is in rough agreement with the estimation made by Crisp [1968], of a decrease in shear strength due to an expansion of pore water caused by temperature and pressure changes. Crisp estimated that an expansion of pore water by two percent would occur by raising a sample from 12,000 feet deep and 2 degree centigrade temperature to surface temperature and pressure. This expansion could significantly alter the strength properties of a sediment and Crisp showed shear strength should decrease 10 to 15 percent.

The in-situ tests conducted by Inderbitzen showed a uniform increase in strength with depth in the sediment, but the laboratory tests were erratic, suggesting that the difference may have been caused by disturbance during sampling and preparation for testing.

Penetrometers offer the great advantage of potentially being self-contained instruments. They either record or transmit a force versus time curve from which depth of penetration by integration and soil properties can be inferred. In order to extrapolate to different shapes and velocities, however, the curve's shape must be a characteristic of the sediment parameters. There are real problems with instrumentation and directional stabilization as the penetrometer penetrates since centric impact rarely occurs with other than symmetrical objects [Schmid, 1966]. Three other problems also complicate the penetrometer approach to determining sediment properties in the oceans. First, to get deep information, the penetrometer must have enough energy to penetrate, and at low terminal velocities in water it will probably require a smooth, known, driving force. Second, viscous forces may predominate on small penetrometers making extrapolation to larger objects very difficult. Third, penetrometers do not retrieve samples for analysis of other sediment parameters.

Acoustic sounding and seismic methods do not discriminate enough of the structure of the upper layers of sediments important to the penetration problem to allow their use at the present time. In the future the use of high frequency pulsed sources mounted on deep vehicles, hold promise for better resolution of the upper layers.

The methods of determining sediment strength that have been discussed were developed for use in classical foundation engineering where a safety factor based on engineering judgement would be applied to the final result. The penetration problem is quite different as it requires an exact answer since an error factor of two could mean the difference between an object being completely buried below the surface or having one half of the object exposed and easily located.

II. METHOD OF ANALYSIS

Prior to a discussion of the method used to solve the penetration problem in the air-to-sediment case and the modifications required for use at sea, it is suitable to quote directly from Terzaghi and Peck [1948].

> "Because of the unavoidable undertainties involved in the fundamental assumptions of theories and in the numerical values of the soil constants, simplicity is of much greater importance than accuracy. If a theory is simple, one can readily judge the practical consequence of various conceivable deviations from the assumptions and act accordingly. If a theory is complicated, it serves no practical use until the results are condensed into graphs or tables that permit rapid evaluation of the final equations on the basis of several different assumptions."

A. ASSUMPTIONS THAT PERTAIN TO THE SEDIMENT

Deep-sea sediments are not well defined in the literature dealing with soil mechanics. Therefore a list of important assumptions considered in developing the penetration prediction method are stated:

1. The sediment is completely saturated with sea water.
2. The water content of the sediment is 75 percent or more, as is typical of marine deposits in the deep ocean basins.

3. Organic material that would tend to bind the sediment particles together is either absent or is present in very small quantities.

4. The sediment will fail along its weakest plane.

5. The only shear resistance is cohesion.

6. The initial penetration takes place in such a short time that the effect of permeability is nil. In a study of time-dependent deformation of clays Barden [1969] noted that the effect of adsorbed water on individual particles was that pore pressure equals the applied pressure at the first application of load.

7. Any lithification or cementation that may have developed along individual particle-to-particle contacts is broken at the time of impact. This implies a portion of the sediment is remolded at impact. If the particles do not react with one another by other than mechanical means, the mixture will behave as a viscous fluid [Peck and others, 1953, Pazwash and Robertson, 1969].

8. Shear strength varies in an irregular manner with depth. The variation of velocity gradients is greater in the deep ocean basins than over shallow areas [Ewing and Nafe, 1963] which implies that deep ocean sediments have been deposited in layers. This is confirmed by visual observation of deep-sea core samples which often show horizontal layers of different colors and textures. When studying in-situ strengths, Inderbitzen [1970] found that horizontal variations were much less than vertical variations. He also

found that the percentage of variation in shear strength decreased with depth, which may indicate that biological and chemical processes are taking place in the upper layers and minimal consolidation occurs.

9. The bulk wet density of the sediment can be considered constant with depth in the surficial sediments. The shear strength of a saturated sediment depends to a large extent on the structural arrangement of the particles and Scott [1967] points out that soils can have different structures at the same density, but may not have the same structure at different densities, which implies that shear strength is not a unique function of density. X-ray diffraction and polarized light microscope techniques cannot reveal the details of particle configuration or orientation in fine-grained marine sediments. However, electron microphotographs of sediments from the Gulf of Mexico show them characterized by a loose, open arrangement of randomly oriented particles and that particle rearrangement resulting from gravitational consolidation is not apparent [Bowles, 1969].

10. The energy transmitted to the sediments in the form of elastic or gravity waves from the initial impact shock is negligible in comparison to the total energy dissipated during penetration. Impacts on soils and fluid media have been studied for a long time, but there is a very difficult instrumentation problem with detecting energy transmitted away from the impact site. According to Hunter [in Schmid, 1966] the Hertz impact theory, which refers to impacts in the elastic

range, states that the portion of total energy that is vibrational energy is very small as long as the impact velocity is less than the velocity of sound in the medium. Schmid [1966] measured the distant dynamic disturbances caused by a small penetrometer impacting into materials whose rheological properties were known or easily tested, such as, greases, wax, and homogeneous soils. High frequency vibration was detected in the hard materials and it was determined by use of surface accelerometers that the largest amount of energy propagated from the point of impact was 4.3 percent of the total energy available. His calculated propagation speed suggested that the motions measured at the surface were Stoneley waves. Ochi and Bledsoe [1962] when conducting model tests of ship hull forms slamming onto a water surface found that forces were very large for .01 seconds and pressure due to impact phenomena were over within .07 seconds, yet the model's velocity decrease during this time was less than 4 percent. Chuang [1970] in a similar investigation, did not detect any significant acoustic pressure variations at a distance away from the impact point and concluded that water could be considered incompressible for impact velocities from 0 to 50 feet per second.

B. METHOD OF SOLUTION FOR THE AIR-TO-MUD CASE

A rational, phenomenological approach was used to solve the penetration problem rather than an empirical method because of the poor state of knowledge that exists relative to actual behavior of deep-sea sediments. With engineering judgment, this method may be extended to different objects and different cases more easily than an empirical approach to the problem.

1. Role of Hydrodynamics

The sediment was treated as a homogeneous, incompressible fluid to enable an estimate to be made of (1) the momentum transferred from the body to the sediment, and (2) the drag forces exerted on the object at high velocities. If the sediment was a true fluid it would have an infinite strain for an applied stress. Therefore, the forces required to initiate failure in the sediment and bring the body to rest were taken as the forces calculated using the ultimate bearing capacity formula developed by Prandtl and Terzaghi.

Treating deep-sea sediments as fluids has been an approach applied to the study of turbidity flows and slumping on the continental slopes. The term "spontaneous liquefaction" is often used when referring to saturated clays and implies fluid properties. Briefly, Morgenstern [1967] states that liquefaction occurs when the sediment is loaded to the collapse stress of the sediment fabric and the load is then transferred to the interstitial pore water. The increase in pore pressure then produces hydraulic gradients which further disrupt the sediment fabric causing the solids and pore water to flow macroscopically as a viscous fluid. Houston and Mitchell [1969] describe the fluid phenomena as occurring in sensitive clays which contract during shear because of their open fabric. If the clays are saturated, the contraction tendency results in a large transfer of normal stress from the clay skeleton to the pore water causing pore pressure to increase. In saturated deep-sea sediments this transfer of normal stress may be almost instantaneous. Continuing the description of Houston and Mitchell [1969], as the remoulding caused by continuing strain becomes more pronounced, the effective normal stress may fall to a very low value. Very little strain is required to break bonds at particle contacts and there is some build-up of pore pressure even before a significant number of bonds are broken because of slight elastic compression of the fabric and incompressibility of the pore water. The resistance of sensitive clays due to dilational energy was determined to be small or absent by Houston and Mitchell [1969], and Walker [1969]. Because, first, at high void ratios little or no tendency toward dilation was observed during shear, even at high strains, and second, the effective stress had been so reduced at high strains the mobilized resistance of the clay fabric was small. Mandl and Givens [1964] when conducting high velocity penetration tests into a clay, judged that the compressibility phase of impact lasted until the surface boundary breaks and that the static yield strength of the clay was exceeded by many orders of magnitude under impact and the clays behaved in a dynamic manner similar to a fluid. Schmid [1966] when conducting low velocity free-fall impact experiments on a clay also observed that liquefaction occurred.

Another reason to treat deep-sea sediments as a fluid was that their bulk wet density has a narrow range of variation with depth in the upper layers of sediment and the assumption of a median density over the range of expected penetration is a good approximation.

2. Ultimate Bearing Capacity Equation

The bearing capacity of a soil is a measure of its ability to support a load relative to its limiting equilibrium. According to Harr [1966], the first rational approach to developing a method to predict ultimate load carrying capacity of a soil was provided by Terzaghi who recognized that if the three dominant factors contributing to bearing capacity, the weight of the soil, the effects of surcharge, and the strength parameter of the soil, could be assessed, a good estimate of bearing capacity would be obtained. Terzaghi chose as a model of the failure mechanism of the soil the solution to the problem of penetration of circular punches into metal as developed by Prandtl and Reissner. In the original solution Prandtl was able to neglect the effect of the weight of the metal moved to the influence of surface loadings on the surrounding material. When the material was assumed to be isotropic and homogeneous with no angle of internal friction, Prandtl's solution yielded,

$$q_d = \gamma D_t + 5.14c \tag{16}$$

On the basis of experiments and Prandtl's solution, Terzaghi and Peck [1948] derived the following semi-empirical equation for the bearing capacity of a circular footing.

$$q = 1.3c\, N_c + \gamma D_f\, N_q + .6\, \gamma N_\gamma \tag{17}$$

where q = pressure at surface to cause failure (psi)

c = cohesion or shear strength of the soil (psi)

γ = unit weight of the soil

D_f = depth of footing below the surface of the soil (in)

N_c, N_q, N_γ = factors which depend on the angle of internal friction and depth of footing

The first term represents a contribution due to the shear strength of the soil, the second the effect of material removed by putting the footing below the surface (equivalent to buoyancy in water), and the third term, the effect of an angle of internal friction (assumed to be zero for deep-sea sediments). The equation is modified slightly for square or oblong footings and Meyerhof [1961] gives constants for wedge and cone shaped footings. More complete discussions of the bearing capacity equation and slight variations in the values of the constants can be found in texts on soil mechanics [Terzaghi and Peck, 1943; Harr, 1966; and Hough, 1969]. Terzaghi's equation was the closest to Prandtl's (which requires theoretical failure surfaces) and it has been empirically verified for many years. It was therefore selected as a reliable relationship for estimating the static strength of deep-sea sediments. The values of the constants and the shapes used in equation (17) are given in Table I.

In the bearing capacity equation, the shear resistance mobilized on the failure surface of any surcharge material is neglected, hence the equation is conservative and relates only to events occurring below the footing or penetrating object. During penetration, static resistance will occur in the undisturbed portion of the sediment below the deepest penetrating part, the other surfaces of the penetrating object are subjected to remolded sediment or sediment already set in motion by the penetrating object. Therefore the bearing capacity equation constants used in penetration prediction were considered to be for shallow footings for all depths of penetration.

3. The Character of Failure

Before a final method of solution was selected, motion pictures of penetrations into soft sediments and still photographs of soil failures were studied. In the motion pictures, the sediment was observed to move laterally outward from the object and have somewhat of a separation point from the object. While dropping plates vertically into a simulated sediment, Erchul [1968] found that polymer coatings to reduce drag on the plates had little effect at high entrance velocities and postulated that the sediment may not have been in contact with the plates. He also observed that at low velocities the lubricants did reduce adhesion to the plate and considerably greater penetration occurred with lubricated plates compared to unlubricated ones.

To find a qualitative indication of the effect of fluid in interstitial spaces, Rowe and others [1962] dropped probes into finely ground (less than 40 microns) silica dust. At atmospheric pressure the dust displaces laterally and craters were formed. In a vacuum with no air in the interstitial spaces, resistance to penetration was 100 percent greater and the dust did not move laterally and no mounds or craters were formed.

The motion pictures of penetrating objects in the test pit revealed little splatter and little surface disturbance at a distance from the penetration point. Clark and Robertson [1965] observed motion pictures of a buoyant body exiting from water and came to the conclusion that energy lost due to surface effects was small. Moran [1965] also arrived at the same conclusion.

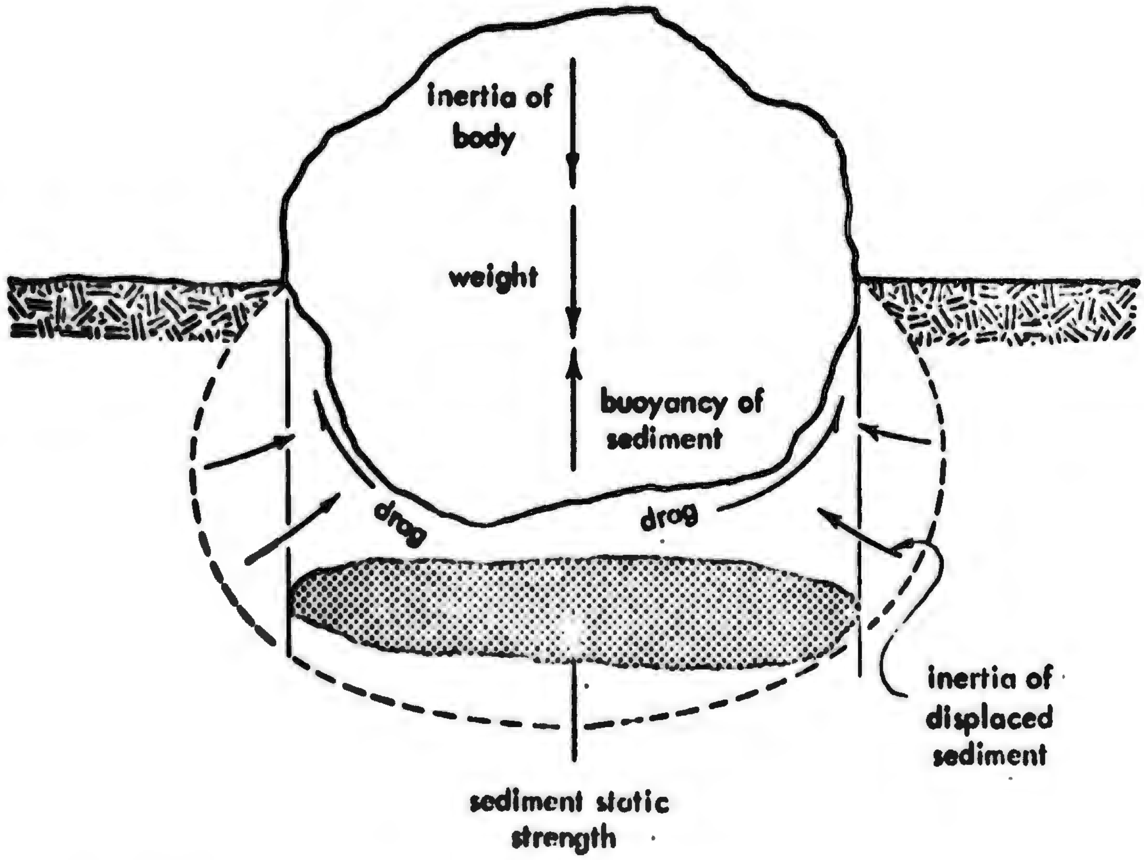
4. Equation of Motion

Since penetration is a dynamic phenomena involving the unsteady motion of a body, the first attempt at evaluating the penetration depth involved writing an equation of motion for the object as it penetrated the sediment. The final solution required a work energy approach that allowed the change in velocity and penetration depth to be determined incrementally with a computerized numerical scheme without the requirement to integrate the equation of motion and establish the instantaneous relationship between force, mass and acceleration.

The forces acting on an object penetrating a sediment characterized as a fluid with a static strength are shown in Figure 2. The equation of motion can be written as follows:

$$Ma = \sum \text{Applied Forces} \qquad (18)$$

Where the applied forces are: weight of the object, the sediment static strength, the buoyancy provided by the sediment, the force to overcome the inertia of the sediment, and the drag forces.



$$-M\ddot{x} = Mg - \rho_0 - \gamma_s A x - m'\ddot{x} - \frac{1}{2} C_d A \rho_s \dot{x}^2$$

body's inertia	weight	static strength	buoyancy	sediment's inertia	drag

Figure 2. FORCES ACTING ON A PENETRATING OBJECT

The change of the body's motion as it penetrates the sediment is the equivalent of the resistance encountered by the body, or the energy involved in the change is equal to that expended in propelling the body. Momentum is transferred to a surrounding fluid by; (1) a certain volume of fluid being accelerated uniformly, (2) the fluid being put into turbulent motion, (3) compression waves, (4) gravity waves or spray [Hoerner, 1958]. All of the momentum is eventually consumed by viscous friction. The last two modes of momentum transfer have been assumed to be negligible for the velocity ranges and object sizes under consideration and were discussed previously.

The treatment of the drag force, or the momentum put into the fluid by turbulent motion and viscous drag, outlined below, follows that given by Mandl and Givens [1964].

The drag forces cannot be evaluated easily for unsteady motion through a fluid boundary. The coefficient of drag can be approximated by;

$$C_d = \left(\frac{\beta}{Re} + C_{D_\infty}\right). \qquad (19)$$

The first term represents the contribution due to viscous drag; the second is that due to form drag; β is a constant depending on the shape of the body and is usually represented by the first term in an infinite series (Oseen's approximation). For a circular disk placed broadside to a stream $\beta = \frac{64}{\pi}$, while for a sphere $\beta = 24$ (Lamb). The term C_{D_∞} corresponds to the asymptotic case as Reynolds number approaches infinity in Navier-Stokes flows, it depends on geometry and not the fluid dynamic properties. Inspection of experimentally obtained drag coefficients versus Reynolds number relationships for bluff bodies show that C_d is a slowly varying function at large Reynolds numbers. For bluff bodies with sharp edges nearly all the drag is form drag. The experimentally determined values of C_{d_∞} in the case of bodies with sharp edges is approximently 1.0. For bluff bodies without sharp edges, such as spheres, the form drag also depends on the position of flow separation which in turn depends on the critical range of Reynolds numbers. The equation of motion then becomes:

$$(m'+M)\ddot{x} = Mg - p_o - \gamma_s Ax - \frac{1}{2} A \frac{\beta \mu}{D \rho_s \dot{x}} - \frac{1}{2} \rho_s A C_{d_\infty} \dot{x}^2 \qquad (20)$$

If the viscosity of clay is taken to be on the order of 3×10^{-3}, lbs - sec/in^2 [Whitman in Mandl and Givens, 1964], the Reynolds number for the objects that were under study with a three foot maximum dimension and with a velocity of ten feet-per-second, is on the order of 2×10^2. Admittedly a constant value of viscosity for a rheologically complicated substance such as a deep-sea clay is a gross over simplification, but the order of magnitude of the terms indicates that the viscous drag contribution to the equation of motion may be ignored [Mandl and Givens, 1964]. Also, towards the terminal phase of motion where the effect of viscosity is liable to increase rapidly with decrease in the rate of strain, the influence of viscosity will be negligible since the velocities are small and the other terms in the equation are larger by several orders of magnitude. Since form drag represents pressure forces on the body which are significant at the higher velocities, it could not be neglected.

5. Added Mass Effects

Another reason to treat the sediment as a fluid was to have a method available to estimate the volume and velocity of sediment displaced as the object penetrated. Womack [1967] verified that the amount of saturated clay moved during penetration was equal to the size of hole created.

The energy required to move the sediment is conserved since once the sediment is put in motion by the object it will continue to move away from the object creating a larger crater as the object is slowed by other forces. It is very important though, because the drag term of the equation of motion is dependent on velocity squared and the inertial effect of the sediment motion will alter the velocity-time history of penetration which has significant effects depending upon the shape and impact velocity of the object.

Added mass is caused by hydrodynamic pressure forces which are proportional to the instantaneous values of acceleration and according to Wendel [1950] appear to have the same value in a viscous or inviscid fluid as long as small bodies are not involved. The added masses were determined according to equations and methods given by Saunders [1957], which are tabulated in Table II.

The assumptions pertaining to the fluid approximation of deep-sea sediments can be summarized as follows and are the same as given by Moran [1965] in a study of water entry and exit.

1. Irrotational flow - viscous effects on the pressure felt by the body are generally small and the variations in inviscid forces are more important than viscous drag.

2. Incompressible flow - impact velocities are well below the speed of sound.

3. Surface effects are negligible.

The problem with determining depth of penetration from equation (20) is that it cannot be integrated during the unsteady motion of an object transiting a fluid boundary from one fluid to another. This is true for the following reasons: (1) m', the added mass and mass of the displaced sediment, is a function of depth of penetration for an object whose submerged portion changes shape as it submerges; (2) the dominant term, that of static soil strength, varies with the depth in a highly irregular manner; (3) the location of the air-to-sediment boundary condition is unknown a priori; and finally, (4) the flow is unsteady.

6. Transformation of the Equation to Work-Energy

The equation of motion may easily be resolved into an equation of energy and work which is time independent and a function of increments of distance. The development is given below.

$$\sum F_x = M \frac{d^2x}{dt^2} \tag{21}$$

Multiplication by dx gives

$$\sum F_x \, dx = M \, dx \frac{d}{dt} \left(\frac{dx}{dt}\right) = M \frac{dx}{dt} \, d \left(\frac{dx}{dt}\right) \tag{22}$$

The first integral with respect to displacement is:

$$\int F_x \, dx = 1/2 \, M \left(\frac{dx}{dt}\right)^2 + C \tag{23}$$

The left hand term represents the work done on M during the interval dx and can be evaluated if F_x is a known function of x. The right hand term represents the corresponding change in kinetic energy of the object.

Kinetic energy is a scalar quantity that depends only on the mass and magnitude of the velocity. Since the velocity is squared it is always positive. The total mechanical energy of the body is equal to:

$$E = KE + PE \qquad (24)$$

For an object penetrating the sediment and coming to rest, the energy of the object can be accounted for by:

$$E_1 + E_{IN} - E_{OUT} = E_2 \qquad (25)$$

This simple balance states that the total energy E_1 of the object at the beginning of an interval plus any energy put into the object minus any energy taken out must equal the final energy, E_2, of the object at the end of the interval. When the object has lost its energy in overcoming buoyancy, static soil strength, inertia of the sediment, and drag, it will stop its motion.

A particular reference level for the energies is not needed since energy is relative. The potential energy depends on an arbitrary selection of datum for zero potential. Also the kinetic energy is arbitrarily expressed relative to the condition at zero velocity. Hence any physical measurement over an interval describes a change in energy. It follows that reference to an arbitrary datum used for the expression of energy will cancel.

The work-energy method approach to solving a problem is powerful but dangerous because an answer is always obtained with no indication that the answer is correct. The method balances work to equal energy available and if a portion of of the energy available is not considered, or incorrectly computed, work is still done and an answer results. In the unsteady case of penetration, using an iterative solution almost requires a computer because errors in computation will not be indicated but will appear as energy gained or lost. The answer will not appear wrong unless a gross error was made.

In analysis of the penetration problem only mechanical energy was considered, with the sediment and object being a conservative system in the gravitational field. Thermal, chemical, electrical and atomic energies were neglected.

7. Method of Solution Used with a Computer

The numerical iteration scheme used to solve the penetration problem was the same for each object shape. Briefly, it divided the object into sections or slices in the same plane as the sediment surface. Then the work necessary to submerge each section and the work done by the sum of the submerged sections, the forces due to the inertia of added mass and displaced mass of the sediment, the static strength of the sediment, and drag in moving an incremental distance equal to a section thickness were calculated and subtracted from the kinetic energy and change in potential energy of the object. Penetration depth was determined when the total kinetic energy of the object equaled zero.

A description in mathematical terms follows and a block outline of the computer solution is shown in Figure 5.

Constants and necessary approximations for each object are listed in Table I. The computer programs are included as Appendixes C through H.

Refer to Figure 3 for an explanation of the definitions that follow.

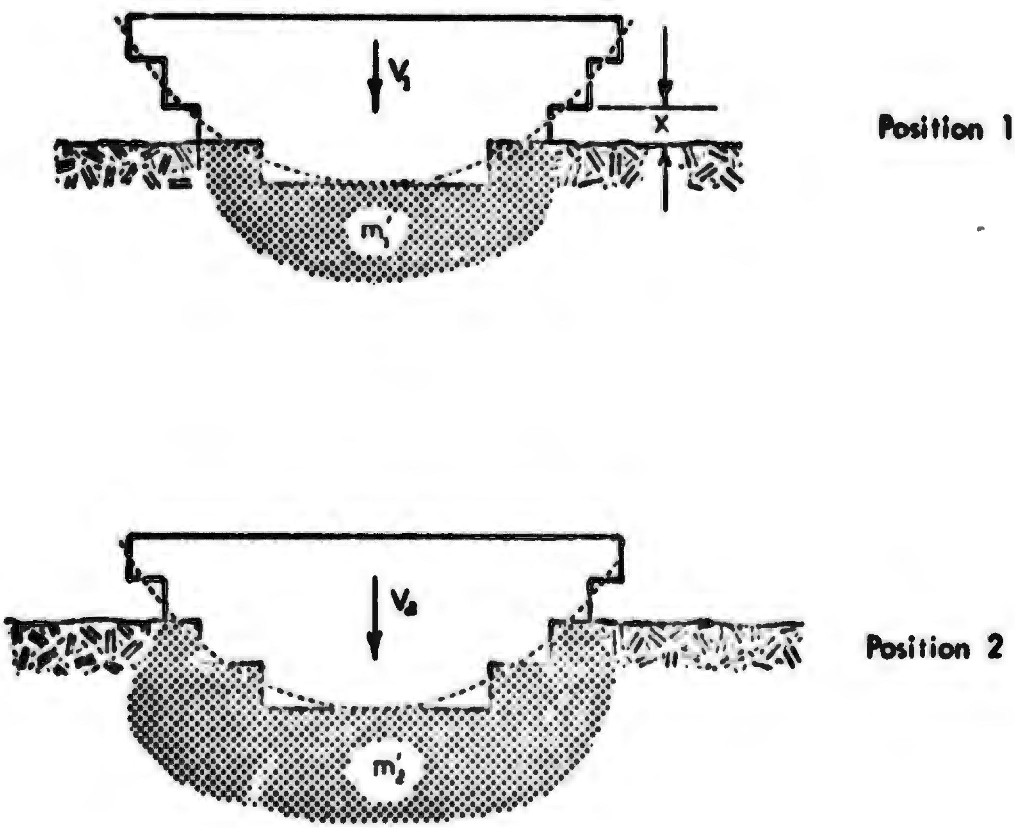


Figure 3. DEFINITIONS

v_1 = average velocity of the object as it transits distance x from position 0 to position 1. (Assumes a linear velocity gradient)

v_2 = average velocity of the object as it transits distance x from position 1 to position 2

M = mass of the object

m_1' = added mass at section 1, plus the mass of displaced fluid at section 1

m_2' = added mass at section 2, plus the mass of displaced fluid at section 2

$\Delta m = m_1' - m_2'$

U = work done

U_b = work done against buoyancy forces as object transits from position 1 to position 2

U_s = work done against sediment static strength as the objects transits from position 1 to position 2

U_d = work done against drag forces as the object transits from position 1 to position 2

ΔU = the change in energy of the body as it transits from position 1 to position 2, not including change in potential energy

E_1 = total energy of the object at position 1

E_2 = total energy of the object at position 2

ΔPE = change in potential energy of the object over distance x

From equation (22)

$$U = \int_{v_1}^{v_2} m' \, v \, d v \tag{26}$$

$$U = 1/2 \, m' \, v_2^2 - 1/2 \, m' \, v_1^2 \tag{27}$$

it follows that

$$\Delta U = 1/2 \, m_1' \, v_2^2 - 1/2 \, m_1' \, v_1^2 + 1/2 \, m' v_2^2 + U_b + U_s + U_d \tag{28}$$

NOTE: 1. $\Delta m'$ was accelerated from a static condition, zero velocity to the velocity at the end of the section over which it was computed.

2. $\Delta m'$ was assumed to be zero after the object had penetrated to its maximum dimension since separation of the sediment from the object was apparent at this point.

The incremental distance, x, is fixed, and the various masses are known as is the work necessary to move the object from position one to position two. Velocity at position two is unknown. Therefore from the work energy relationship

$$E_2 = E_1 + PE - \Delta U = 1/2\ Mv_2^2 \qquad (29)$$

Combining equation (28) with (23) and solving for v_2 gives

$$v_2 = \sqrt{\frac{2(\Delta PE + E_1 + 1/2\ m_1'\ v_1^2 - U_b - U_s - U_d)}{(M + \Delta m' + m_1')}} \qquad (30)$$

In the iteration scheme, when v_2 equals zero, the sum of the increments, x, is the penetration depth.

The work done against buoyancy forces is a straight-forward calculation that is discussed in elementary fluid mechanics texts. In the computer iteration scheme where the sections of an object are taken to be slices with vertical sides it becomes;

$U_b = 1/2\ \gamma\ A\ x^2$ (for the section being submerged)

plus $\sum \gamma\ A\ x^2$ (for all sections below the one being submerged)

The work done against drag forces was taken to be:

$$U_d = 1/2\ \rho C_{d_\infty}\ A\ v^2\ x \qquad (31)$$

where γ = bulk wet density of the sediment

C_{d_∞} = drag coefficient for the approximate object shape that is below the sediment surface

A = the maximum cross sectional area of the object below the sediment surface and normal to the velocity vector

v = average velocity over the distance moved, assuming a linear variation in velocity.

The work done against the sediment static strength was calculated from the ultimate bearing capacity equation.

$$U_s = C_f N_c A c x \tag{32}$$

where C_f = a constant depending on footing shape

N_c = a constant depending on the type of sediment and footing profile

c = shear strength of the sediment

When the penetrating object had a flat plane forcing into the sediment such as a cylinder impacting on end, the cross sectional area, A, of the flat area and the shear strength, c, of the sediment at the penetration level of the flat area were used in the equation above. In the case of objects with rounded or sloping sides, a judgment had to be made of a cross sectional area and representative shear strength. The area selected was the maximum cross sectional area normal to the velocity vector at the surface of the sediment, or the maximum cross sectional area of the object if the area had penetrated beneath the sediment surface. This method of approximating a sloping or curved surface by a projected horizontal area appears valid for blunt objects [Meyerhof, 1967]. Since the shear strength characteristics of deep-sea sediments in the upper layers appear to change radically with depth in the sediment column, a shear strength for equation (32) was determined by selecting an average depth according to the zones of plastic failure implied by equations (16) and (17). This was selected as one-half of the penetration depth until the maximum cross sectional area had been reached, then it became the depth of penetration minus one half the penetration depth when the maximum cross sectional area was coincident with the surface of the sediment as illustrated in figure (4).

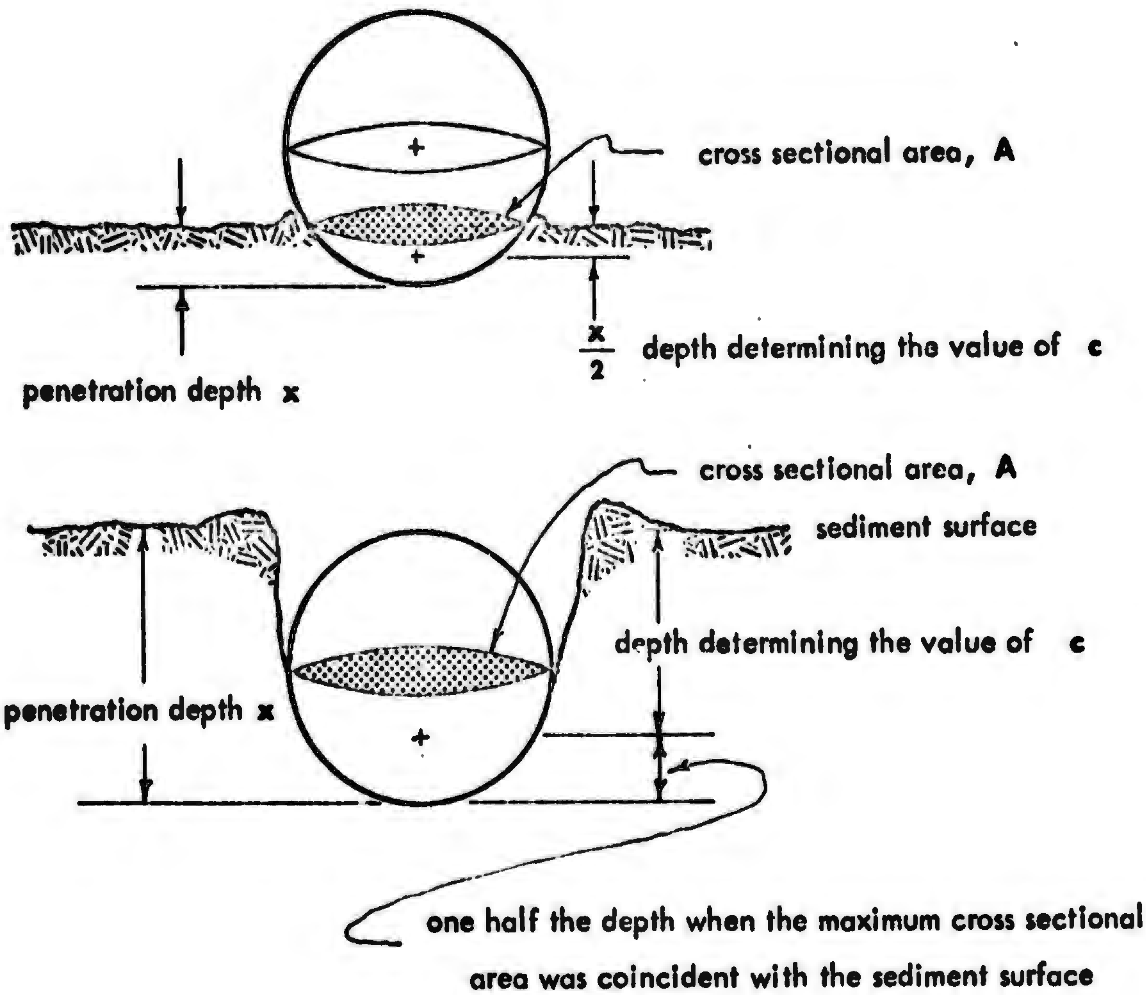


Figure 4. DETERMINING THE DEPTH OF "c" FOR NON-FLAT OBJECTS

The method described was adequate for curved and conical objects and approximates a representative strength in the theoretical zones of plastic failure in the sediment. An alternative and more refined method of selecting A and c, would have been to use the differences in the cross sectional area from section to section and apply the value of c at the depth of each section. This increased the complexity of the iteration procedure, hence was attempted only when there were discontinuities in the penetrating object's shape such as might occur with a truncated cone.

The distance of each iteration was chosen only to conserve computer time and approximate the expected accuracy of the field tests. Larger and smaller iteration intervals were tested for effects on the final depth and as long as the interval was less than one-half of the distance between shear strength measurements, convergence was always apparent. With a linear shear strength profile, the interval is limited only by the desired accuracy of the solution.

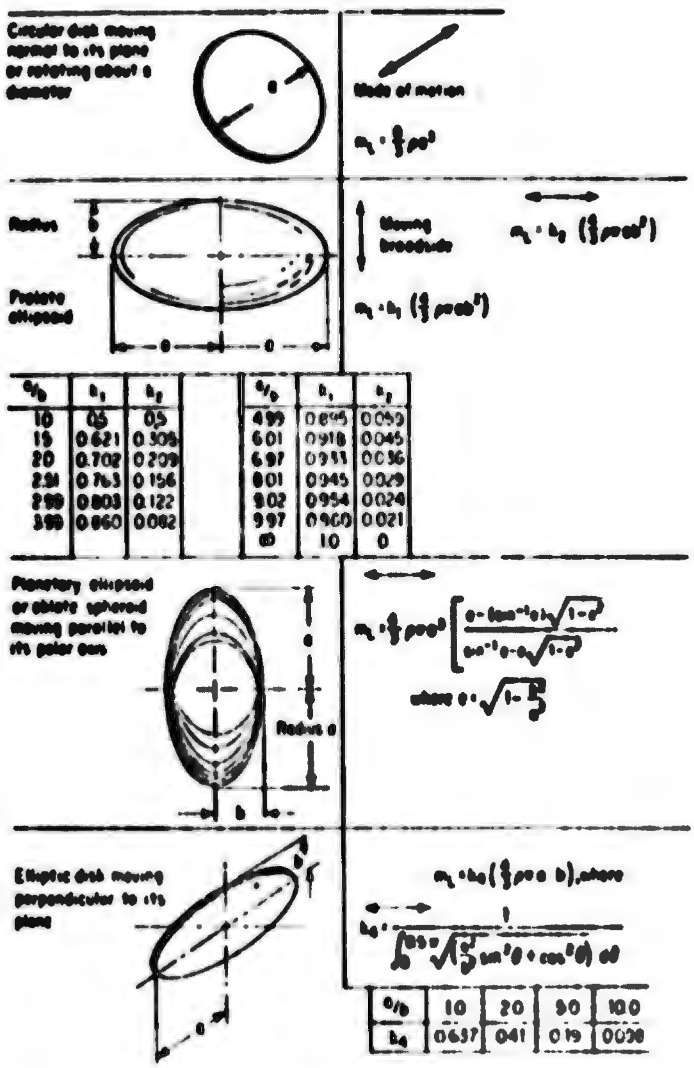
The equations for added mass are given in Table II. A flow chart of the basic program is given in Figure 5.

Appendix A presents a set of curves which qualitatively illustrate the relative influence of each force in the penetration equation. They were obtained by using the sediment shear strength profile typical of the world's deep-ocean basins as determined by Hoag [1970] and shown in Figure 13.

OBJECT	SECTION FORM	COEFFICIENT OF DRAG[1]	FOOTING SHAPE FACTOR[2]	BEARING CAPACITY FACTOR[2]	APPROXIMATION SHAPE FOR COMPUTING ADDED MASS
Sphere	Cylinder	0.3	1.3	5.7	One half of an oblate spheroid moving parallel to its polar axis
Horizontal Cylinder	Rectangular Parallel-epiped	0.68	1.3	5.7	One half of a prolate ellipsoid moving broadside with projected area equal to the area of the section form with the same ratio of maximum and minimum dimensions
Cylinder-On-End	Cylinder	0.3	1.3	5.7	One half of a circular disk moving normal to its plane
Cube	Square	1.1	1.3	5.7	One half of a circular disk with an area equal to the area of a square moving normal to its plane
Rectangular Parallel-epiped	Rectangular Parallel-epiped	1.0	1.3	5.7	One half of an elliptical plate with the same area and ratio of maximum and minimum dimensions of the section form moving normal to its plane (k = .51)
Cone	Cylinder	0.3	1.0[3]	4.7[3]	One half of a prolate ellipsoid moving on its long axis (k = .095)

Table I. CONSTANTS AND SHAPES USED FOR COMPUTATIONS

(see next page for footnotes)



a/b	k_1	k_2		a/b	k_1	k_2
1.0	0.5	0.5		4.99	0.895	0.059
1.5	0.621	0.305		6.01	0.918	0.045
2.0	0.702	0.209		6.97	0.933	0.036
2.51	0.763	0.156		8.01	0.945	0.029
2.99	0.803	0.122		9.02	0.954	0.024
3.99	0.860	0.082		9.97	0.960	0.021
				∞	1.0	0

a/b	1.0	2.0	5.0	10.0
k_4	0.637	0.41	0.19	[illegible]

Table II. FORMULAS FOR CALCULATING ADDED MASS [4]

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[1] Hoerner, S. F., Fluid Dynamic Drag, Practical Information on Aerodynamic Drag and Hydrodynamic Resistance, Chap. II, Published by the author, Midland Park, New Jersey, 1958.

[2] Terzaghi, Karl and Peck, Ralph B., Soil Mechanics in Engineering Practice, p. 172, John Wiley and Sons, 1948.

[3] Meyerhof, G. G., "The Ultimate Bearing Capacity of Wedge Shaped Foundations", Proceedings, 5th International Conference Soil Mechanics and Foundation Engineering, v. 2, p. 106, Paris, 1961.

[4] Saunders, Harold E., Hydrodynamics in Ship Design, v. II, p. 421, The Society of Naval Architects and Marine Engineers, 1957.

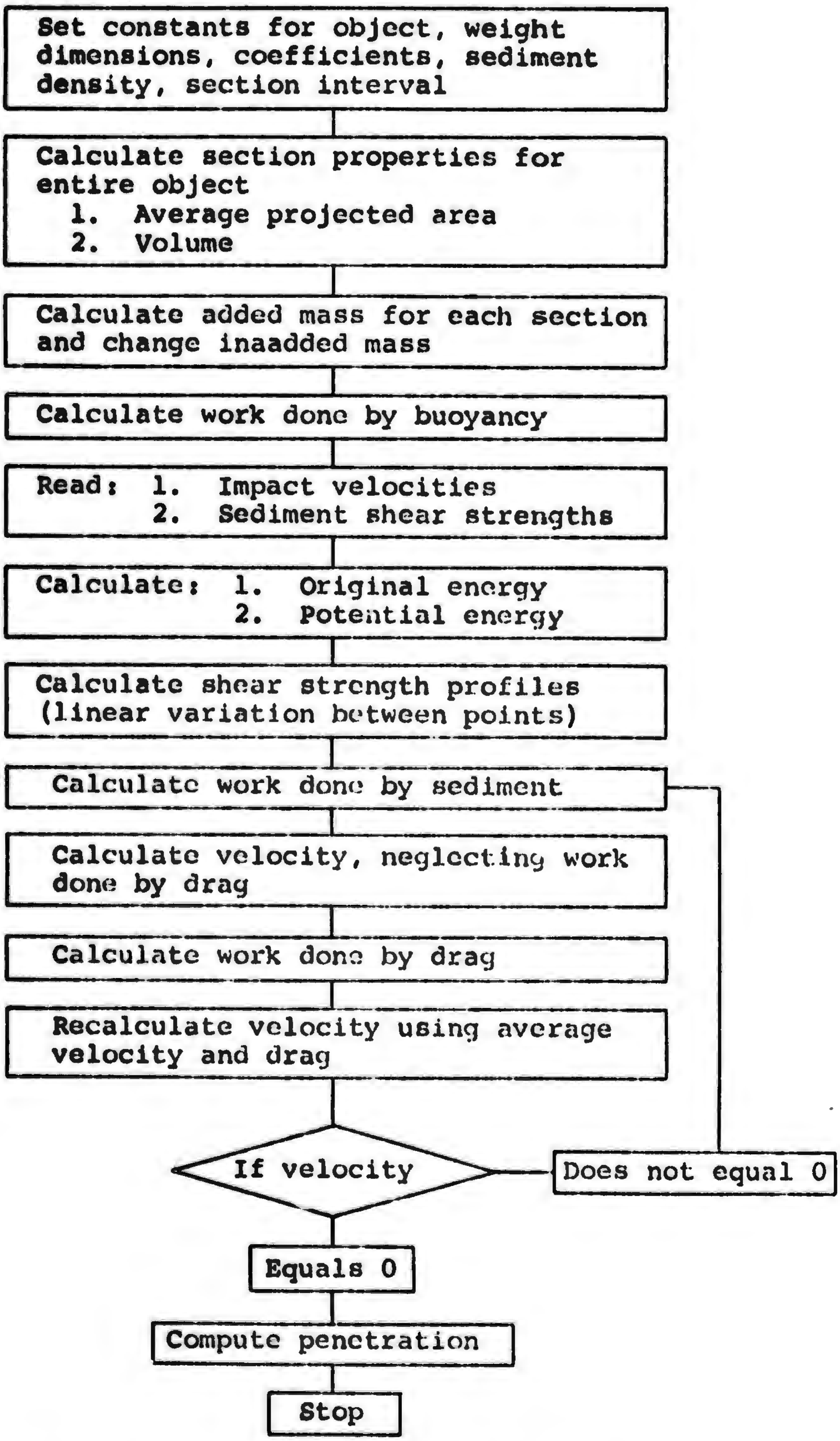


Figure 5. OUTLINE OF COMPUTER PROGRAM

C. MODIFICATION OF THE METHOD FOR USE AT SEA

The method was ultimately developed for general use at sea with as few restrictions as possible placed on size and shape of the object and on the type of sediment. However the only data available to test and verify the method was for an air-to-simulated deep-sea sediment case.

There are three relatively simple alterations that should be made to the computer program before it can be used in a water-to-sediment case. The three alterations should act to increase penetration depths at higher velocities and their overall effect is to increase the importance of an accurate determination of the shear strength profile.

First, the added mass effects will change by the ratio of the density of sea water to the density of the sediment. This can easily be accomplished by dropping the unit value of sea water from the bulk wet density term in the programs. Additionally, the added mass of the object free-falling through the water must be added to the total kinetic energy of the object at impact and a method for calculating the effect of this entrained water mass taken into account.

Second, the buoyancy term will also change by the ratio of the density of the sea water to the density of the sediment.

Third, the drag term will change by the ratio of sea water density to sediment density. Also a drag term must be included for the part of the body that projects above the sea-sediment interface. The easiest way to accomplish this would be to include a drag term for the whole object and add a drag term for the portion of the object submerged in the sediment.

The three modifications will serve to reduce the influence of added mass, buoyancy and drag and cause the sediment static strength term to become even more dominant than in the air-to-sediment case. Keller [1964], used the standard bearing capacity equation, only, to predict the initial settlement depths of a rectangle, square, and cylinder into soft bay sediments. The results were poor and he concluded that problems with determining an accurate strength of the sediment were the reason his calculations always underestimated the settlement depth.

To correctly use the method at sea, several cores should be taken and their physical and mechanical properties averaged. Averaging should reduce errors caused by sampling and testing disturbances. The effect of sensitivity, as it applies to the shear strength used in computing penetration depth, is uncertain. Possibly the remolded shear strength is a better value if it is assumed that impact shock effectively remolds the sediment to an unknown extent. In sensitive sediment, a range of predicted penetration depths should be calculated according to the degree of sensitivity.

The orientation that the object has as it first starts to penetrate has a significant effect on total penetration. After free-fall in several thousand feet of water, the object may still be tumbling or oscillating if it is unstable.

Schmid [1966] found that a significant portion of a falling body's energy may be in its angular momentum which is not included in this method.

For these reasons when predicting penetration depths, a computer routine should be used to solve for a range of impact velocities, shear strength profiles, and object orientations. The calculations can be done by manually using larger intervals, as was done to check the first computer solutions, but since energies are being equated and the method is iterative, extreme caution must be used since an answer, correct or not, always results.

IV. RESULTS OF EXPERIMENTS

A. THE PROBLEM OF MODELING IN SOILS

Some problems with testing and modeling the dynamic behavior of soils are discussed before reviewing the data available to test the penetration prediction method and the results of the tests.

The field of soil mechanics has traditionally been concerned with large scale construction operations. Many of the methods used to calculate the stability of slopes and foundation designs are based on ultimate collapse criteria and much of what has been learned about soil behavior was derived from studies of catastrophic large scale failures. Big construction projects are seldom undertaken without expensive, full-scale, field tests of critical portions of the foundations, and modern buildings are carefully instrumented to monitor their settlement and reaction to seismic disturbances. A good indication of the state-of-the-art of soil mechanics is implied in the large safety factors recommended in texts and building codes. The lack of understanding is, in large measure, due to the inability to parameterize and model a substance as complex as a soil.

When the problem is narrowed to the field of saturated deep-sea sediments, the problems of modeling are somewhat reduced. A modeling approach to investigate the dynamic response of soils to impulsive loads was conducted by Westine [1966] who found that a satisfactory case could be made for a model with saturated clays, but granular materials with angles of internal friction were impossible to simulate, since dilation and pore water pressures were hard to model. Frolich [1967] attempted to model the dynamic behavior of submarine sediments, but unfortunately he passed away before publishing his final results.

There are several areas where modeling dynamic penetration phenomena in deep-sea sediments may prove to be impossible.

Under dynamic loads a saturated deep-sea sediment may behave as a bingham body. The inertial resistance of the sediment to deformation coupled with the threshhold stress, or static resistance of the sediment, may be very hard to separate if the mass and therefore, inertia, of the penetrating body is small or on the same order of magnitude as the static resistance and inertial resistance of the soil. An analogous problem, but simpler by one factor, is unsteady fluid flow at low Reynolds numbers where inertial and viscous forces are the same order of magnitude. In the dynamic testing of soils this problem can be circumvented by full-scale tests using objects with large masses.

A similar problem involves surface effects and the adhesion of deep-sea sediments to an object. The effects of adhesion have been shown to be influenced by polymer coatings, surface roughness, surface chemical composition, etcetera, by Erchul [1969] and other investigators studying pile driving on land. Surface effects may control penetration significantly if the object has a large surface area in relation to its total mass. A means of minimizing adhesion effects would be full scale tests with large masses.

If a study's purpose is to learn more about adhesion, or mass effects, then modeling may be the best approach. However extrapolation of modeled test results to objects larger by an order of magnitude may be invalid.

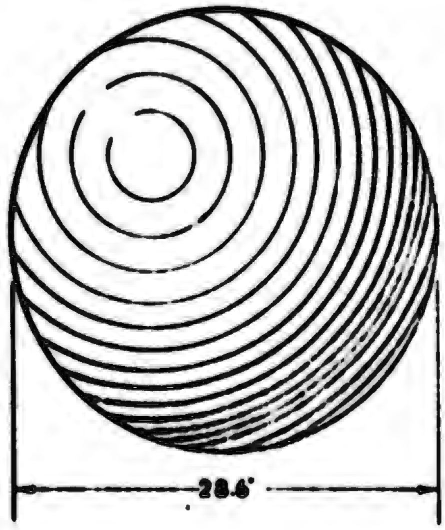
Finally, when attempting to model a sediment composed of clay particles which are very small, to reduce them further by an attempt at modeling the interparticle attractive forces and pore water viscous effects, may be impossible. Also, the instruments available to measure the modeled sediment strength may not have the required accuracy or precision for a reduced scale.

B. DATA AVAILABLE

The Naval Ordnance Test Station, Pasadena, California, constructed a large pit from sheet piling, 37.5 feet in diameter, and filled it to a depth of 16 feet with a very weak sediment from Seal Beach Lagoon, California. The pit was used to conduct tests on the holding strength of anchors, breakout forces of objects imbedded in the mud, and experiments with dynamic penetration. The penetration experiments were carried out under the direction of Dr. R. J. Smith in September, 1965. The penetration experiments are described below.

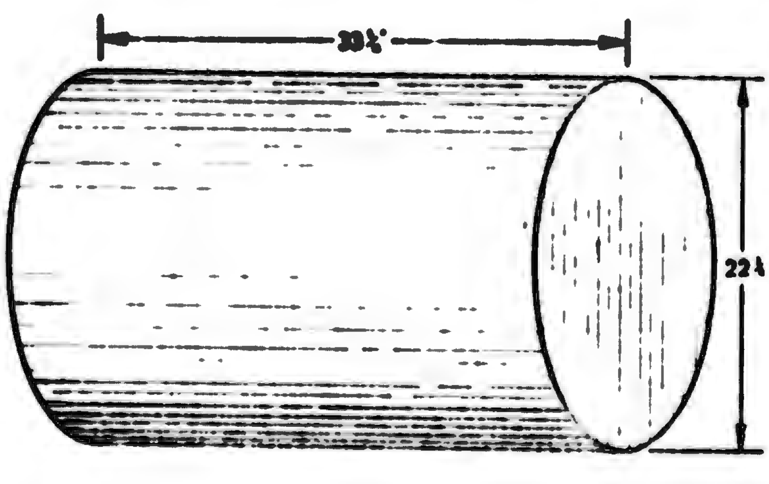
1. Description of Objects and Tests

Figures 6 through 11 show the six different objects that were dropped into the test pit. All six were fabricated



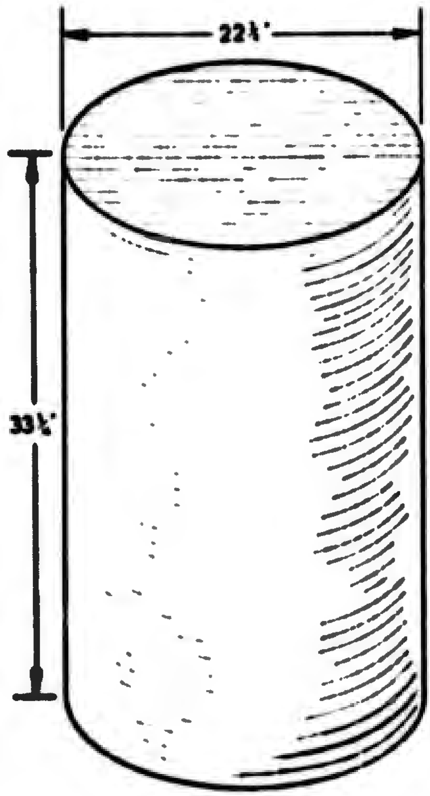
The sphere was made of a heavy steel plate and weighed 561 pounds in air. A padeye provided an attachment point for lifting.

Figure 6. SPHERE



The horizontal cylinder was made from a 55 gallon oil drum. It weighed 540 pounds in air. It was lifted by a two pennant bridle with one pennant welded at each lip.

Figure 7. HORIZONTAL CYLINDER



The cylinder-on-end was also made from a 55 gallon oil drum. For the first tests it weighed 540 pounds in air. Later a flat, round plate was welded over the lip of the drum at the end that penetrated, making it smooth to reduce the amount of air that might have been trapped there. The plate increased the weight to 561 pounds in air. The drum was lifted by a three pennant bridle attached to its upper end.

Figure 8. CYLINDER-ON-END

The cube was fabricated from steel plate and weighed 702 pounds in air. It was lifted by a four pennant bridle to each corner of one face.

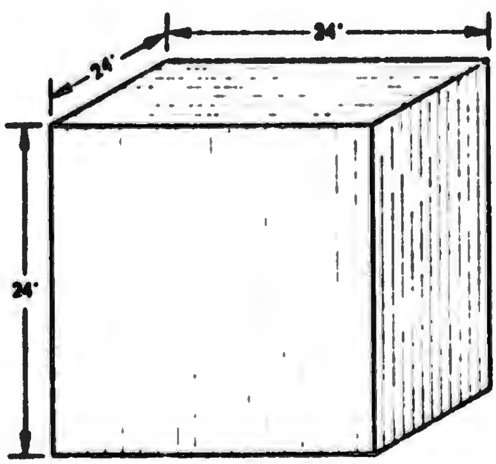
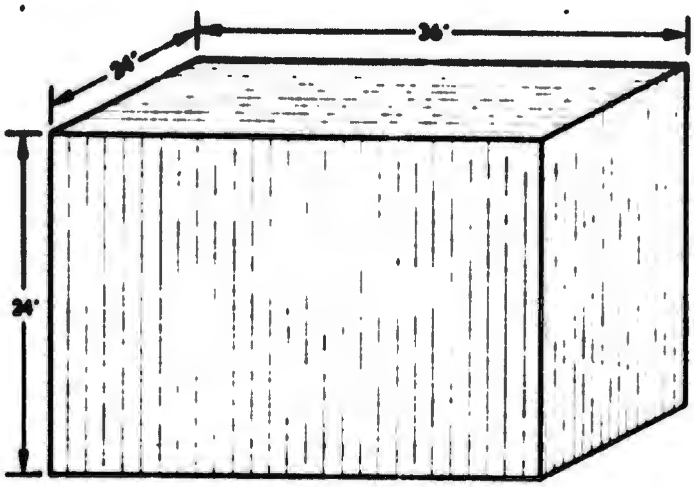


Figure 9. CUBE



The rectangular parallelepiped weighed 1,014 pounds in air. It was constructed of steel plate and lifted with a four pennant bridle to four corners of a large side.

Figure 10. RECTANGULAR PARALLELEPIPED

The cone was fabricated of steel plate and weighed 1,127 pounds in air. It was lifted by a three part pennant to the flat side and dropped point down.

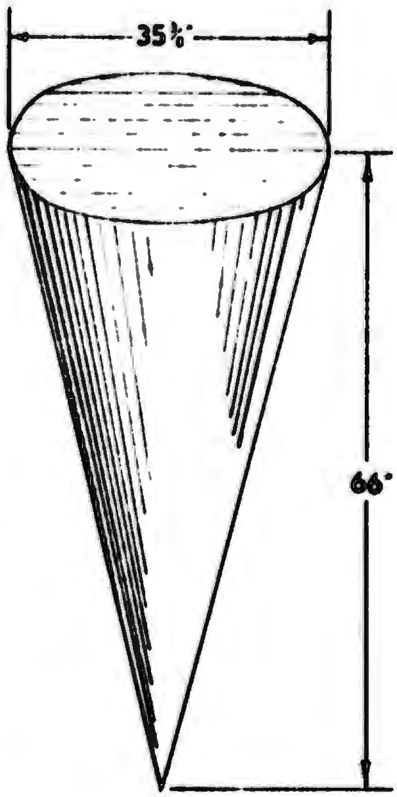


Figure 11. CONE

with a steel shell for structural rigidity and the cavity of the shell was completely filled with fresh water for weight. The weight could be changed if desired, however for penetration tests they were pressed full at all times. Dimensions of the objects are shown in inches.

The objects were suspended by a crane over preselected stations in the mud pit. They were released by a quick release hook that was tripped manually by pulling a line from the side of the pit. The objects were released at different heights above the mud-air interface to allow them to reach velocities of 5, 10, 15, and 20 feet per second as the object's lowest portion contacted the sediment-air interface. The zero velocity test was considered to be a zero release height, and the object was released with its lowest portion just in contact with the sediment-air interface.

Slow motion pictures, 32 frames per second, of almost all the penetrations were available. They were carefully studied in a frame-by-frame projector to double check the rough data sheets for height of drop and penetration depth. The movies also gave an indication of the stability of the object as it penetrated. Remarks about each penetration are given in Table X. Times for penetration and times for rebound were estimated by counting the frames of the movie film for each event. The movies confirmed the observations of Chuang [1970] that air trapped below a body impacting on a fluid does not alter the penetration depth. Any air that was trapped below the body usually vented by bubbling up alongside the object after it had come to rest. Only in one or two cases was it observed to form a jet with a significant amount of entrained mud.

The penetration depth was determined by visual observation of marks painted on the objects which were scales divided into one quarter inch increments. The depth reference was the undisturbed surface of the pit. Depth observations were made at each corner of the rectangular objects and at a diameter of the axisymmetrical objects. The penetration depth was considered to be the numerical mean of the several measurements. Any exceptions to this method and angles of tilt at the object's final rest position are noted in the remarks column of Table X. The exceptions occurred when the cylinders-on-end tipped completely over after coming to rest. The penetration before tipping was used if it could be read from the movies with an accuracy of one half inch.

2. Description of the Sediment

There was a real problem finding a suitable material to simulate a true deep-sea sediment, compounded by the 700 cubic yards of material required to fill the test pit. The material selected was lagoonal mud, described as "unconsolidated grey sediment with medium sand sized mica flakes", from the tidal flats of Seal Beach Lagoon. Tables III through V contain detailed analysis of its mechanical properties, and mineralogical and chemical analyses of the lagoonal mud from samples taken from the borrow pit. A year after the penetration tests were completed, Muga [1966], while measuring

TABLE III. MECHANICAL PROPERTIES OF THE SEDIMENT IN THE TEST PIT[5]

Depth (in)	0-3	4-7
Color (GSA No.)	5GY 6/1	5GY 6/1
Odor	H_2S	H_2S
Bulk Wet Density (gm/cc)	1.452	1.559
Vane Shear Strength (psi)	0.364	1.495
Remolded Strength (psi)	0.364	1.736
Sensitivity	1.0	0.9
Water Content	82.9	66.3
Specific Gravity of Solids	2.914	3.019
Dry Density (gm/cc)	0.794	0.937
Void Ratio	2.676	2.226
Porosity (%)	72.8	69.0
Saturated Void Ratio	2.416	2.002
Organic Carbon (%)	1.385	0.578
Percent Sand	6.0	2.0
Percent Silt	30.0	18.0
Percent Clay	64.0	80.0
Median Diameter (mm)	0.0020	0.0018

Note: Samples were obtained with a two and one-half inch core liner from the site where the sediment originated.

[5] Samples collected by R. J. Smith and analyzed at the Naval Civil Engineering Laboratory in Port Hueneme.

TABLE IV. MINERALOGICAL ANALYSIS OF THE TEST PIT SEDIMENT[6]

COARSE SILT TO SAND	PERCENTAGE
Quartz	15.39
K-Feldspar	7.69
Calcite	3.36
Opal	1.47
Muscovite (illite)	11.54
	Total = 39.45 percent
ACTIVE CLAYS	
Kaolinite	16.31
Mixed Layer	29.27
	Total = 35.58 percent
INACTIVE SILT TO CLAY SIZES	
Goethite	5.83
Halite	4.53
Organic	4.41
	Total = 14.77 percent

Note: The mixed layer was composed of 67 percent montmorillonite and 33 percent chlorite. The muscovite was chiefly terrigenous (clastic) and occurred in coarse silt-sized grains. The analyses were made by a combination of x-ray diffraction, chemical, and petrographic methods. Infrared absorption analyses and differential thermal analyses were used to obtain supplemental data. The values shown are recomputed to 100 percent and are reliable to about ±15 percent.

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[6] Whelan, J. A., A Report on Mineralogy of Ocean Bottom Sediments, p. 10 unpublished report to the Naval Civil Engineering Laboratory, September, 1967.

TABLE V. CHEMICAL ANALYSIS OF TEST PIT SEDIMENT[7]

OXIDE	PERCENTAGE
SiO_2	48.34
Al_2O_3	18.26
Fe_2O_3	7.88
MgO	2.98
CaO	1.92
K_2O	2.74
Na_2O	3.02
H_2O	2.78
L.O.I.	9.67
Total	97.59
Surface H_2O	73.01

[7]Whelan, op. cit., p. 8a.

TABLE VI. RANGE OF VARIATION OF TEST PIT SEDIMENT[8]

"The main feature of the soil is its highly variable properties, being both nonhomogeneous and nonisotrophic. Some of the variations are indicated below.

RANGE OF VARIATION (42 TESTS)

	MINIMUM	MAXIMUM	AVERAGE
Vane Shear Strength (psi)	0.0	1.050	0.530
Remolded Strength (psi)	0.0	0.861	0.390
Original Water Content (%)	43.5	79.6	63.5
Void Ratio	1.104	2.126	1.710
Porosity	52.5	68.0	61.9
Liquid Limit	41.0	68.0	56.1
Plastic Limit	27.5	43.4	34.2
Liquidity Index	70	255	136
Percent Sand	1.7	25.5	10.2
Percent Silt	30.8	54.4	40.5
Percent Clay	35.8	66.0	46.4

"In addition, soil samples were subjected to numerous triaxial, permeability and viscosity tests. From these tests it was determined that; (i) the yield strength of the 'soil' is approximately 0.5 psi; (ii) permeability is practically nil; (iii) cohesion, c, is almost zero; (iv) angle of internal friction is almost zero and (v) viscosity is independent of the rates of shear or deformation (i.e., rpm)."

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[8] Muga, J., Breakout Forces, p. 4, U. S. Naval Civil Engineering Laboratory Technical Note N-863, Port Hueneme, September, 1966.

break out forces in the test pit, conducted more tests to verify the mechanical properties of the sediment. Table VI is a summary of Muga's tests. It is obvious that the lagoonal mud was not uniform but characterized by variability, but a major cause of the variability was undoubtedly the result of sampling disturbances and continual reworking. Muga also stated that the mean viscosity was 300 square feet per second. This value represented a series of measurements taken with a commercial rotating-type viscometer. He did not attempt to correlate the viscosity with the vane shear strength because of the "marked variability in the soil properties". Since the sediment contained approximately 40 percent silt to sand sizes, there was certainly some angle of internal friction caused by these large sizes and this was probably the reason Muga found a high viscosity measurement. It also appeared that there were more coarse grain sizes present a year after penetration tests were conducted which indicated possible contamination with other material. For this reason Muga's values were not taken as absolutely correct, but they were included to illustrate the variability of the sediment used for the tests.

Figure 12 shows the mean shear strength profile of the sediment from 550 measurements. Although the mean strength profile is not representative of the average shear strength profile for the world's deep-ocean basins shown with a solid line, Figure 12, from Hoag [1970], it is remarkably close to the shear strength profiles of the edges

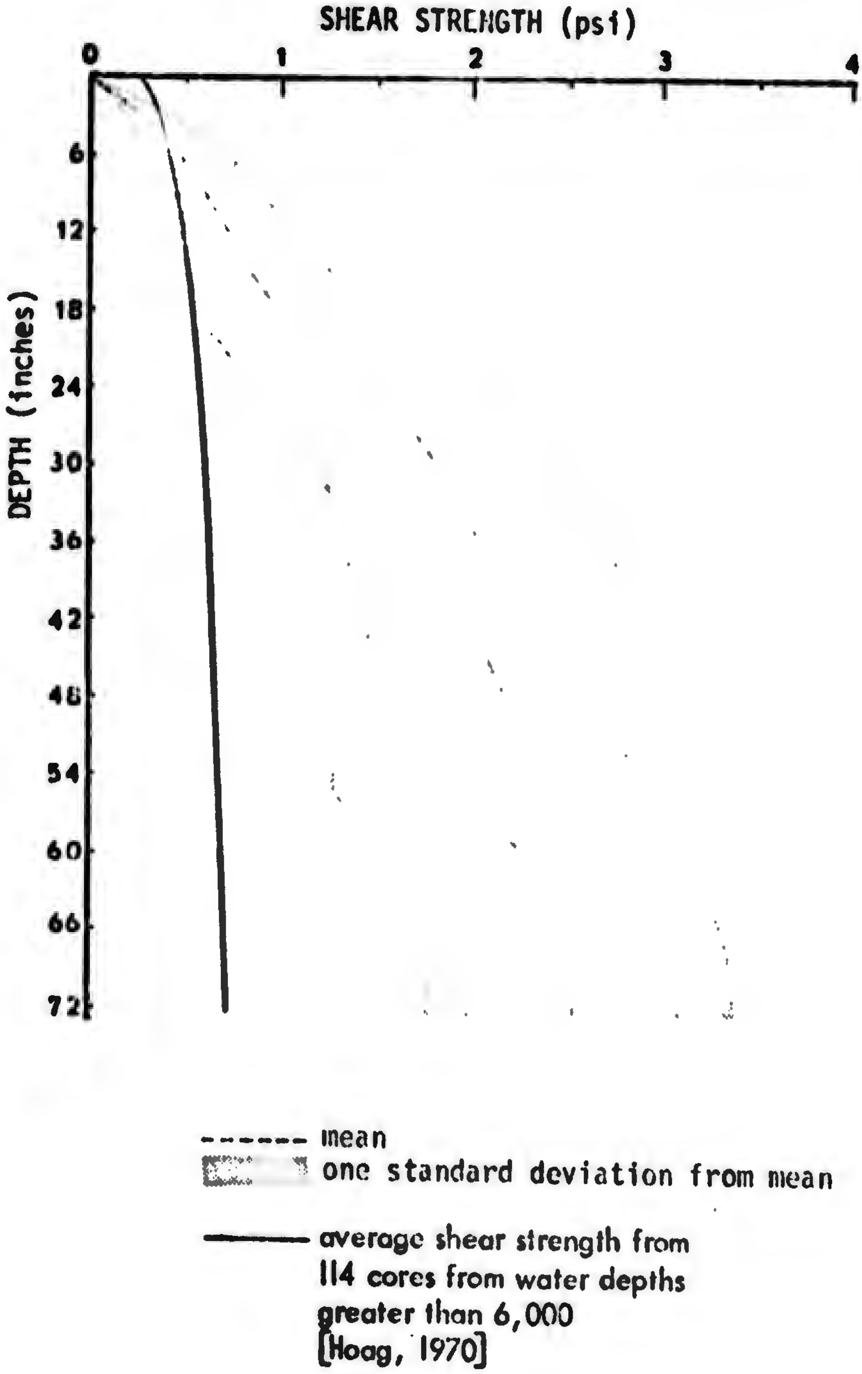


Figure 12. TEST PIT MEAN SHEAR STRENGTHS

of the Zigsbee Abyssal Plain as shown by Bryant and others [1967].

The numbering system designating the location, or station, where each penetration test was conducted is shown in Figure 13. The shear strengths at each station were taken using a two inch by five inch vane. The vane was operated by hand from a punt floating on the surface. It was driven into the sediment in six inch increments and torque applied by hand with a standard torque wrench and the maximum torque, converted to shear strength, recorded. Not all of the vane tests were conducted in the presence of an engineer and some were done by different personnel. Generally the shear strength profiles are consistently similar, with some erratic points, but there is some correlation between very erratic profiles and the date of tests, which indicated operator skill and care may have had an influence. The method of obtaining shear strength values greatly influences the value obtained according to Terzaghi [1960] and it was difficult to get consistent readings from an unstable punt with no control on the vane's rotational speed.

Other methods of determining shear strength profiles in the mud pit were considered, but rejected for the following reasons. In 1965, the existing penetrometer probes related resistance encountered to shear strength by empirical tables or graphs, and the very low strength of the mud pit was out of the empirical range. The use of these devices would have required modifications of the instruments and

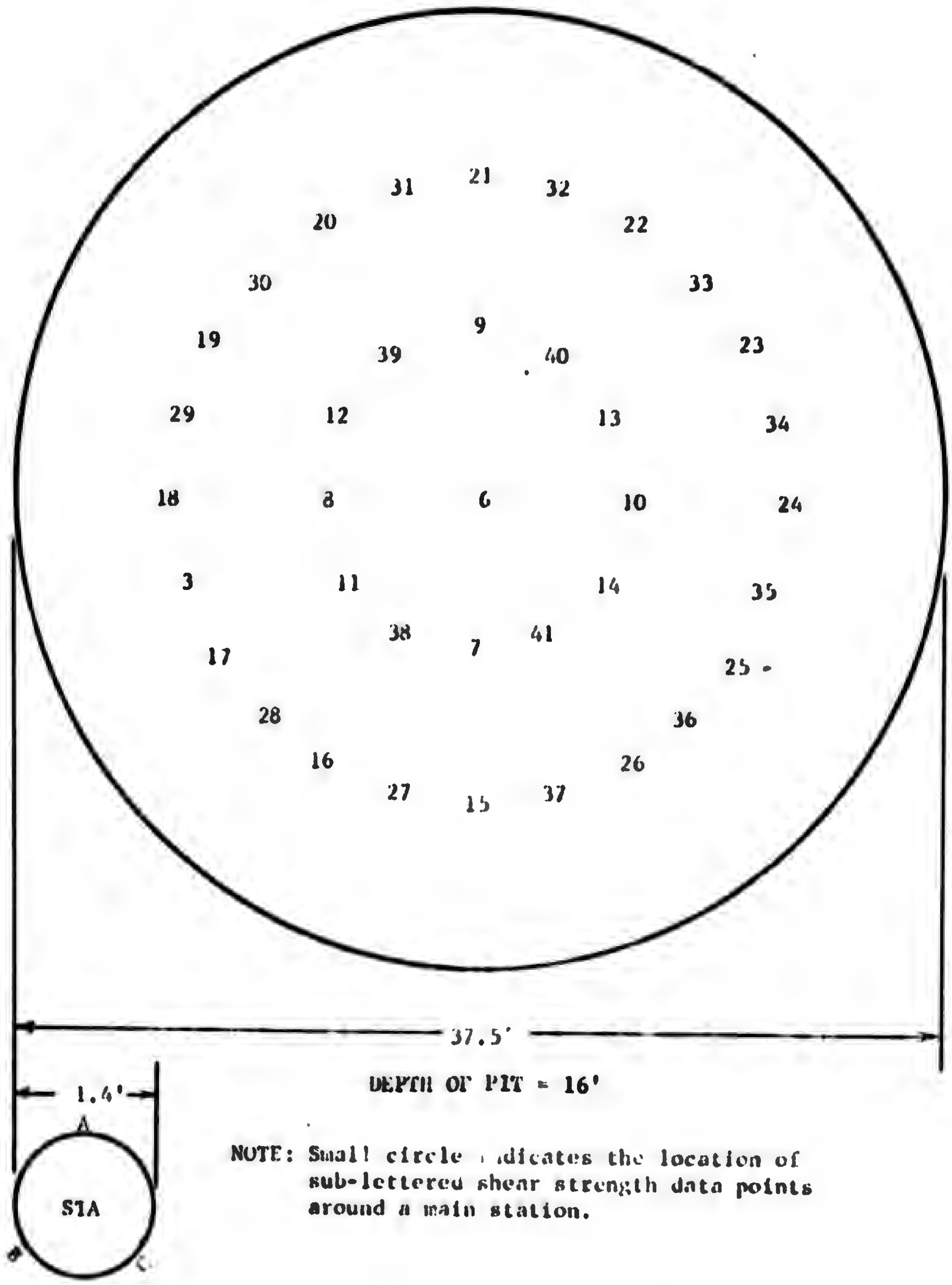


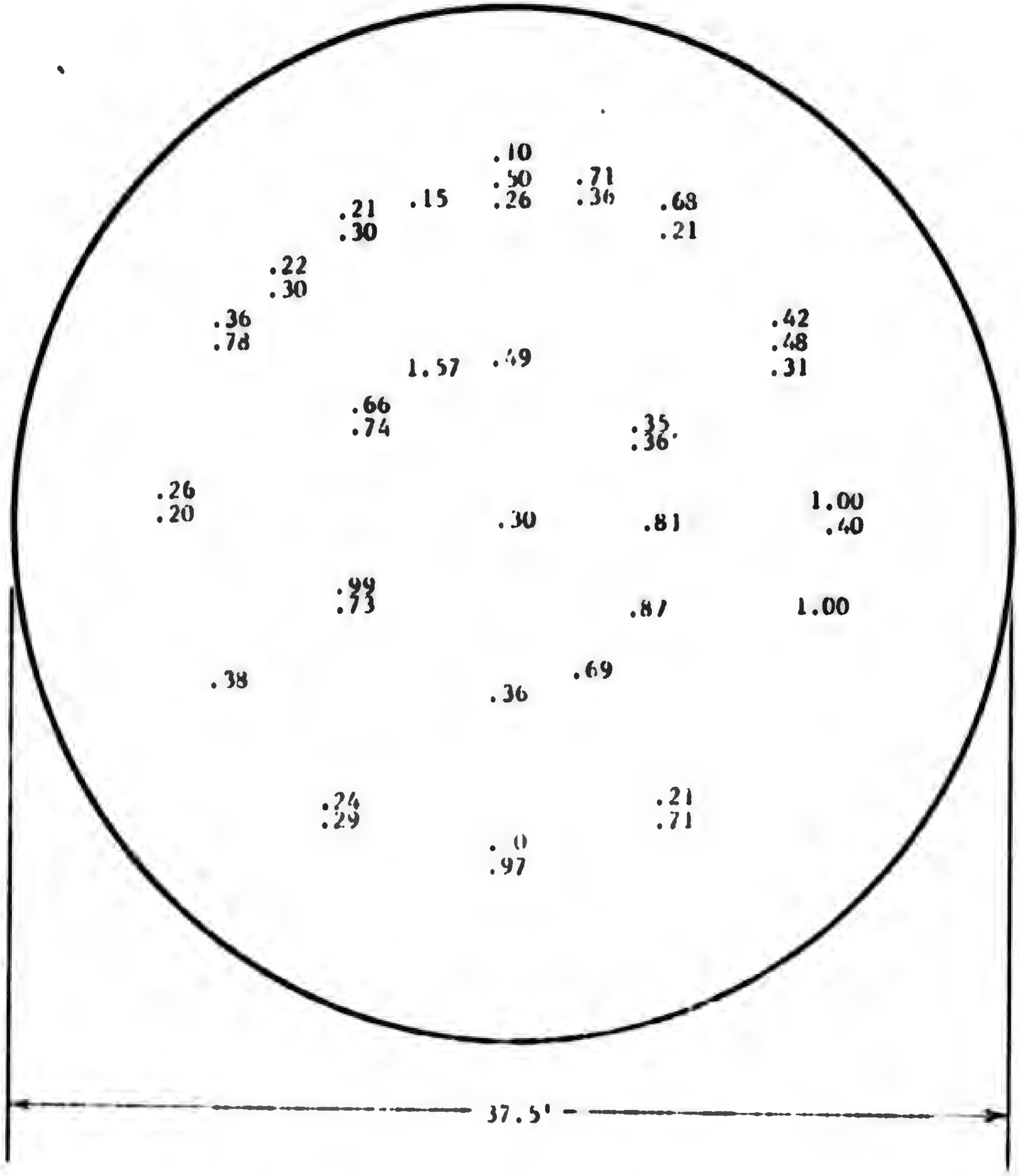
Figure 13. LOCATION OF DROP STATIONS IN THE TEST PIT

extensive testing to obtain empirical relationships. Second, the sediment in the mud pit probably had some slight but unknown angle of internal friction and the vane test measures a cohesive shear strength which is influenced by the angle of internal friction in a minor way. However, the vane test seemed the most practical test for shear strengths in cores and in-situ testing. Therefore, vane shear strengths were used exclusively to keep the results comparable to a real situation.

The horizontal variability of the observed shear strengths at six inch depths is shown in a plan view of the mud pit, Figure 14. The measurements taken on different dates in the same location also show a spread in values.

The variability of the shear strength in the mud pit was probably not random for the following reasons.

1. The huge volume of material required to fill the pit necessitated handling by large construction equipment which could have scooped up isolated chunks of material and allowed them to be placed in the pit essentially undisturbed, while most of the sediment was greatly disturbed during excavation, hauling and placement. The very high shear strengths have been attributed to the relatively small vane coming in contact with one of these hard chunks. The chunk would not necessarily affect penetration depth unless an object was dropped very close to one because the sediment was incompressible and moved as a unit. Most of the objects were large compared to the chunks or vertical distance between anomalously high observed shear strengths.



NOTE: More than one value indicates measurements were taken on different dates.

Figure 14. SHEAR STRENGTHS AT SIX-INCH DEPTHS PLOTTED ON A PLAN VIEW OF THE TEST PIT (psi)

2. Although it was not noted in the analysis of the sediment, some organic material or foreign objects may have been present since no special precautions were taken to sieve the sediment while it was being placed.

3. The extremely low values of observed shear strength may be attributed to the method of handling the sediment after a penetration trial. The holes made by the objects and other experiments with the sediment were smoothed over, filling depressions with a shovel and rake. Then shear strengths were taken at each station and penetration drops conducted at a later time. After all the stations had been used, the procedure was repeated. Since other tests were being conducted concurrently, the hole filling and smoothing was a continuous operation. Undoubtedly some very soft material and water accumulated at the bottoms of the holes and this accounts for the anomalously low shear strengths at considerable distances below the surface.

The low sensitivity of the sediment before sampling and the continual reworking it underwent while tests were in progress, led to the conclusion that the sediment used for the tests had a sensitivity of one and that the observed in-situ shear strength of the sediment was a good representation of its actual in-situ strength, if the problems of test operator error and the anomalous points due to hard chunks or soft spots could be resolved.

Fortunately, enough data, 716 points, existed to make a statistical analysis and a mean strength profile of the mud pit. Table VII includes a matrix of all the observed shear strengths. The anomalously high and low values were identified by eye. Since the profile should have been fairly smooth with all the reworking the sediment underwent during placement and tests, the hard and soft spots were easily selected by visual inspection. The values considered anomalous are underlined in Table VII.

The mean and standard deviation of shear strengths as a function of depth, both with and without the anomalous values, are listed in Table VIII. It should be noted that the anomalous values often cause the standard deviation to more than double. The mean shear strength profile of the mud pit and one standard deviation calculated without the anomalous points are shown in Figure 12.

At each station the anomalous points were adjusted to fit a smooth profile that generally was within one standard deviation of the mean. The adjustment process was again subjective, as the precision of the original data did not warrant a more sophisticated approach. The observed shear strengths for each station were plotted with the mean profile. Then the anomalous points were moved to fit a general smooth trend of points within one standard deviation from the mean. The figures in Appendix B illustrate the adjustment at each station and the solid line is the actual shear strength profile used by the computer solution to predict penetration depth.

The shear strength and standard deviation value at the air-sediment interface was taken to be zero, in that sea

VELOCITY ft/sec	STATION	DEPTH 6"	12"	18"	24"	30"	36"	42"	48"
SPHERE									
0.0	6	.30	.38	.78	.70	1.34	1.63	1.53	1.55
5.0	7	.36	1.04	1.03	1.56	4.00	6.53	4.17	2.16
10.0	9	.49	.77	.85	5.58	4.14	1.91	1.91	1.77
15.0	20	.30	.12	.45	2.44	2.78	2.78	5.75	3.14
20.0	26	.71	.71	3.14	1.74	2.09	2.21	2.38	2.30
5.0	15	-	.52	1.08	1.51	1.74	1.95	2.11	2.44
10.0	-	.69	.66	.52	1.39	1.55	2.05	2.44	3.01
15.0	-	-	.36	.91	1.39	1.74	1.57	2.05	2.70
20.0	-	-	1.04	1.74	2.29	1.76	4.87	2.70	2.79
HORIZONTAL CYLINDER									
0.0	23	.42	1.74	2.38	1.57	7.31	10.11	5.57	3.84
5.0	15	.97	1.25	1.08	1.88	2.04	1.96	2.33	5.22
10.0	21	.26	.68	1.24	4.18	2.44	1.76	2.33	2.75
15.0	16	.29	.52	.17	.29	.76	2.16	1.74	1.76
20.0	22	.68	.73	1.74	2.16	2.45	3.36	2.58	3.84
20.0	12	1.74	2.18	2.78	1.22	1.01	1.74	1.30	.69
CYLINDER ON END									
5.0	-	-	.61	1.39	2.09	2.44	7.27	5.15	-
10.0	-	.37	.54	1.04	1.36	2.44	2.78	5.21	4.80
15.0	-	.52	.78	1.91	3.82	2.38	2.01	2.11	1.97
20.0	-	.69	1.81	1.43	1.06	1.97	1.57	1.65	1.76
0.0	22	.21	.35	.52	1.10	3.12	2.78	2.56	3.10
5.0	14	.87	1.04	1.04	1.41	1.13	1.48	1.87	1.76
10.0	16	.24	.33	.71	.87	1.74	1.74	1.79	1.81
15.0	12	.66	1.76	2.21	.87	.83	1.57	1.43	.42
15.0	21	1.03	.75	1.18	1.37	1.53	2.26	1.91	2.02
20.0	11	.73	1.27	.99	.52	1.52	1.91	1.39	3.96

NOTE: (1) A SINGLE DASH INDICATES MISSING DATA

(2) UNDERLINED VALUES WERE CONSIDERED ANOMALOUS

Table VII. SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

VELOCITY ft/sec	STATION	DEPTH 6"	12"	18"	24"	30"	36"	42"	48"	54"	60"	66"	72"
CYLINDER ON END (CONT)													
5.0	20	.21	.31	.31	1.44	1.44	2.44	5.54	2.44				
10.0	25	.21	.57	1.46	2.11	2.05	2.07	2.09	6.26				
15.0	19	.36	.45	.40	1.22	1.39	1.74	2.35	4.45				
20.0	35	1.81	1.04	1.39	2.26	2.32	3.50	2.79	1.91				
CUBE													
5.0	-	1.01	1.04	1.76	.87	1.23	1.53	.56	.35				
10.0	-	1.06	.71	1.01	2.68	6.92	2.10	2.38	2.10				
15.0	-	.61	.72	3.48	2.97	1.88	1.74	1.55	1.60				
20.0	-	.75	1.29	.52	.66	2.83	5.07	6.95	3.04				
RECTANGLE													
0.0	24	1.39	.71	1.04	.52	1.74	2.12	2.78	2.87				
5.0	13	.35	1.02	1.37	2.68	2.99	5.87	3.65	2.77				
10.0	11	.99	.68	.71	1.70	1.74	2.07	1.95	3.13				
15.0	17	.38	.69	.69	1.56	2.00	3.48	5.93	4.35				
15.0	19	.78	.33	.35	.69	1.74	6.10	4.86	3.91				
20.0	18	.26	.35	1.31	.78	1.56	3.30	4.52	2.44				
CONE													
0.0	23	.31	.35	.52	.75	.95	2.78	1.71	2.61	3.36	2.61	2.70	2.96
0.0	a	.66	1.30	5.43	5.35	2.60	1.74	2.44	2.60	2.66	3.70	2.69	5.70
0.0	b	.29	.40	.68	.99	1.53	1.82	5.78	2.59	4.52	5.30	2.40	2.82
0.0	c	.66	.71	1.50	1.48	2.35	2.92	4.95	2.28	4.70	2.75	2.21	5.70
5.0	13	.36	.29	.71	2.12	1.36	3.35	3.33	2.82	1.95	1.79	1.90	1.88
"	a	.76	1.22	.69	1.33	8.60	9.99	2.65	2.35	1.60	1.32	1.62	5.21

TABLE VII. (CONTINUED) SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

VELOCITY ft/sec	STATION	DEPTH 6"	12"	18"	24"	30"	36"	42"	48"	54"	60"	66"	72"
CONE (CONT)													
5.0	b	1.18	.54	.49	3.11	2.49	1.79	1.72	2.08	1.44	1.31	1.28	1.28
"	c	.95	.67	.82	1.88	3.03	3.15	2.96	1.80	2.57	2.12	1.62	2.10
10.0	30	.22	.15	.31	3.25	7.50	6.30	6.90	4.92	8.70	3.65	3.01	2.49
"	a	.17	.35	.66	2.28	4.78	5.00	8.46	5.80	6.11	5.45	3.27	3.29
"	b	.45	.19	.22	.34	.75	3.45	8.32	9.46	7.64	4.63	2.92	4.93
"	c	.33	.24	.69	2.33	2.19	2.49	4.38	3.31	2.92	3.15	3.67	3.59
15.0	31	.15	.15	.20	.55	1.14	1.68	2.45	1.79	7.26	3.76	5.79	5.35
"	a	.10	.15	.41	1.20	2.25	1.60	1.74	5.43	8.93	9.90	4.47	4.85
"	b	.28	.15	.17	.24	.80	1.32	1.11	2.71	2.40	3.80	3.38	4.01
"	c	.70	.43	.33	1.04	2.89	2.07	4.12	5.91	6.66	5.46	5.32	3.57
20.0	32	.36	.38	.76	1.32	1.60	6.32	5.70	2.60	2.23	2.36	2.54	5.80
"	a	.43	.73	1.03	2.16	2.30	5.35	2.34	3.01	2.64	2.85	3.72	3.80
"	b	.66	1.01	.87	7.20	4.94	2.82	2.17	1.97	2.54	2.80	2.74	4.13
"	c	1.39	.54	1.91	2.86	2.97	3.39	1.60	1.76	3.34	3.45	2.66	3.16
OTHER MEASUREMENTS													
	39	1.57	1.22	1.13	.87	.70	.68	.68	1.57	2.61	2.18	3.27	1.94
	41	.69	.73	.73	1.57	1.58	1.37	5.90	7.65	2.36	2.70	2.65	2.78
	-	.67	.60	.45	.90	1.40	1.56	1.75	1.50	1.25	1.90	1.75	1.60
	18	.20	.45	.85	1.05	1.05	1.45	1.65	1.40	1.25	1.20	1.15	1.30
	a	.40	.65	.65	.75	.35	.85	.75	.90	.90	.20	.35	.60
	b	.60	1.20	.85	.85	1.00	1.00	1.10	1.20	.90	.70	.70	1.00
	c	.80	1.20	1.85	1.70	1.15	1.10	1.15	1.30	1.15	1.00	3.20	1.70
	21	.10	.15	.35	.60	1.00	1.05	1.00	.80	.60	.40	.90	2.50
	a	.30	.70	1.10	1.20	1.00	1.05	1.15	.85	.95	1.30	1.90	2.90
	b	.40	.85	1.20	1.60	2.05	1.50	1.10	.95	1.10	1.30	2.15	2.90
	c	.60	1.05	1.25	1.65	2.25	1.65	1.25	1.20	1.45	1.75	2.60	3.25
	24	.40	1.05	.80	.90	1.05	.80	.80	1.35	1.40	.90	.75	.90
	a	.60	1.40	1.20	1.15	1.20	1.20	1.20	1.50	1.60	1.80	1.35	1.50
	b	1.10	1.75	2.15	2.05	1.35	1.75	1.60	1.60	1.75	2.05	1.95	2.20

TABLE VII. (CONTINUED) SEDIMENT VANE SHEAR STRENGTHS IN THE TEST PIT

TABLE VIII. MEAN SHEAR STRENGTHS AND STANDARD DEVIATIONS OF TEST PIT.

DEPTH (in)	MEAN SHEAR STRENGTHS (psi)		ONE STANDARD DEVIATION (psi)	
6"	$.50_{(55)}$	$.60_{(69)}$	.23	.38
12"	$.73_{(60)}$	$.75_{(73)}$	.32	.44
18"	$.99_{(61)}$	$1.11_{(73)}$	.47	.84
24"	$1.50_{(60)}$	$1.72_{(73)}$	.63	1.21
30"	$1.80_{(60)}$	$2.22_{(73)}$	.62	1.57
36"	$2.03_{(56)}$	$2.77_{(73)}$	.70	1.94
42"	$1.98_{(50)}$	$2.87_{(73)}$	.60	1.87
48"	$2.20_{(57)}$	$2.71_{(72)}$	.74	1.60
54"	$1.93_{(25)}$	$3.40_{(34)}$	.75	1.96
60"	$2.34_{(25)}$	$2.69_{(34)}$	.71	1.81
66"	$2.52_{(28)}$	$2.47_{(34)}$	.82	1.21
72"	$2.52_{(24)}$	$3.04_{(34)}$	.87	1.49

Note: The first columns under the shear strengths and standard deviations are values computed with the anomalous points discarded. The second columns are values computed with all the data points. The subscripts in parenthesis are the number of data points.

water was continually added to the test pit to offset evaporation losses and the top of the pit was continually being reworked by raking. In general, a virgin undisturbed sediment should have a finite strength at the surface.

C. RESULTS

Table IX summarizes the observed penetration depths, the predicted depths, and tabulates the difference between observed and predicted. A numerical analysis of the differences between observed and predicted depths was not made because, with few exceptions, the method developed accurately predicted the penetration depth within the experimental uncertainties of depth measurement and shear strength accuracy. The method overestimated penetration 17 times and underestimated penetration 22 times. The largest differences were underestimates of penetration. In all cases of differences greater than four inches, the prediction had to rely on an adjusted shear strength. This indicated a problem with measuring the shear strength at that station and implied the presence of a soft pocket in the sediment. The large discrepancies also occurred with impact velocities of five feet per second.

Table X sets forth the penetration data along with notes taken from movies of the tests. The time-to-penetrate was observed by counting the frames of the movie film from object impact until all downward motion had ceased. The rebound time was also observed by counting movie frames. The rebound distance was estimated from the pictures and is believed

Table IX. SUMMARY OF RESULTS

OBJECT VELOCITY (ft/sec)	PENETRATION OBSERVED (in)	PENETRATION PREDICTED (in)	DIFFERENCE (in)
SPHERE (wt. = 561 lbs)			
0.0	9.5"	10.7"	+ 1.2"
5.0	13.5"	12.1"	- 1.3"
10.0	14.0"	14.0"	0.0"
15.0	24.2"	24.5"	+ 0.3"
20.0	20.0"	20.5"	+ 0.5"
5.0	16.0"	11.5"	- 4.5"
10.0	16.0"	12.1"	- 3.9"
15.0	19.0"	23.0"	+ 4.0"
20.0	19.5"	20.4"	+ 0.9"
HORIZONTAL CYLINDER (wt. = 540 lbs)			
0.0	5.5"	6.0"	+ 0.5"
5.0	11.5"	7.5"	- 4.0"
10.0	13.0"	13.8"	+ 0.8"
15.0	17.0"	17.0"	0.0"
20.0	16.0"	15.9"	- 0.1"
20.0	14.7"	14.7"	0.0"
CYLINDER ON FLAT END (wt. = 540 lbs)			
5.0	14.0"	8.7"	- 5.3"
10.0	15.5"	12.8"	- 2.7"
15.0	15.0"	14.2"	- 0.8"
20.0	-----	16.2"	-----
0.0	8.0"	8.4"	+ 0.4"
5.0	4.2"	4.4"	+ 0.2"
10.0	18.0"	16.0"	- 2.0"
15.0	14.0"	12.7"	- 1.3"
15.0	18.0"	14.6"	- 3.4"
20.0	19.0"	16.8"	- 2.2"

TABLE IX. (CONTINUED) SUMMARY OF RESULTS

OBJECT VELOCITY (ft/sec)	PENETRATION OBSERVED (in)	PENETRATION PREDICTED (in)	DIFFERENCE (in)
CYLINDER ON FLAT END (wt. = 561 lbs)			
5.0	-----	12.6"	-----
10.0	14.0"	14.0"	0.0"
15.0	18.5"	20.4"	+1.9"
20.0	13.5"	16.1"	+2.6"
CUBE (wt. = 702 lbs)			
0.0	4.5"	3.7"	-0.8"
5.0	5.7"	4.4"	-1.3"
10.0	8.5"	9.7"	+1.2"
15.0	13.0"	12.8"	-0.2"
20.0	17.0"	14.9"	-2.1"
RECTANGLE (parallelopiped, wt. = 1014 lbs)			
0.0	3.0"	3.2"	+0.2"
5.0	5.0"	7.0"	+2.0"
10.0	9.2"	9.4"	+0.2"
15.0	14.8"	14.7"	-0.1"
15.0	15.5"	19.0"	+3.5"
20.0	21.6"	20.1"	-1.5"
CONE (wt. = 1127 lbs)			
0.0	55.0"	50.0"	-5.0"
5.0	53.5"	51.0"	-2.5"
10.0	49.5"	54.0"	+4.5"
15.0	65.0"	64.0"	-1.0"
20.0	62.5"	59.0"	-3.5"

accurate to one inch. Penetration depth refers to the object's final resting position and did not exclude the rebound distance. The percent of ultimate bearing capacity was calculated as; the ultimate bearing capacity of the sediment at the depth the object came to rest, divided by the actual force applied to the sediment by the object at its final resting position. The shear strength adjusted column indicates whether or not an anomalous shear strength value was adjusted which directly affected the calculations of penetration prediction.

The time-to-penetrate measurement was done in an inexact manner, but is remarkably constant when the range of velocities and different object shapes are considered. Its relative constancy in relation to the other parameters may indicate that it is related to a unique basic property of the sediment. Schmid [1966] observed the same phenomena when testing small penetrometers with different impact velocities.

The rebound time and distance were very difficult to estimate due to the short duration and fact that splatter sometimes partially obscured the object. Some of the rebound of the object, and apparent elastic behavior of the sediment was originally thought to be caused by a buoyancy effect. However the cavity formed by penetration did not collapse until rebound was over and the object was essentially at rest. Subjectively it appears that rebound is a function of an elastic property of the sediment.

The percent of ultimate bearing capacity that was reached by the different objects seems to relate to impact velocity. In all the penetration tests the objects were left in place for at least 24 hours and in some cases up to eight days and then checked to see if they had settled further into the sediment. No further settlement was observed in any case. At an impact velocity of five feet-per-second the objects consistantly penetrated to a level where 300 percent of the ultimate bearing capacity was available to support the object. This implies that a structure being emplaced by a free-fall technique would only require a velocity of five feet-per-second to generate the safety factor of three recommended in soil mechanics in a situation where the ultimate bearing capacity equation is used.

As observed in the movies, any air entrapped under the object had negligible effect on either rebound or penetration depth. Rounded objects such as the sphere and horizontal cylinder did not behave differently from the flat sided objects that did entrap some air.

Cratering and pile up of the sediment was slight. In all cases, even with the rectangular parallelepiped impacting at 20 feet per second, the crater lip was less than 2 inches high. The sediment moved laterally away from the objects and not up.

Table X. NOTES FROM PENETRATION TESTS

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	SPHERE — NOTES FROM MOVIES OF THE TESTS
0.0	10.7	+1.2	15	.25	½	.13	240	no	----
5.0	12.2	-1.3	15	.25	1	.13	325	no	The sediment moved with a horizontal motion five feet from the drop position.
10.0	14.0	0.0	15	.22	1	.16	493	no	The sphere rotated during and after rebound.
15.0	24.5	+0.3	15	.22	1	.19	478	yes	A neat crater with a small lip was formed around the sphere. The sediment moved horizontally away from the sphere.
20.0	20.5	+0.5	15	.17	2	.19	795	no	The sediment was observed to move horizontally away and up slightly during penetration. It moved toward the sphere as the sphere came to rest.
5.0	11.5	-4.5	13	.28	½	.10	336	yes	The shear strength at six inches was not recorded. The sphere went straight in forming a small crater.
10.0	12.1	-3.9	13	.22	½	.12	590	no	-----
15.0	23.0	+4.0	13	.22	1	.10	670	yes	The shear strength at six inches was not recorded. A small crater was formed with the sediment having a peeled back appearance at the rim.
20.0	20.4	-0.9	13	.18	2½	.12	1060	yes	The shear strength at six inches was not recorded. The crater slumped in after the sphere came to rest.

TABLE X. (CONTINUED)

HORIZONTAL CYLINDER

NOTES FROM MOVIES OF THE TESTS

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	NOTES FROM MOVIES OF THE TESTS
0.0	6.0	+0.5	14	.22	0	-	206	no	The cylinder went straight in with little splatter and rotated about its axis after maximum penetration.
5.0	7.5	-4.0	14	.22	1	.10	317	yes	The cylinder went straight in but only one end rebounded. At rest one end was three inches lower than the other.
10.0	13.8	+0.8	14	.22	2½	.22	495	no	The cylinder went straight in and rebounded straight up with a small amount of splatter. Four feet away from the cylinder the sediment moved horizontally.
15.0	17.0	0.0	14	.22	4	.25	607	no	The cylinder went straight in but one end penetrated four inches more than the other. The rebound was at an angle. A definite horizontal motion of the sediment was observed up to six feet away from the cylinder.
20.0	15.9	-0.1	14	.22	-	.19	848	no	One end penetrated seven inches more than the other. Not much splatter was observed. A crater was made but it slid in around the cylinder during rebound.
20.0	14.7	0.0	14	.19	3	.22	1020	yes	Cylinder went straight in and rebounded straight up.
									In all the tests the cylinder rotated and wobbled at the maximum penetration depth as if it was floating in a liquid.

TABLE X. (CONTINUED)

CYLINDER ON FLAT END (wt. -540 lbs)
NOTES FROM MOVIES OF THE TESTS

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT, 1965	TIME TO PENETRATE (sec)	REBOUND D DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	NOTES
5.0	8.7	-5.3	10	---	-	---	268	yes	Only before and after pictures were available. The shear strength at six inches was not recorded.
10.0	12.8	-2.7	10	---	-	---	348	no	Only before and after pictures were available.
15.0	14.2	-0.8	10	.19	1	.12	580	no	Cylinder went straight in and rebounded straight up.
20.0	16.2	----	10	.22	1	.12	750	yes	The cylinder was swinging when it was dropped and was canted about six degrees on impact. It continued to tip completely over as it penetrated and came to rest in an almost horizontal position with a little over one half its volume submerged. It was impossible to estimate a penetration depth.
0.0	8.4	+0.4	15	.25	-	---	168	no	The movies showed three different trials at zero velocity. In each case the cylinder tipped over after reaching its maximum penetration depth. The observed penetration was estimated from the movies to be eight inches in all three cases.
5.0	4.4	-0.2	15	.19	½	.12	319	no	----
10.0	16.0	-2.0	15	.22	-	.19	369	no	The cylinder went straight in to about 14 inches then tipped on rebound. One side penetrated to 22 inches and the other to 14 inches.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	CYLINDER ON FLAT END (wt. 540 lbs) NOTES FROM MOVIES OF THE TESTS
15.0	12.7	-1.3	15	.19	1	.12	583	yes	The cylinder went straight in to about 14 inches then tipped on rebound. One side penetrated to 23 inches and the other to 11 inches. Penetration distance was estimated as 14 inches.
15.0	14.6	-3.4	15	.22	-	.19	534	yes	----
20.0	16.8	-2.2	15	.19	1½	.16	596	yes	Cylinder went straight in and tilted on rebound. In the final resting position one side penetrated to 23 inches and the other to 18.
									CYLINDER ON FLAT END (wt. 561 lbs)
5.0	12.6	----	20	.22	-	---	206	no	The movies showed two trials. In both cases the cylinder tipped completely over making it impossible to record an accurate penetration depth.
10.0	14.0	0.0	20	.22	-	---	475	no	Cylinder went straight in and tilted on rebound.
15.0	20.4	+1.9	20	.22	-	---	443	no	Cylinder went straight in forming a small crater. There was about one inch between the cylinder and the wall of the crater which was filled with the liquid splatter.
20.0	16.1	+2.6	20	.19	-	.10	735	yes	----

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	TABLE X. (CONTINUED) CUBE NOTES FROM MOVIES OF THE TESTS
0.0	3.7	-0.8	13	.22	-	---	157	yes	The shear strengths were not recorded for this test, therefore a shear strength profile similar to the mean for the mud pit was used. It was biased toward the other profiles determined on the 13 September. Air was trapped underneath the cube and it continued to jet out for about one second after the cube came to rest.
5.0	4.4	-1.3	13	.22	1	.06	332	yes	The cube went straight in and rebounded straight up. There was no entrapped air.
10.0	9.7	+1.2	13	.22	½	.06	412	yes	----
15.0	12.8	-0.2	13	.22	2	.12	507	no	The cube entered the sediment at a slight angle. One side penetrated five inches below the other. Entrapped air vented as the maximum depth was reached. The cube slid about two inches horizontally during the penetration.
20.0	14.9	-2.1	13	.22	-	.12	638	yes	The cube penetrated straight in and rebounded straight up but canted about two inches after resting. A crater was formed with the sediment raised slightly above the mean surface of the mud pit. The rise was visible three feet from the cube.

TABLE X. (CONTINUED)

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	RECTANGLE NOTES FROM MOVIES OF THE TESTS
0.0	3.2	+0.2	14	.22	-	0.0	154	yes	The rectangle tilted about one inch and slid sideways about two inches during penetration.
5.0	7.0	+2.0	14	.22	½	.12	366	no	----
10.0	9.4	+0.2	14	.22	½	.19	405	yes	The rectangle penetrated straight in until one half the total depth was reached then it tilted with one corner coming to rest three inches below the opposite corner. The sediment formed a crater as usual and moved horizontally away from the rectangle during the penetration.
15.0	14.7	-0.1	14	.22	1	.19	512	no	The rectangle entered straight then at a penetration depth of about eight inches one side dipped about six inches. The rebound further tilted the rectangle and at rest one corner was nine inches lower than the opposite corner.
15.0	19.0	+3.5	14	.25	1½	.16	332	yes	The rectangle penetrated straight in and rebounded straight up. The sediment moved horizontally ten feet distant from the rectangle as it penetrated.
20.0	20.1	-1.5	14	.22	-	.22	708	yes	At a distance of eight feet the sediment moved up then away from the rectangle. The volume of splatter from the impact was estimated to be less than ten percent of the crater volume.

TABLE X. (CONTINUED)

CONE

OBJECT VELOCITY (ft/sec)	PREDICTED PENETRATION (in)	DIFFERENCE FROM OBSERVED (in)	DAY OF TESTS SEPT. 1965	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	
0.0	50.0	-5.0	23	---	-	---	372	yes	The shear strength profile is the average of four sets of data from the location where the cones were dropped. No motion pictures were available for the cone tests.
5.0	51.0	-2.5	23	---	-	---	490	yes	"
10.0	54.0	+4.5	24	---	-	---	645	yes	"
15.0	64.0	-1.0	24	---	-	---	746	yes	"
20.0	59.0	-3.5	24	---	-	---	801	yes	"

IV. CONCLUSIONS AND RECOMMENDATIONS

A rational, phenomenological, theory has been applied to the problems of free-fall penetration into a simulated deep-sea sediment. The theory correlated well with full scale tests. A more complete solution will probably only be available after more is understood about the mechanical properties and dynamic behavior of deep-sea sediment.

A. CONCLUSIONS

The method predicts the penetration of free-falling objects into weak, saturated sediments for an air-to-sediment case within the accuracy of the present state-of-the-art techniques for measuring the sediment mechanical properties. It should work equally well in a water-to-sediment case with some modifications.

The impact duration time, from the instant of contact until the object comes to rest, was observed to be relatively constant and may be a unique property of the dynamic behavior of a sediment type. The duration time was relatively constant even though the penetration distance changed, the object shapes were different, and the kinetic energy of the falling objects ranged from 0 to 5,000 foot-pounds.

The method may be used with larger, heavier objects but caution must be used in extending the method for use with smaller objects since viscous drag and surface adhesion effects may be important for smaller masses.

At high impact velocities the effects of added mass and form drag cannot be neglected in computing penetration depth. The accuracy of the constants and variables in the standard bearing capacity equation have the most control over predicted penetration depths.

B. RECOMMENDATIONS

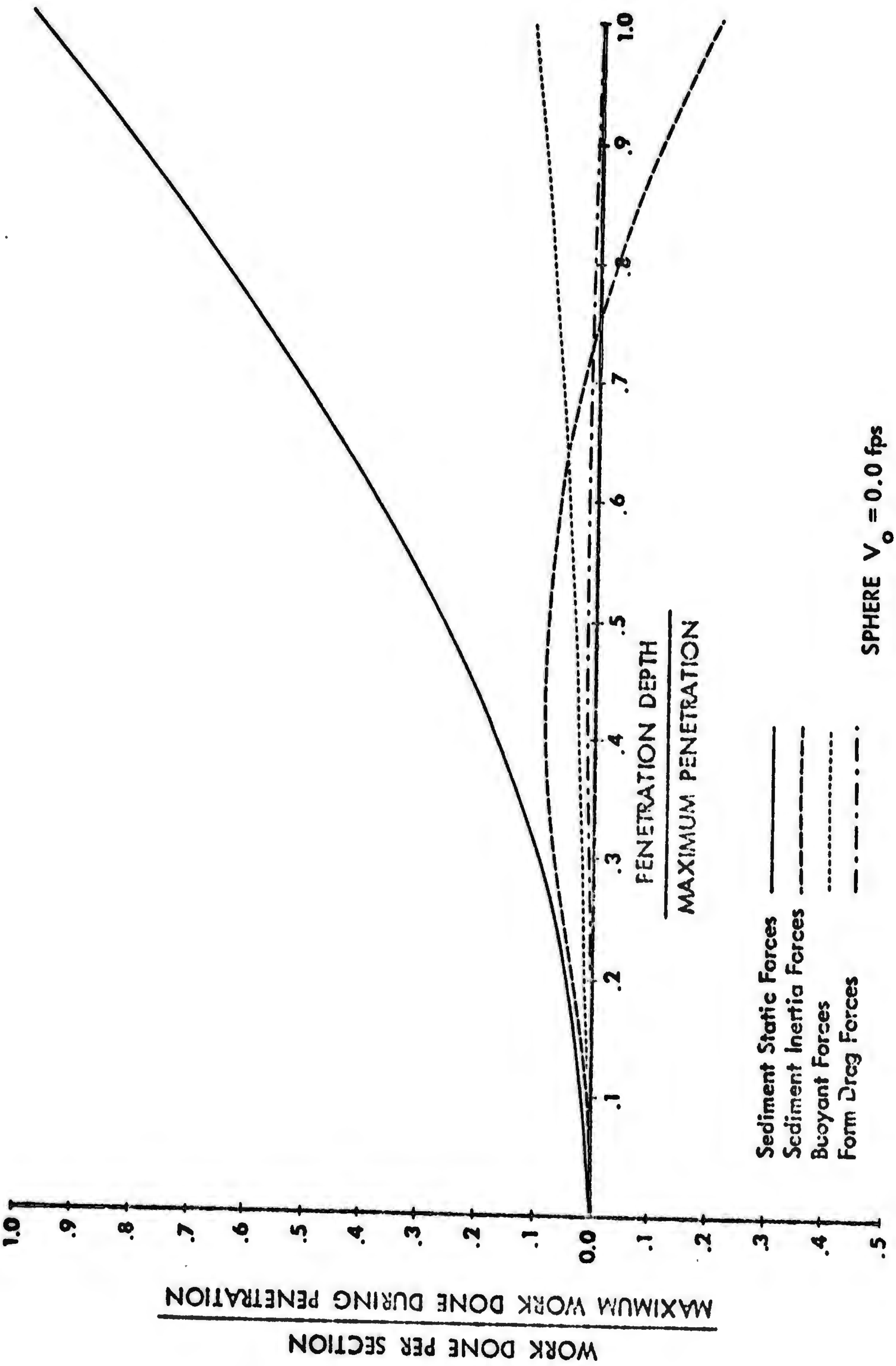
The method should be experimentally verified by full scale tests at sea or by controlled tests in a large tank ashore using a uniform sediment whose mechanical properties are known. Experiments of the scale needed would require a major effort but could include investigations into other unknown areas such as the free-fall attitude and stability of various shapes in water, the verification of terminal velocities of free-falling unstabilized objects in a water column and the study of breakout forces and salvage methods required to retrieve the objects.

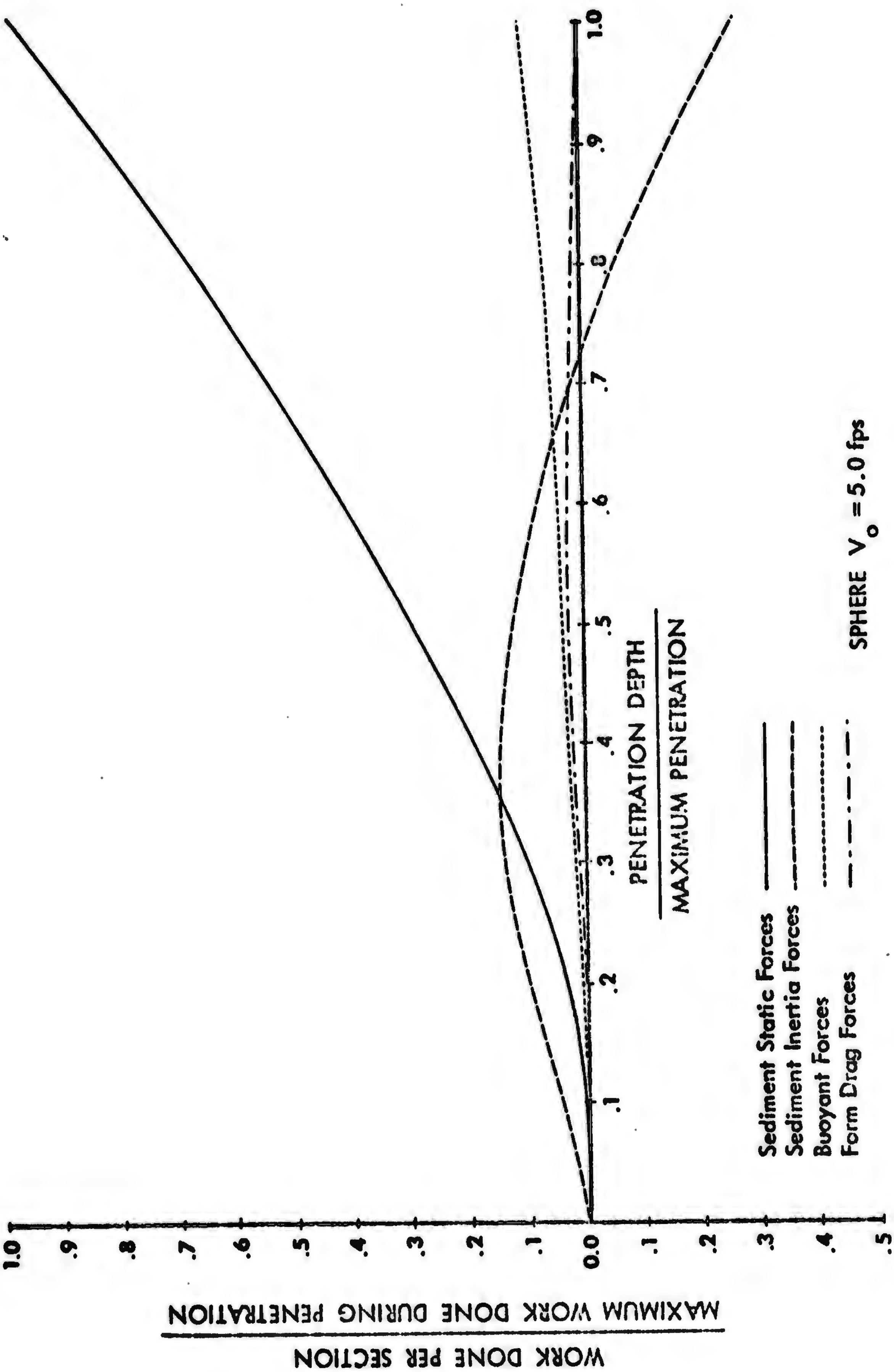
Whenever an object is recovered from the deep-ocean floor every effort should be made to obtain photographs of the object. The sediment around the object should be extensively sampled and completely analyzed to allow verification of this method of predicting penetration depth.

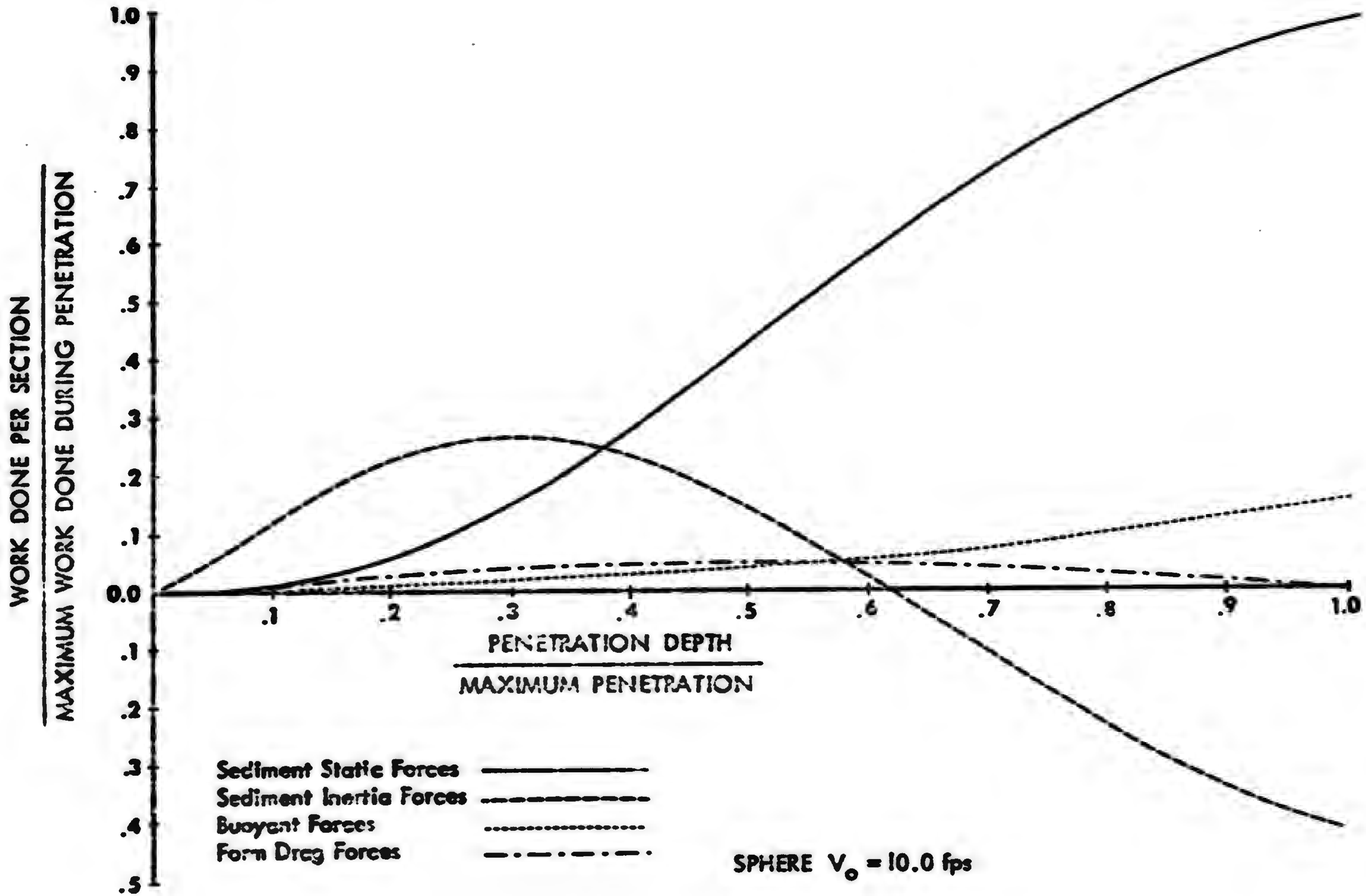
APPENDIX A

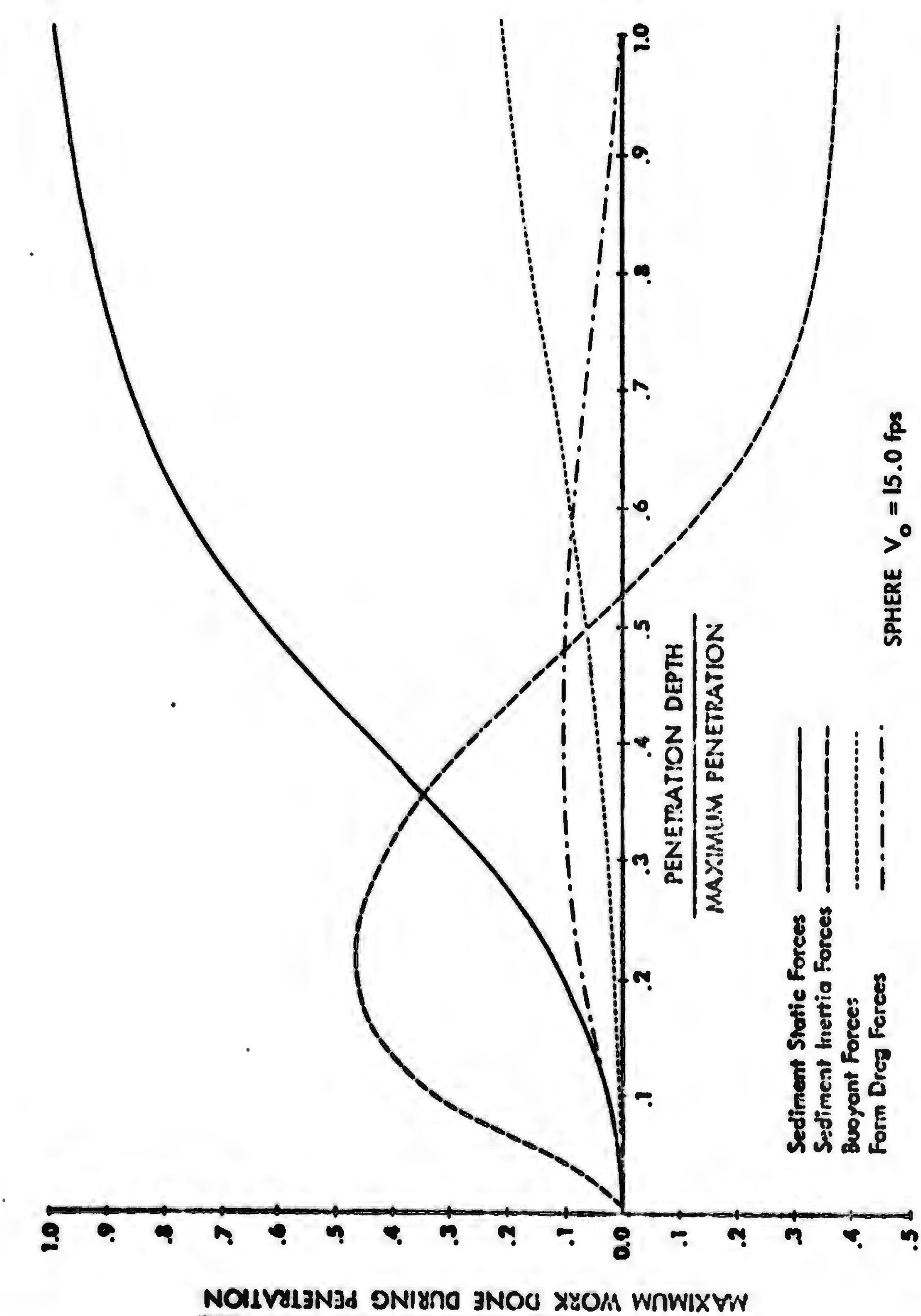
FORCES ON OBJECTS PENETRATING A TYPICAL SEDIMENT

Appendix A includes a set of curves which qualitatively illustrate the relative influence of each force in the penetration equation. They were obtained by using the sediment shear strength profile typical of the world's deep-ocean basins as determined by Hoag [1970] and shown in Figure 13. The curves are normalized for depth of penetration on the abcissa and the maximum force encountered on the ordinate. Time is independent of the calculations and the shape of the curve near the origin is largely a function of the iteration interval.

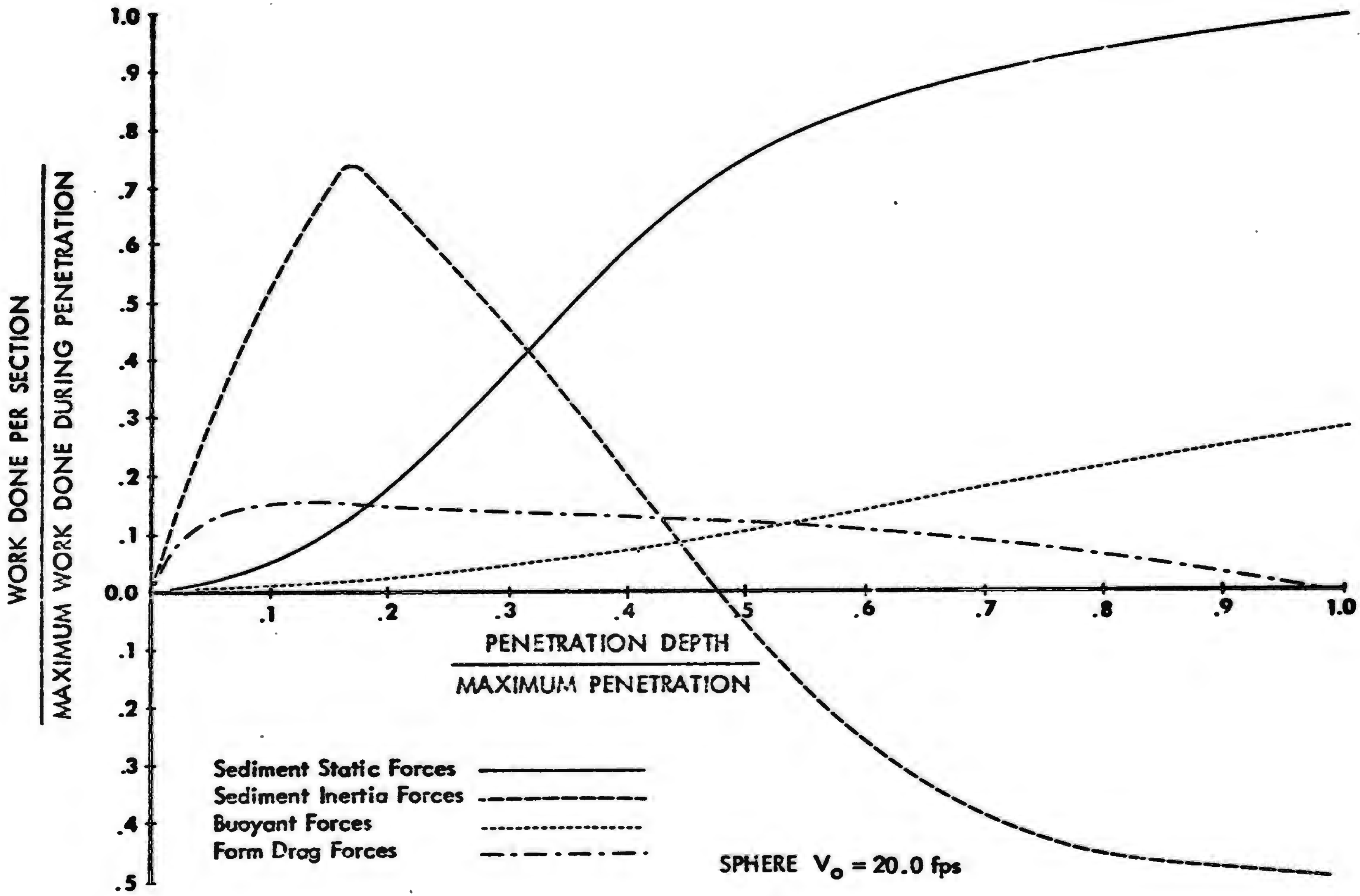

WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE V_o = 0.0 fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE V_o = 5.0 fps
0.0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0

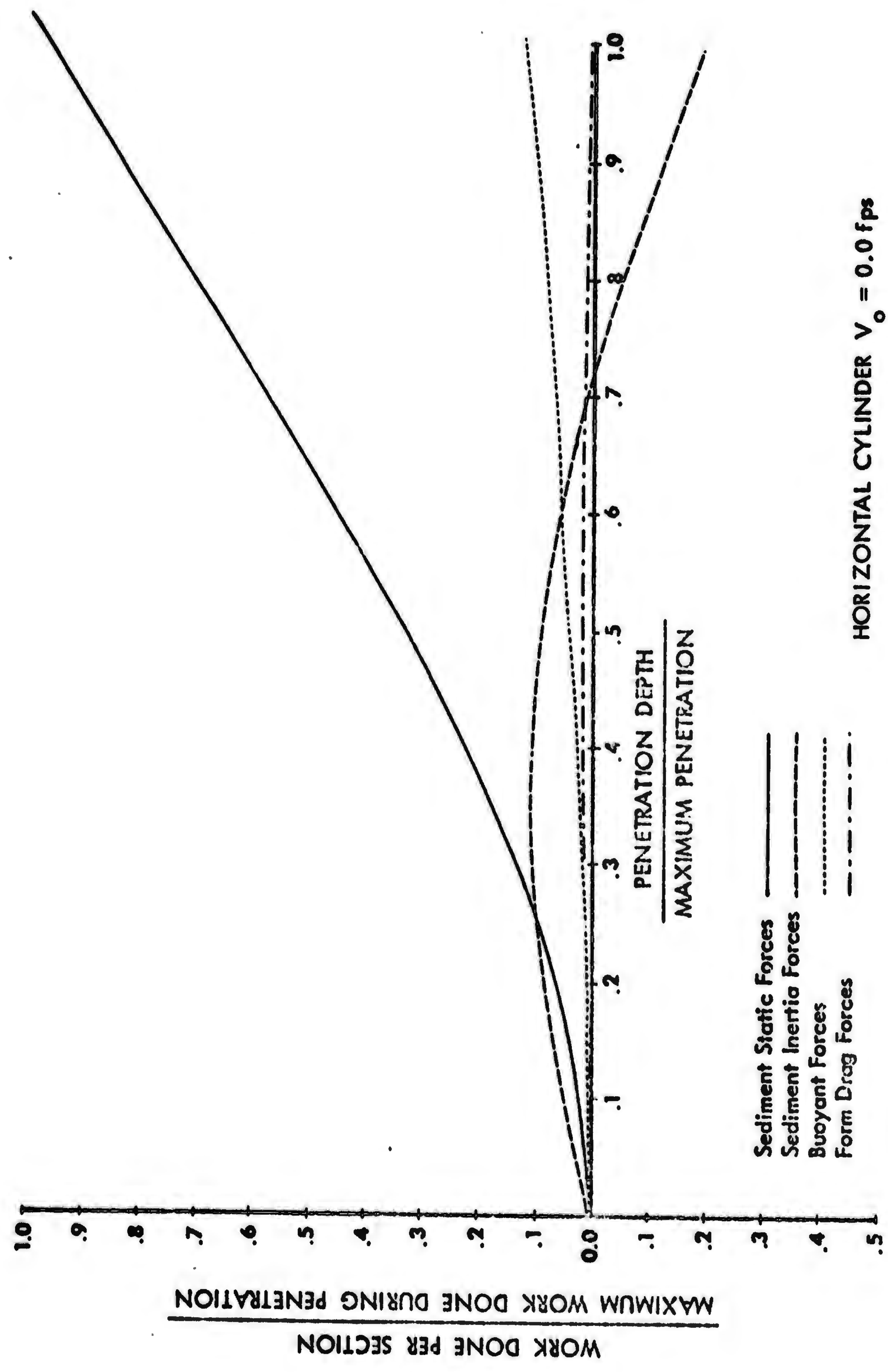

WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE V$_o$ = 10.0 fps



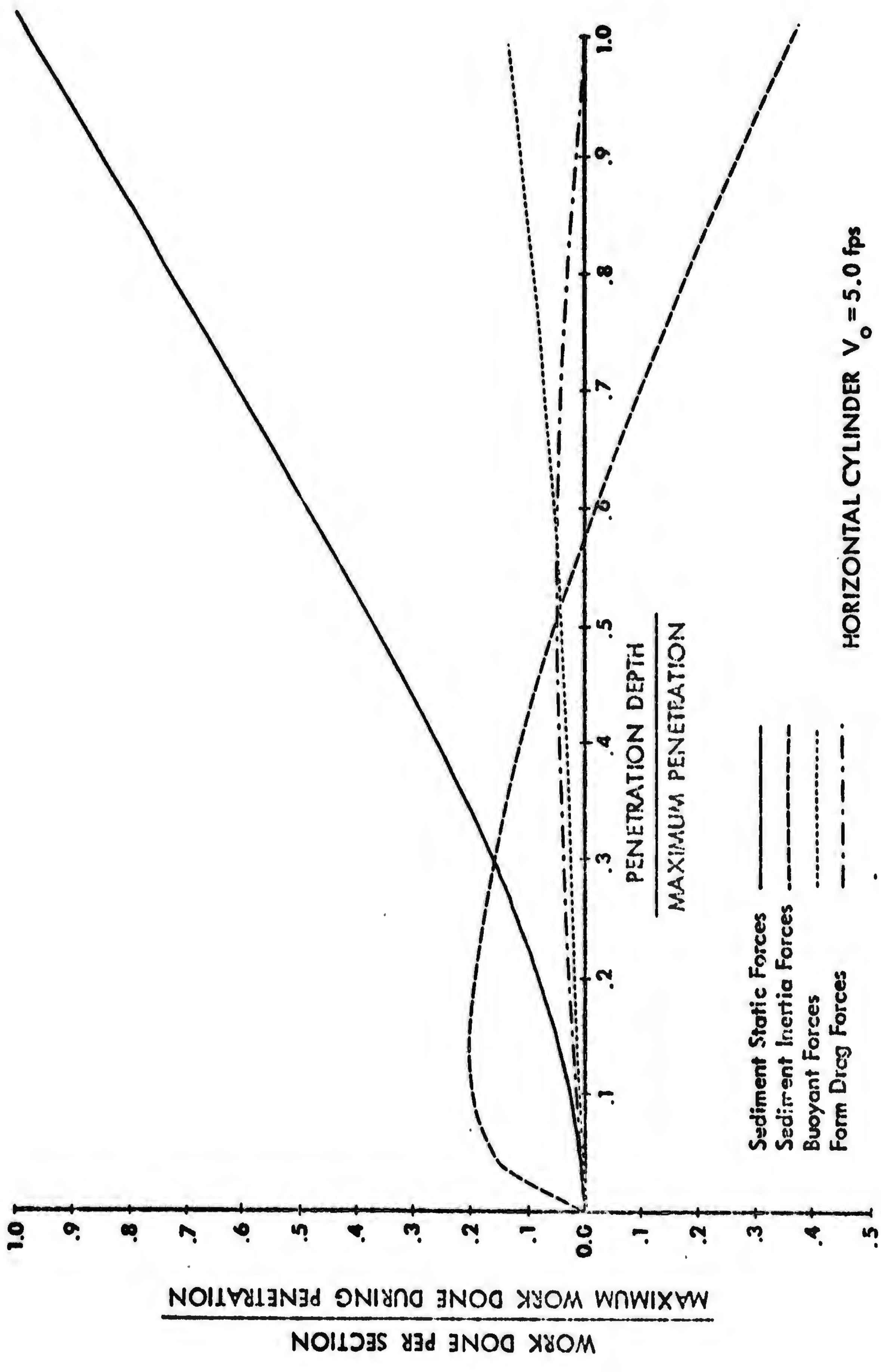
WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH / MAXIMUM PENETRATION
0.0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE V_o = 15.0 fps

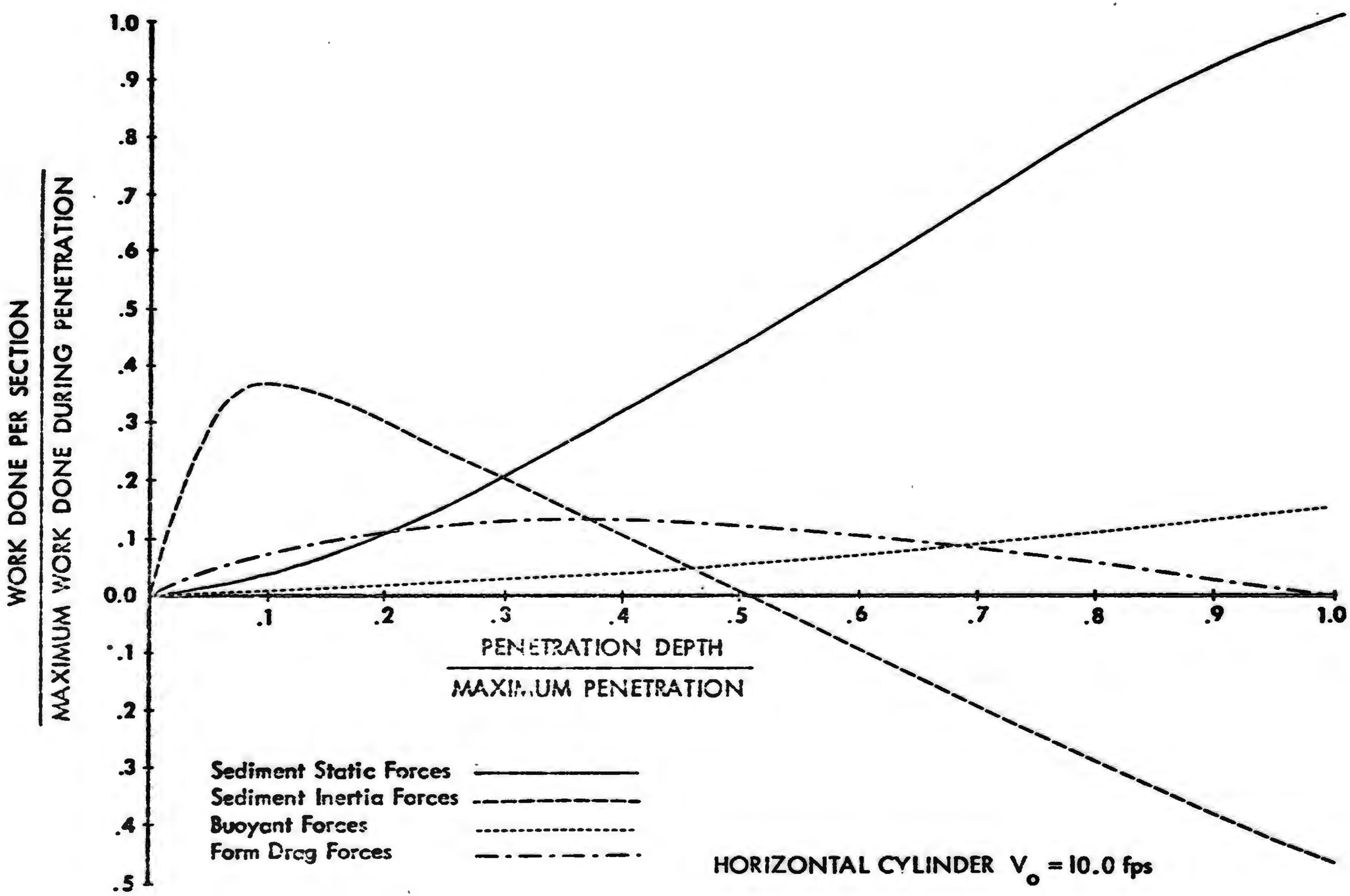


WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
SPHERE V₀ = 20.0 fps

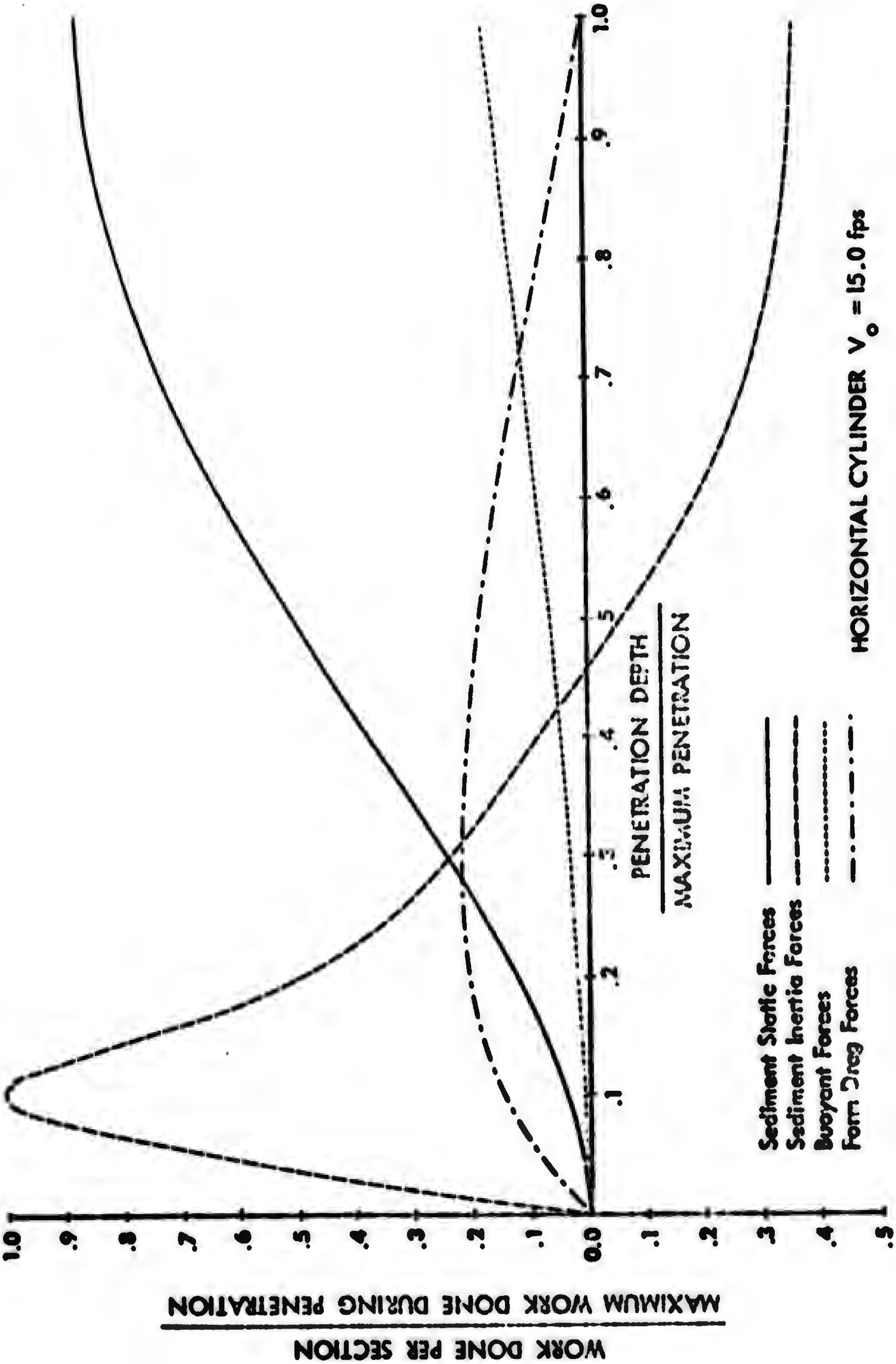


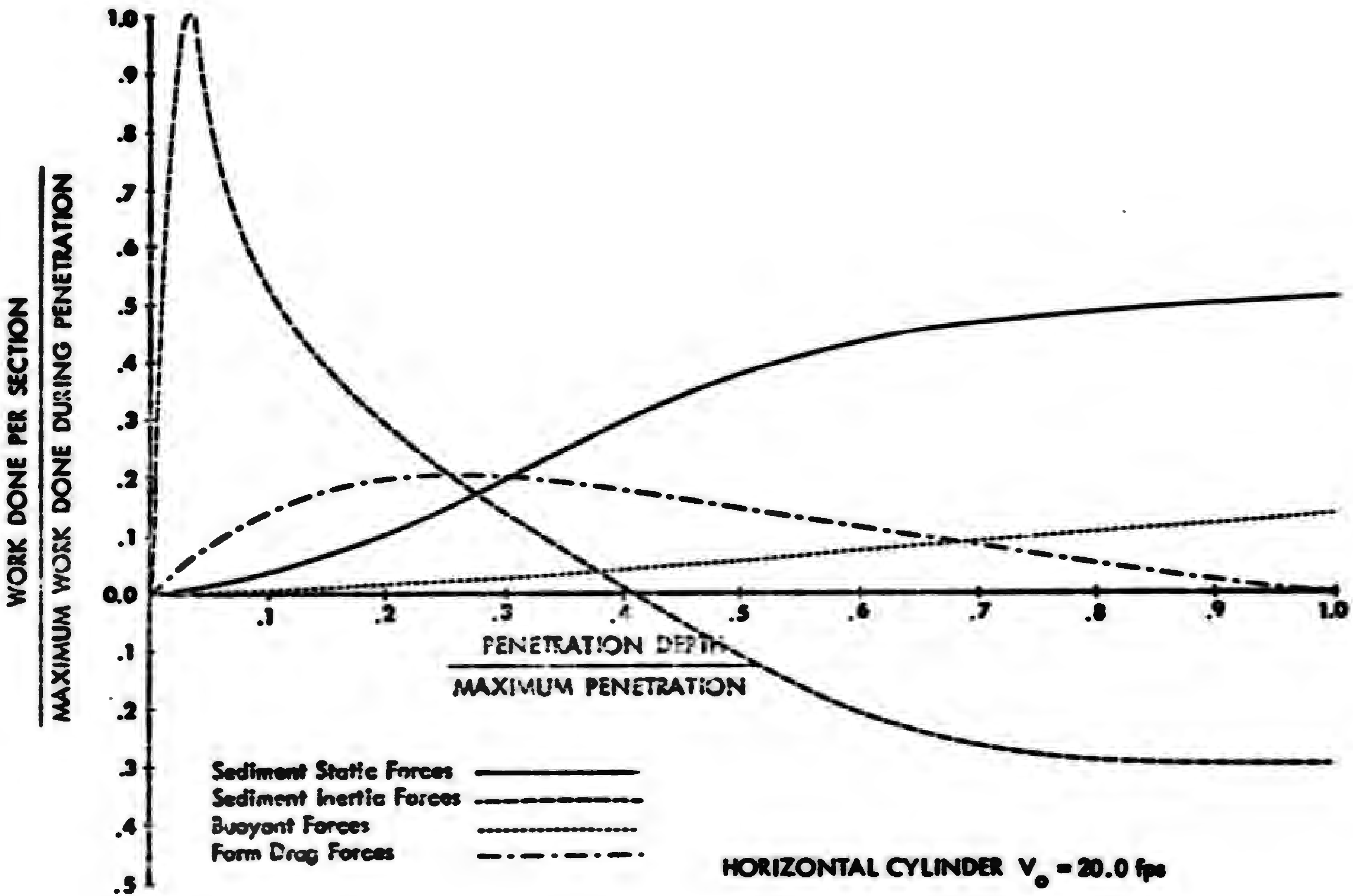
WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
PENETRATION DEPTH
MAXIMUM PENETRATION
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER V_o = 0.0 fps

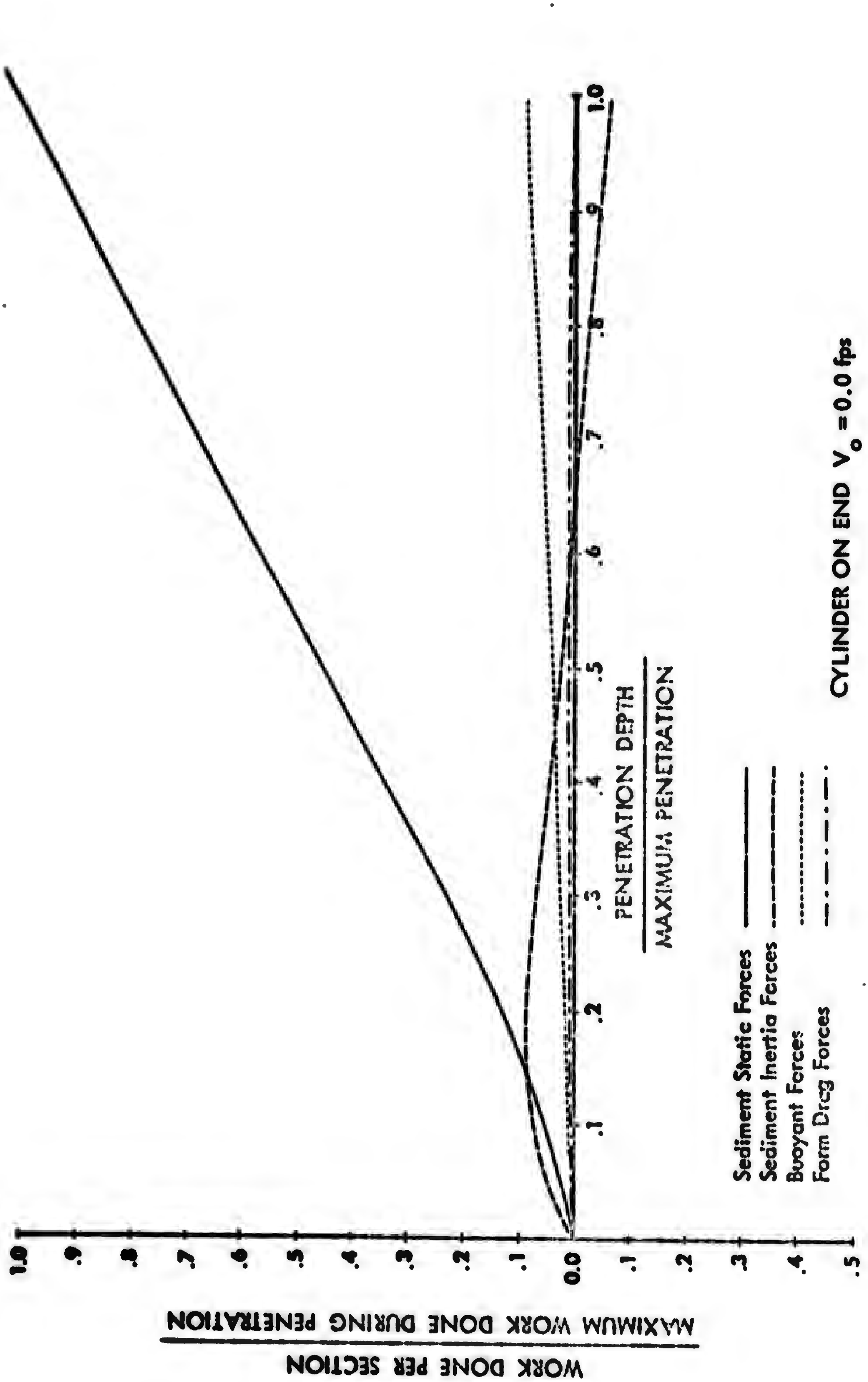

WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER V_o = 5.0 fps
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0



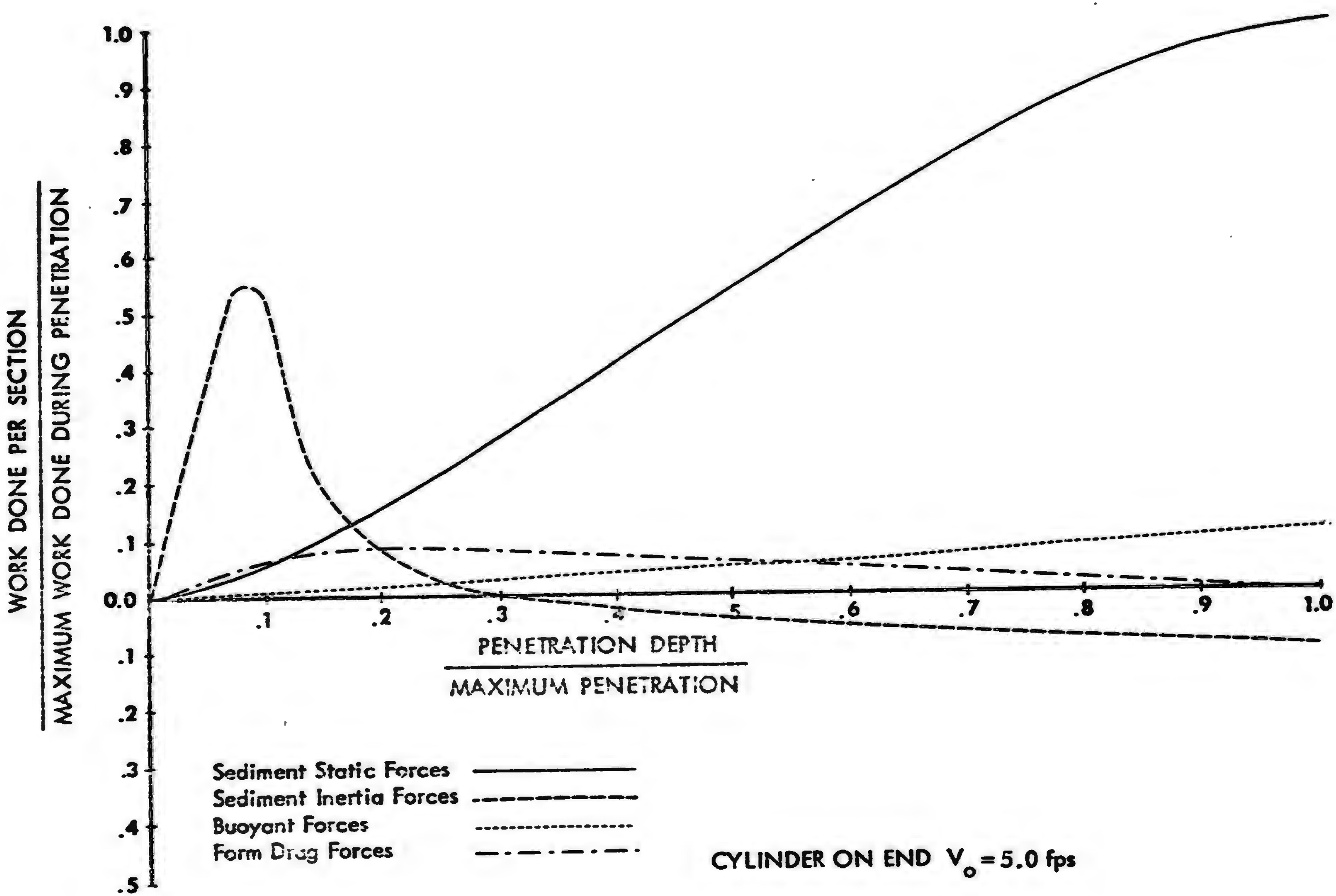
WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER V_o = 10.0 fps


WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0 .9 .8 .7 .6 .5 .4 .3 .2 .1 0.0 .1 .2 .3 .4 .5
PENETRATION DEPTH / MAXIMUM PENETRATION
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER V_o = 15.0 fps

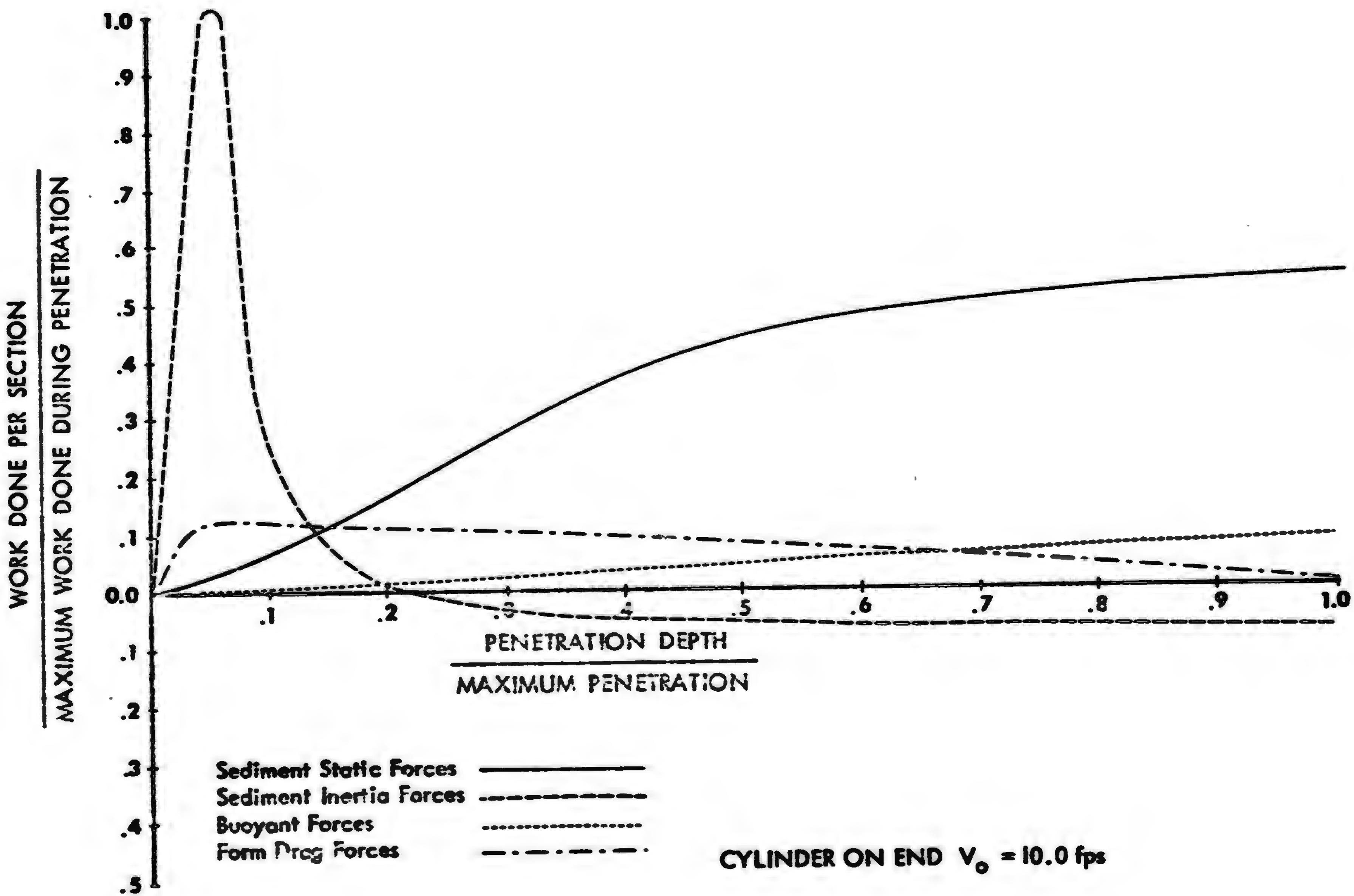

WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
HORIZONTAL CYLINDER V₀ = 20.0 fps



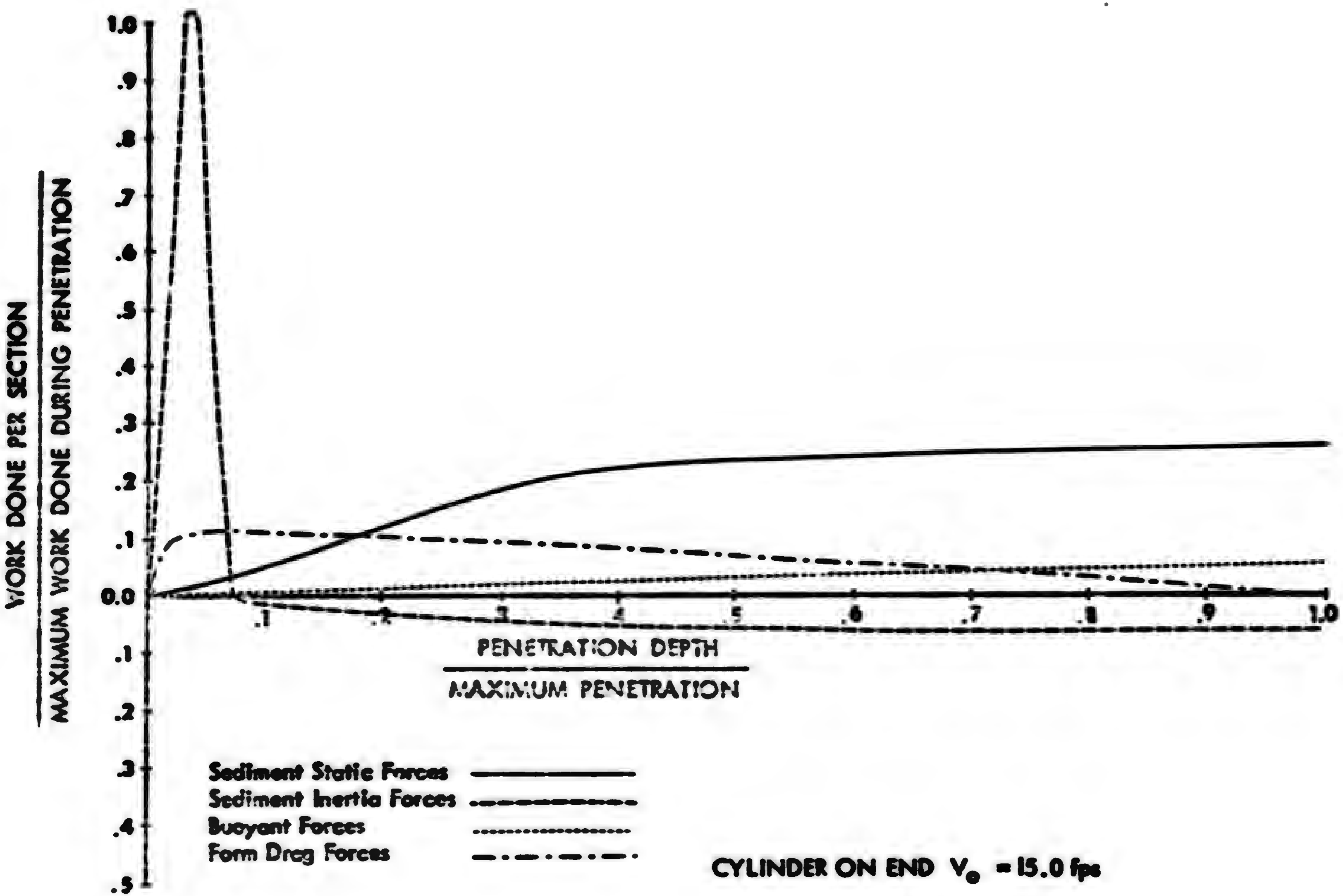
WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
PENETRATION DEPTH / MAXIMUM PENETRATION
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CYLINDER ON END V_o = 0.0 fps



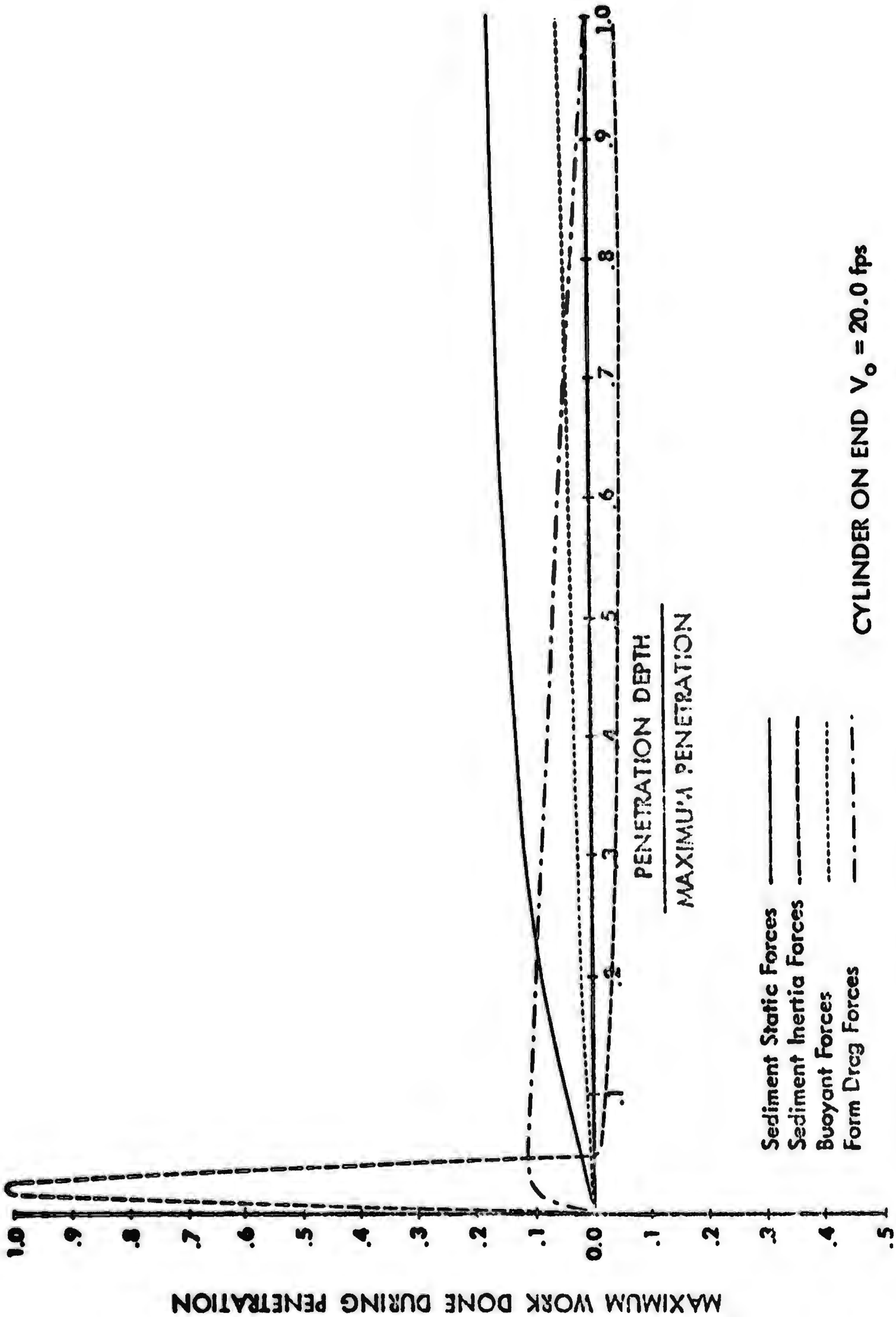
CYLINDER ON END $V_o = 5.0$ fps



CYLINDER ON END V_o = 10.0 fps



WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CYLINDER ON END V_o = 15.0 fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
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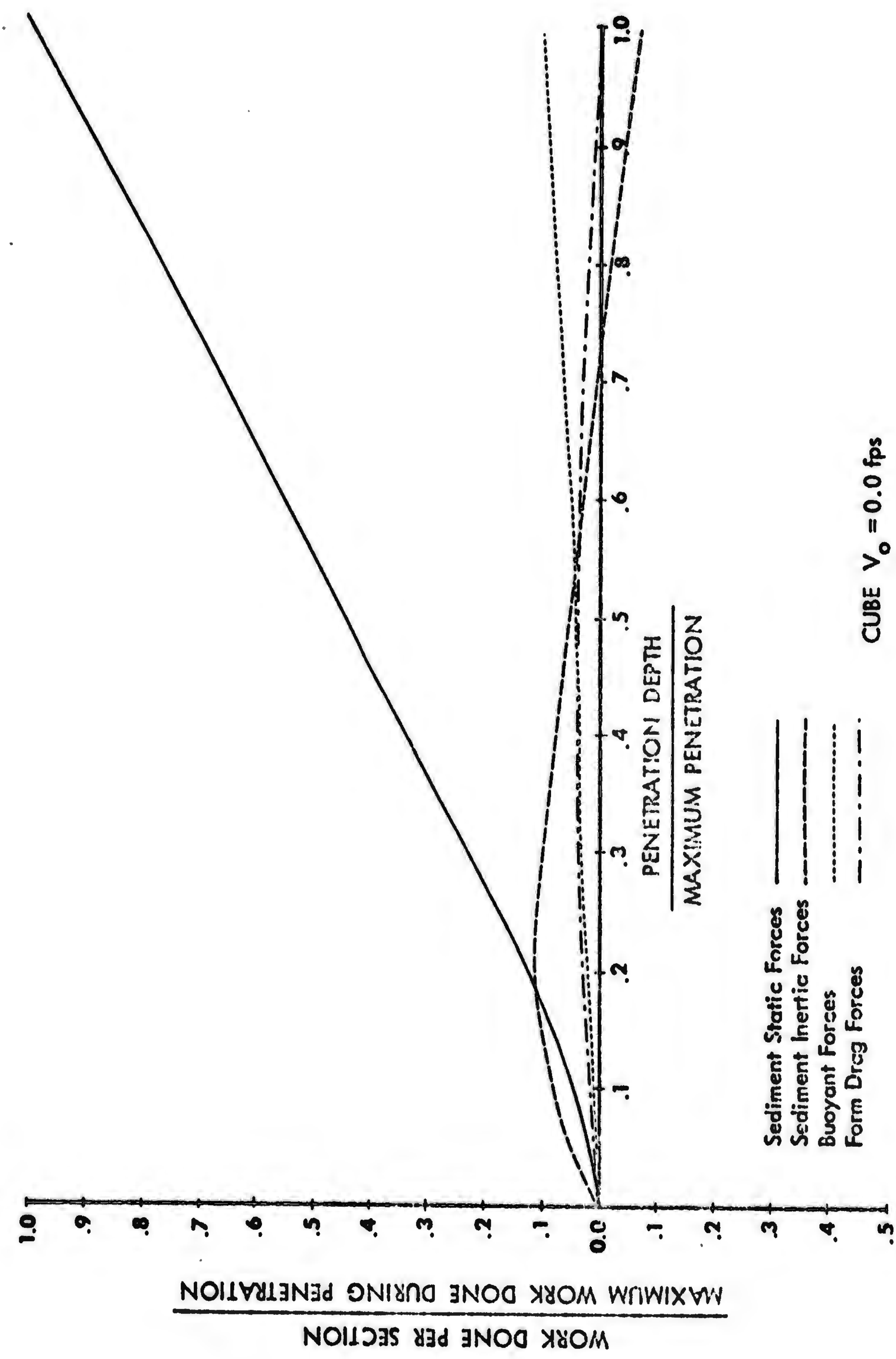
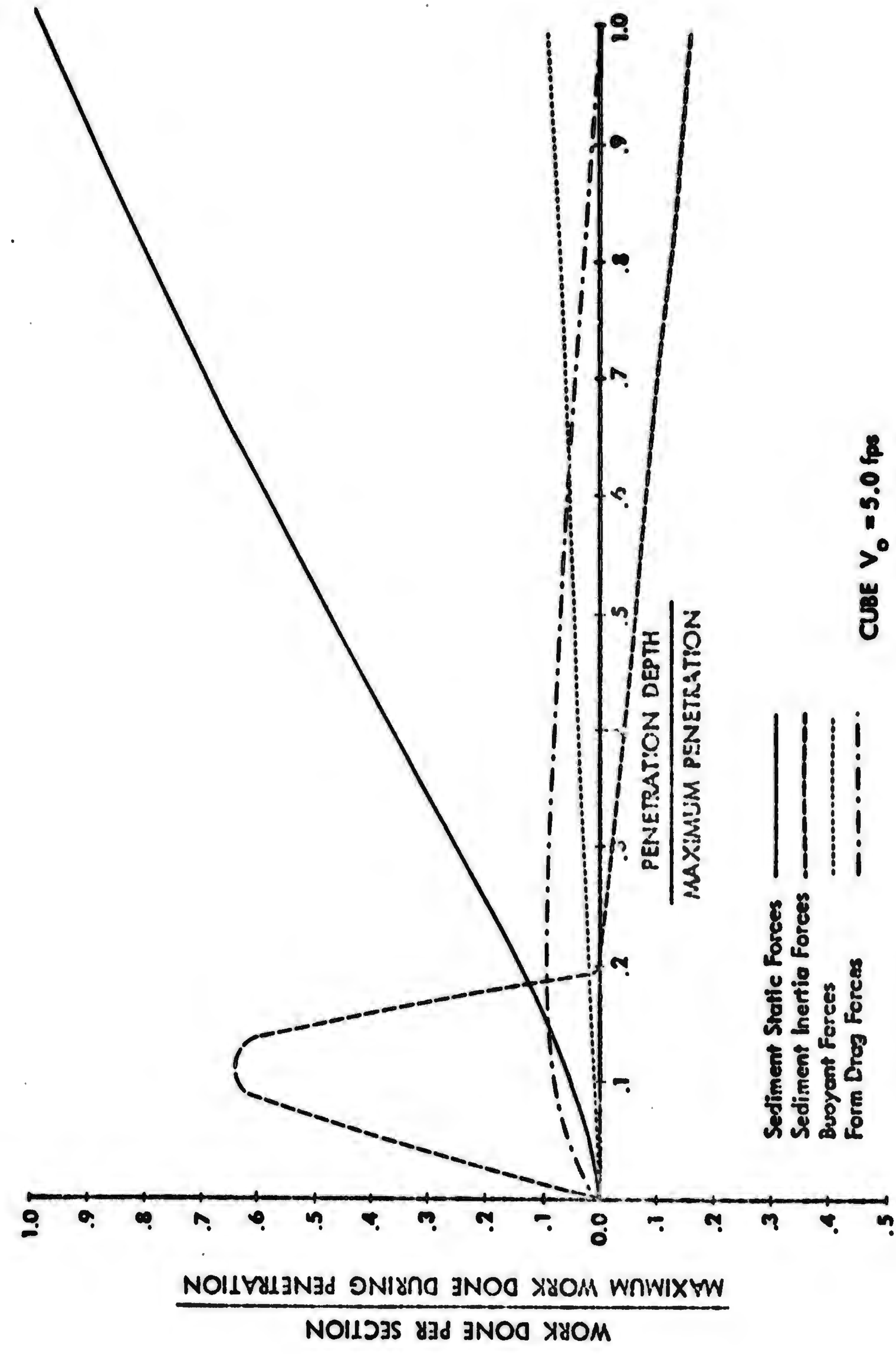
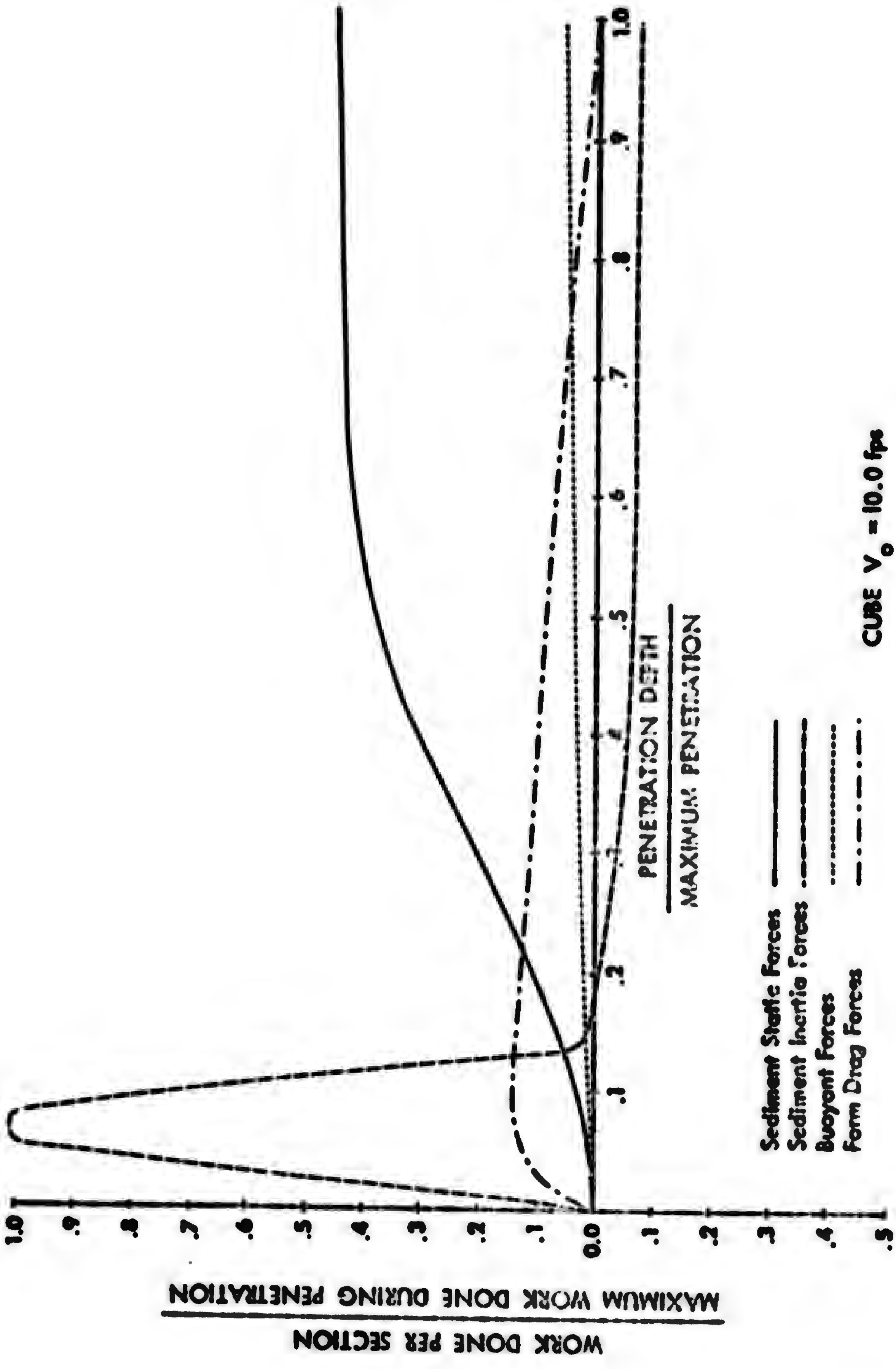
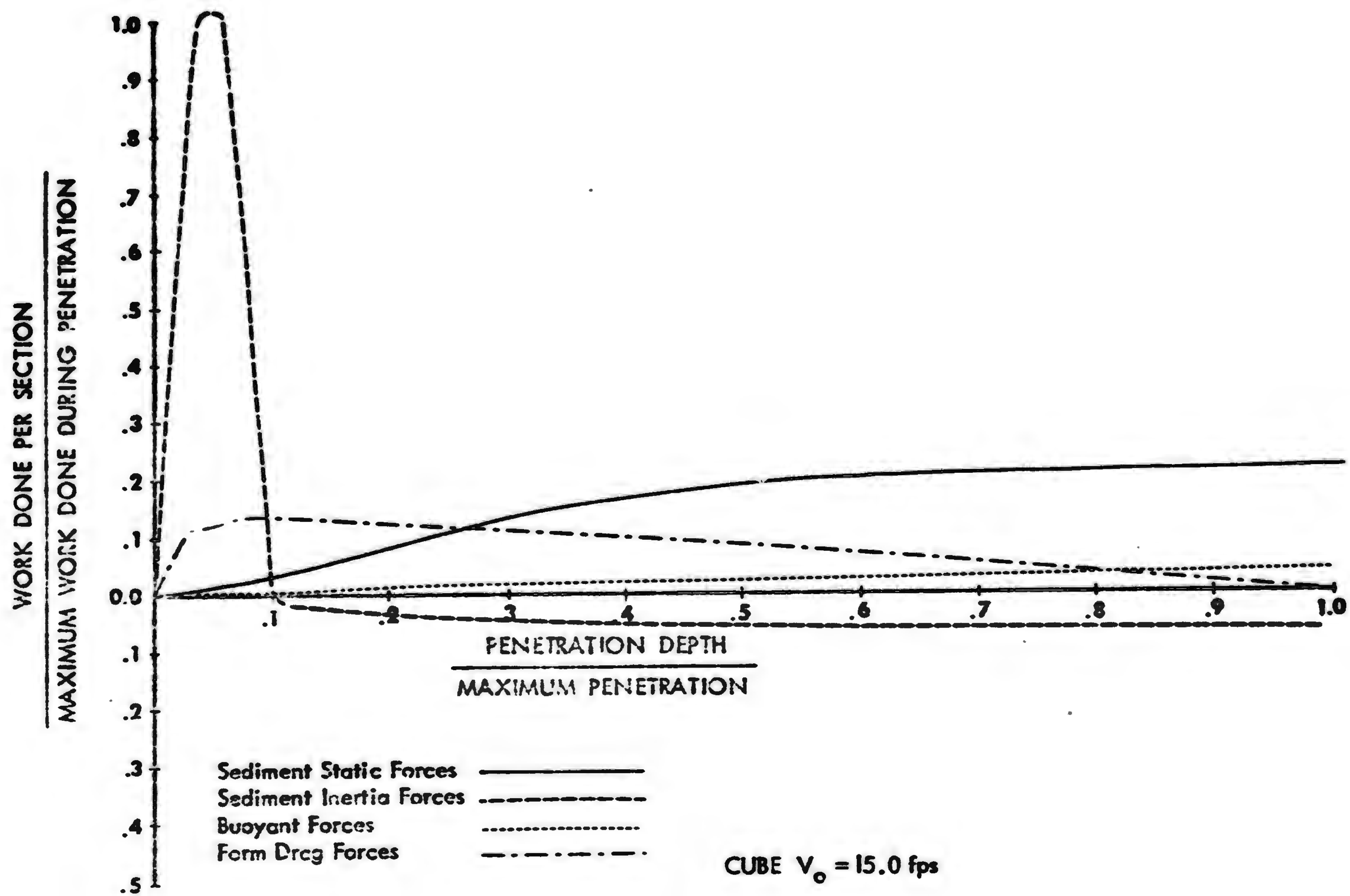
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CYLINDER ON END V_o = 20.0 fps

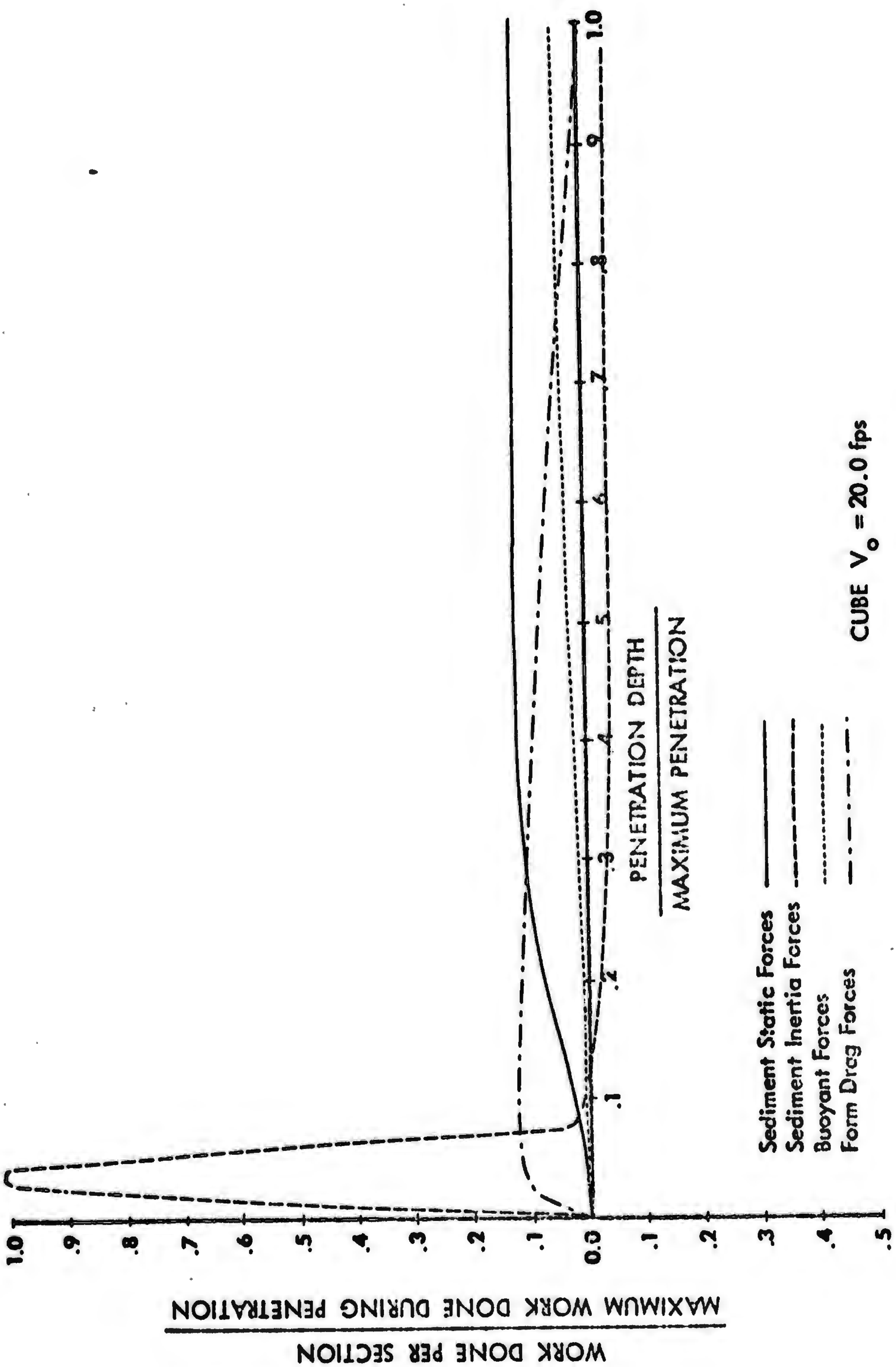

WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CUBE V_o = 0.0 fps

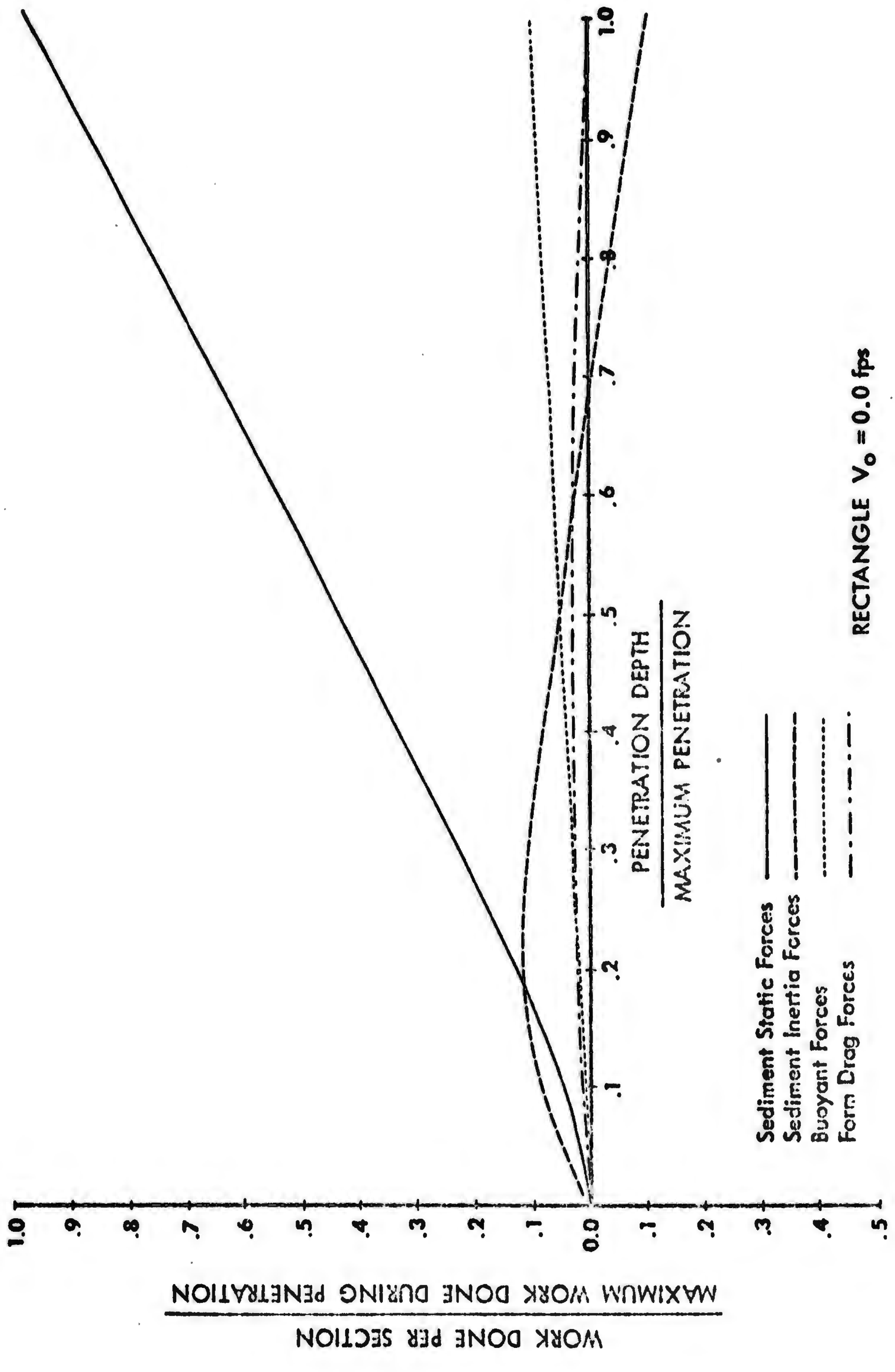


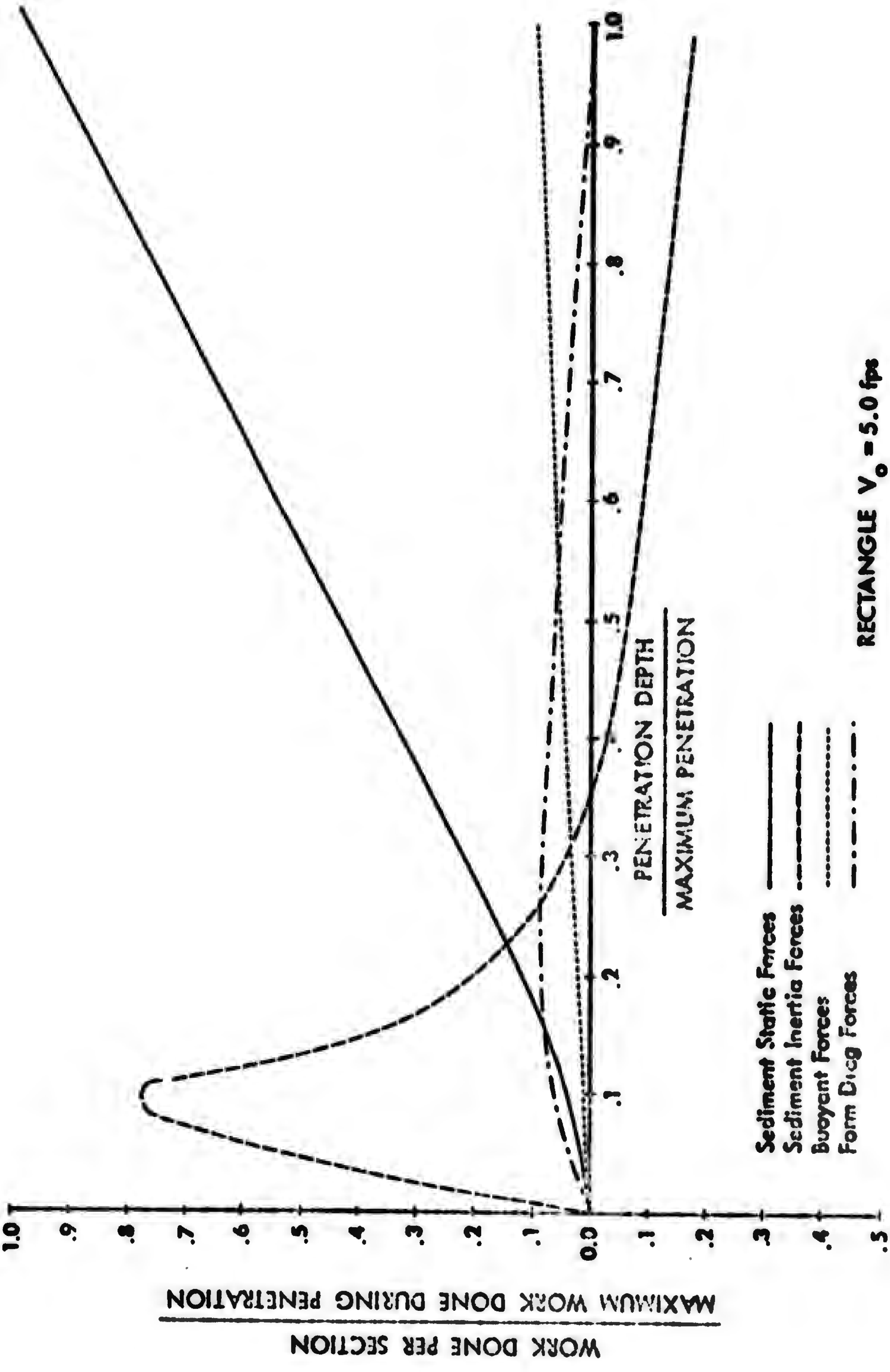
WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.5
.7
.8
.9
1.0
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CUBE V_o = 5.0 fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CUBE V_o = 10.0 fps

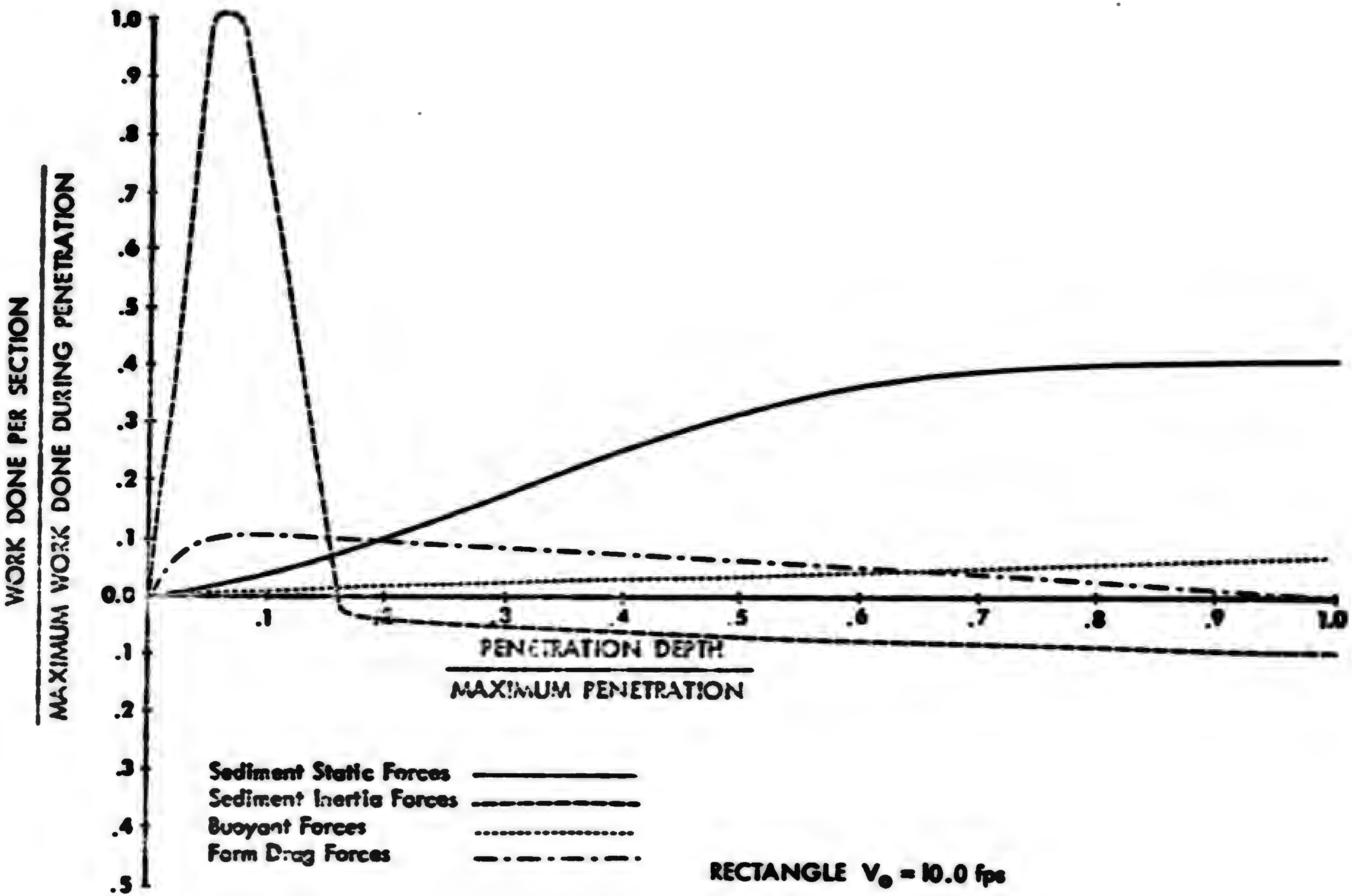

WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CUBE V_o = 15.0 fps

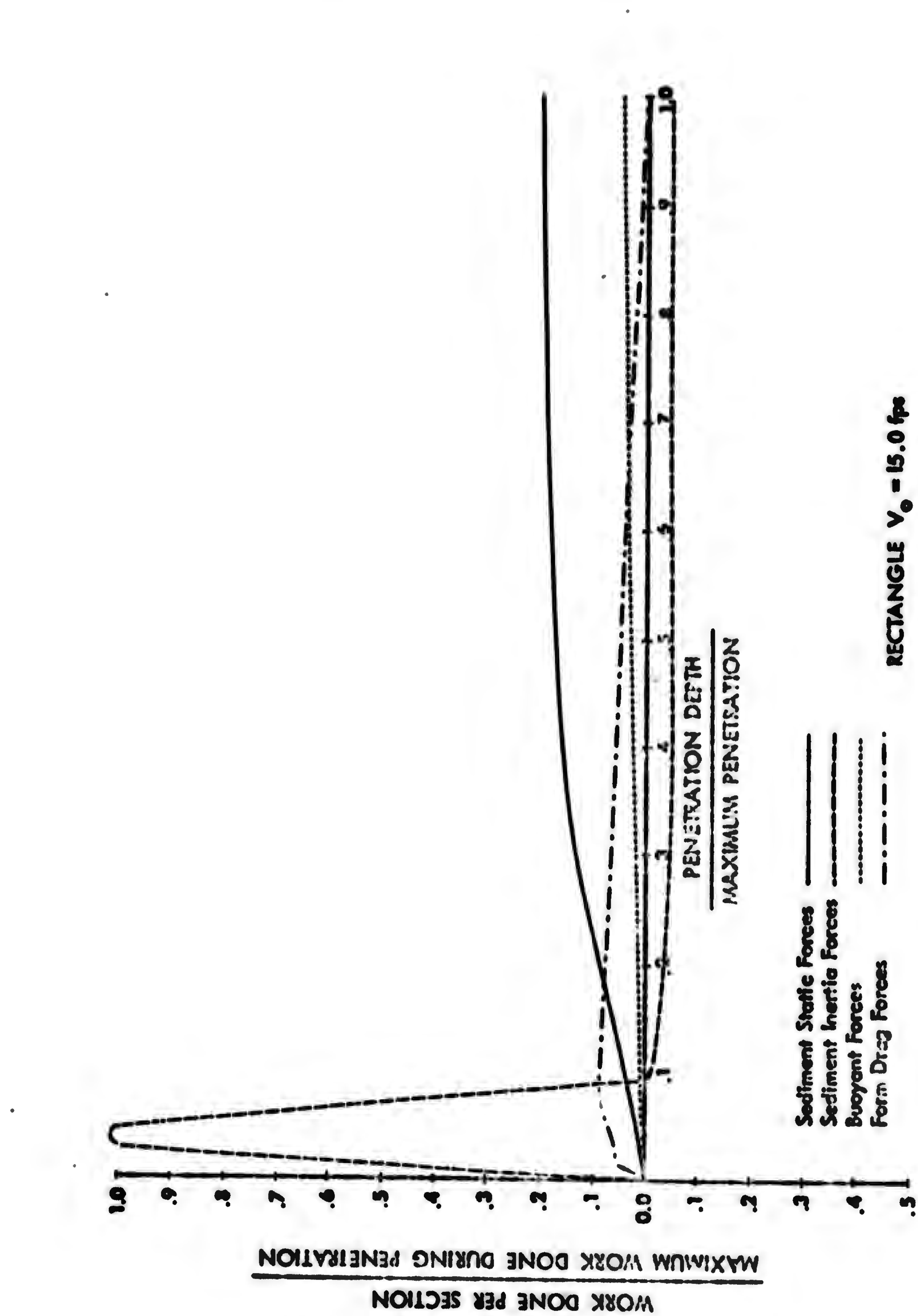

WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
PENETRATION DEPTH / MAXIMUM PENETRATION
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CUBE V_o = 20.0 fps

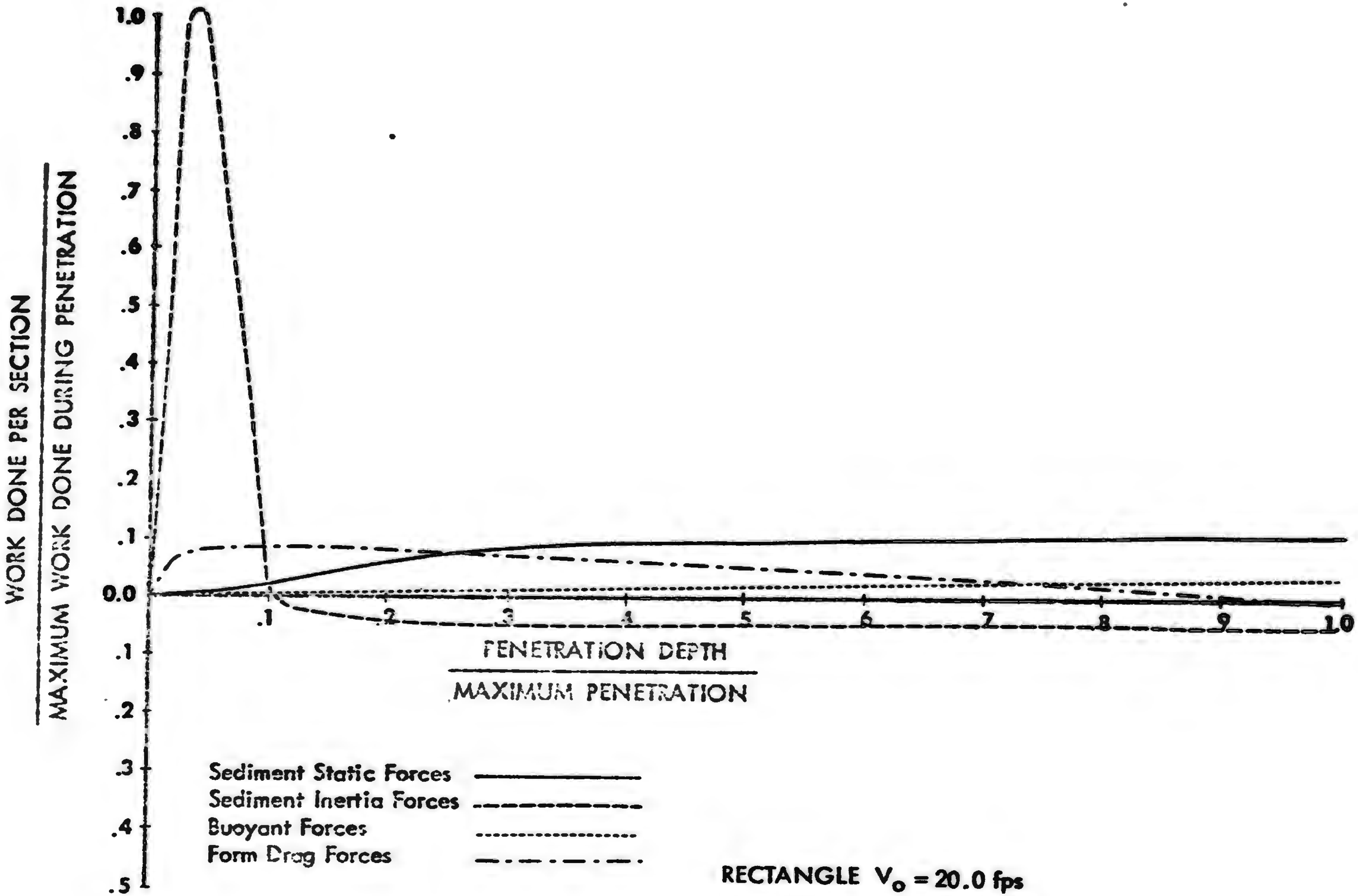

WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0 .9 .8 .7 .6 .5 .4 .3 .2 .1 0.0 .1 .2 .3 .4 .5
.1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
RECTANGLE V$_o$ = 0.0 fps



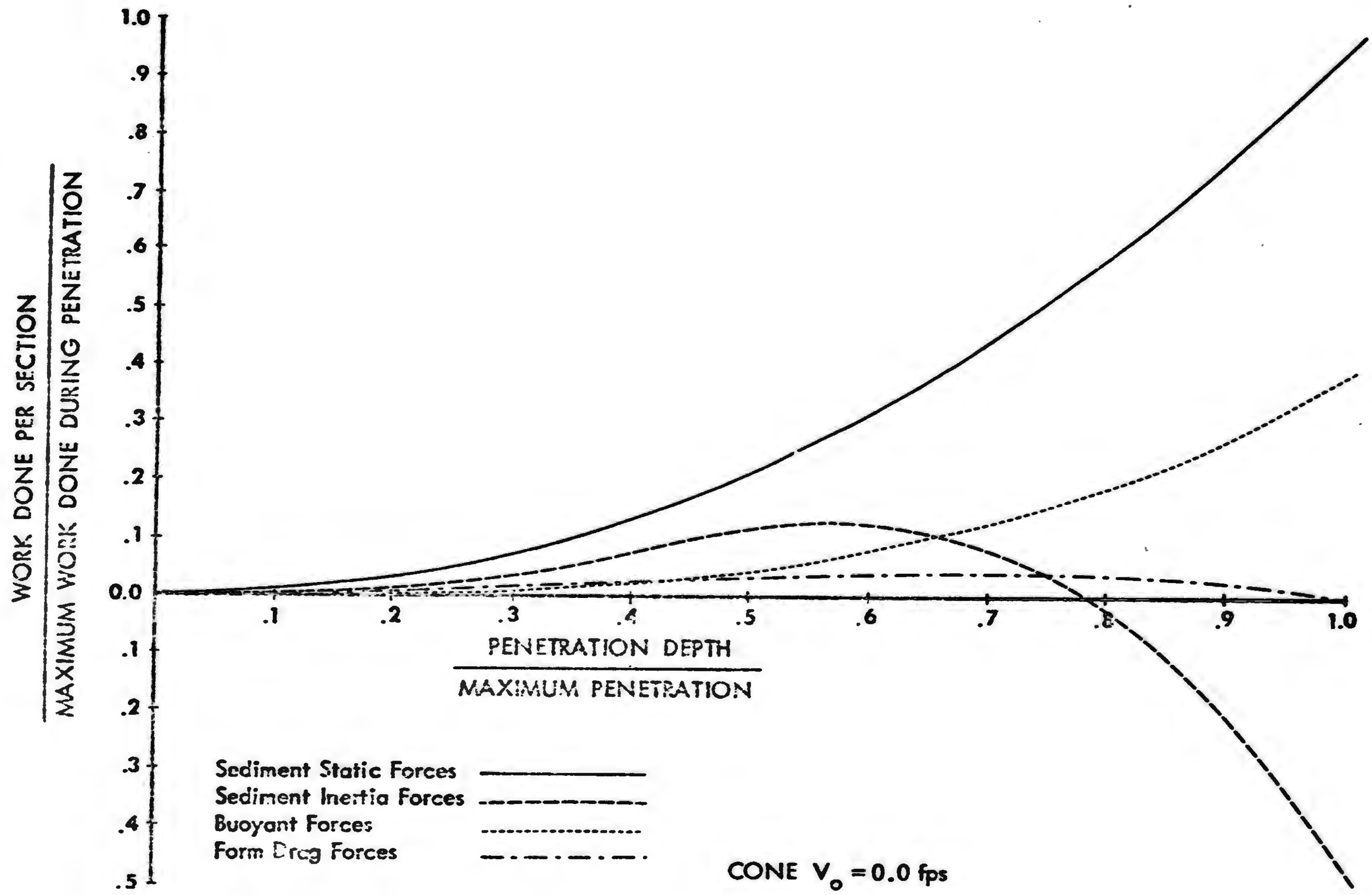
WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
RECTANGLE V_o = 5.0 fps


WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
RECTANGLE V₀ = 10.0 fps

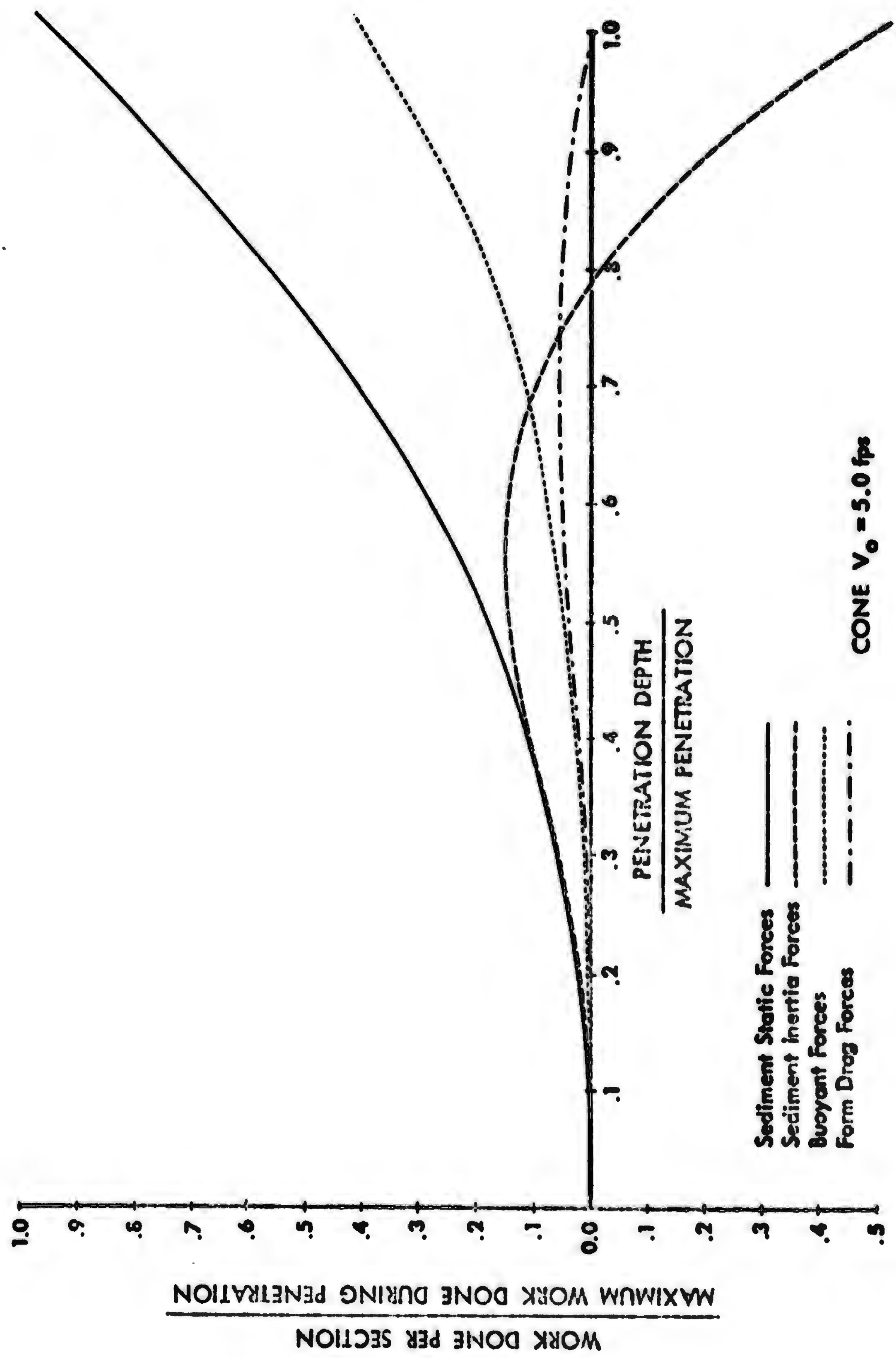

WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
PENETRATION DEPTH
MAXIMUM PENETRATION
1.0
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
RECTANGLE V_o = 15.0 fps

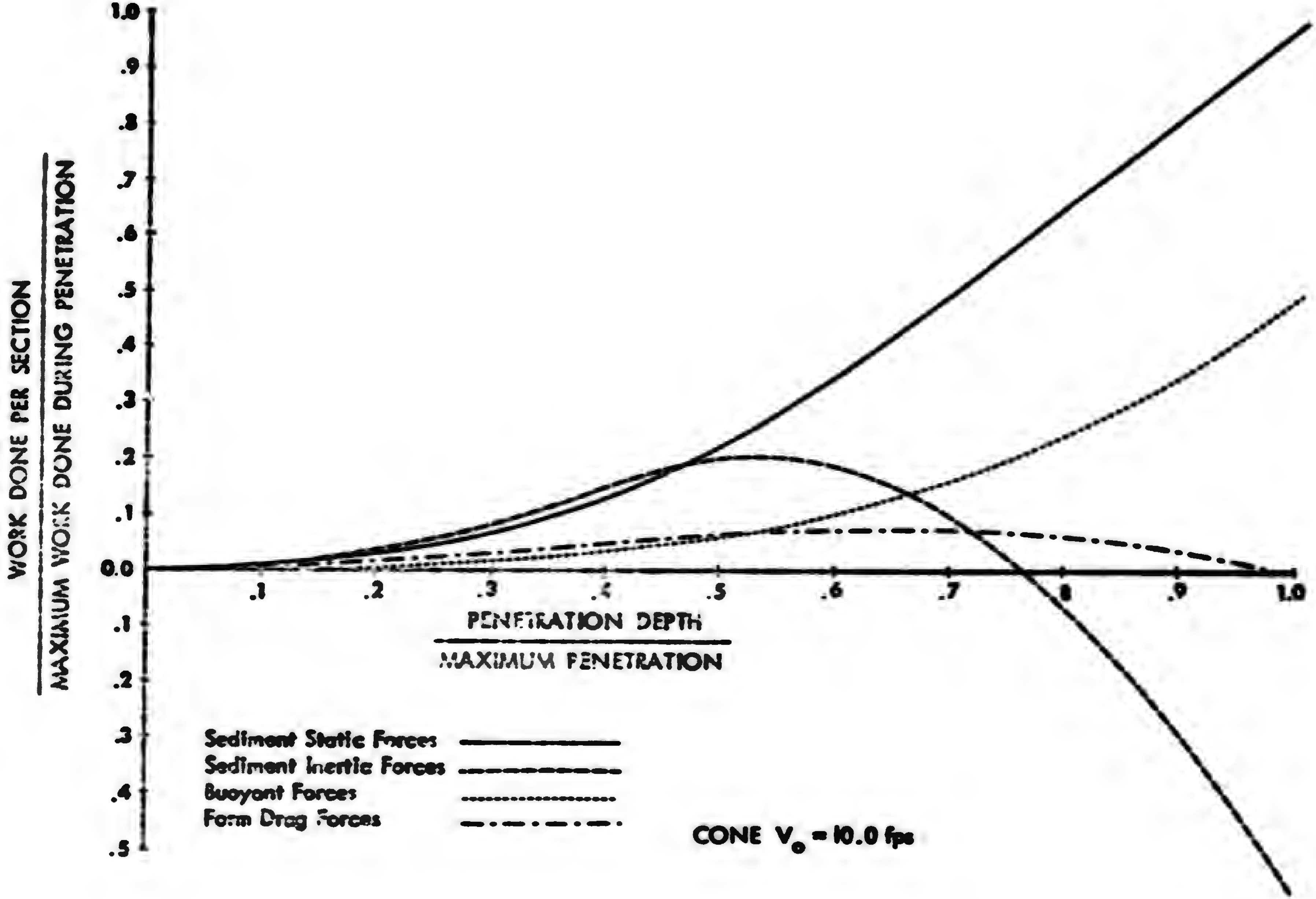


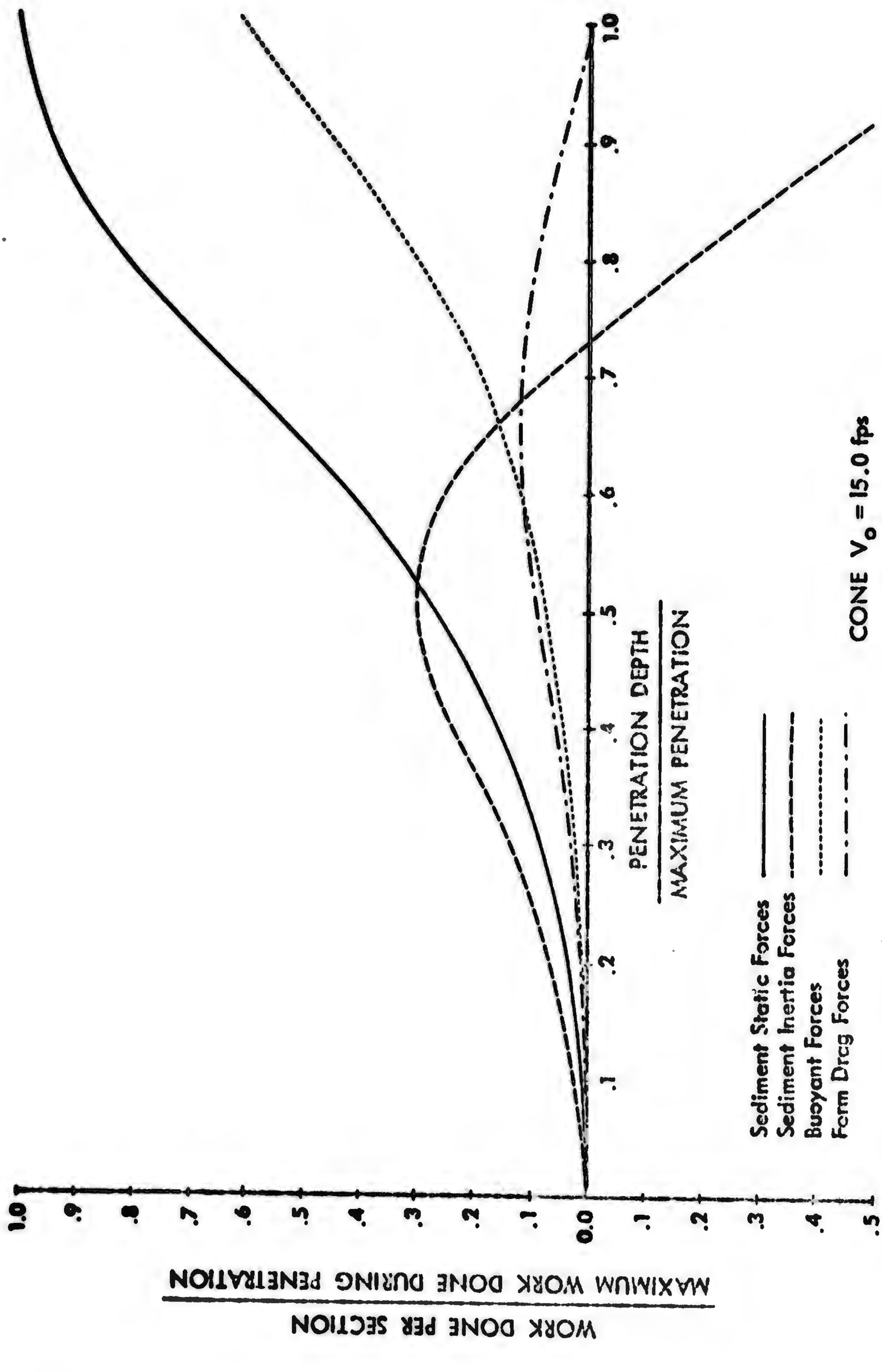
RECTANGLE $V_o = 20.0$ fps



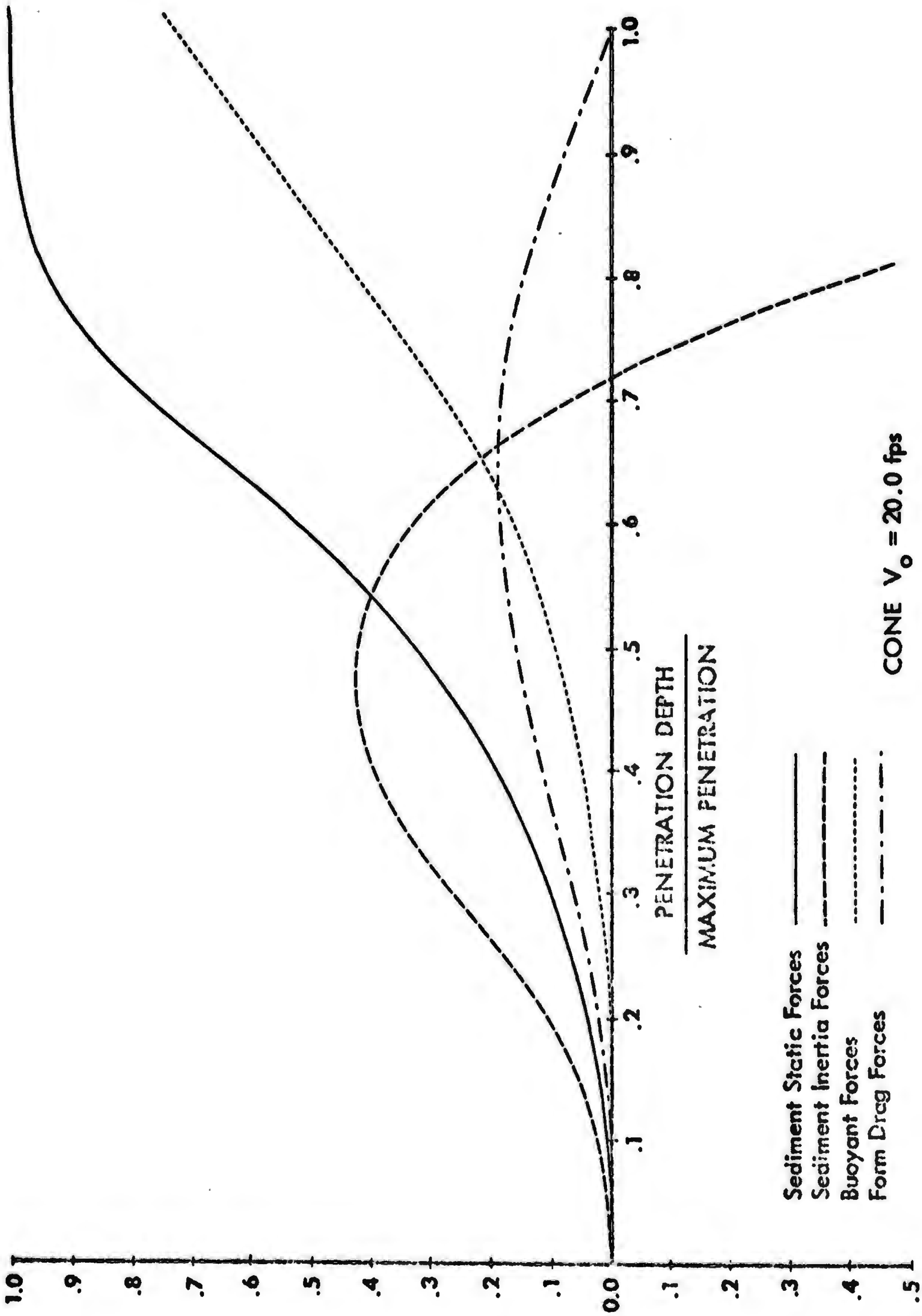
WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH / MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE V$_o$ = 0.0 fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE V_o = 5.0 fps
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0


WORK DONE PER SECTION / MAXIMUM WORK DONE DURING PENETRATION
PENETRATION DEPTH / MAXIMUM PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Sediment Static Forces
Sediment Inertic Forces
Buoyant Forces
Form Drag Forces
CONE V_o = 10.0 fps



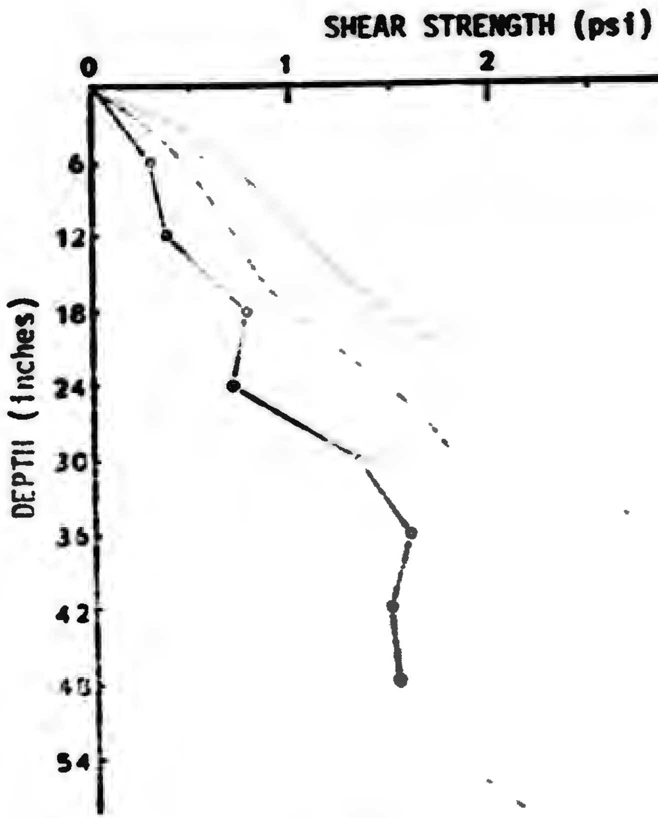
WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE V$_o$ = 15.0 fps


WORK DONE PER SECTION
MAXIMUM WORK DONE DURING PENETRATION
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0.0
.1
.2
.3
.4
.5
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
PENETRATION DEPTH
MAXIMUM PENETRATION
Sediment Static Forces
Sediment Inertia Forces
Buoyant Forces
Form Drag Forces
CONE V_o = 20.0 fps

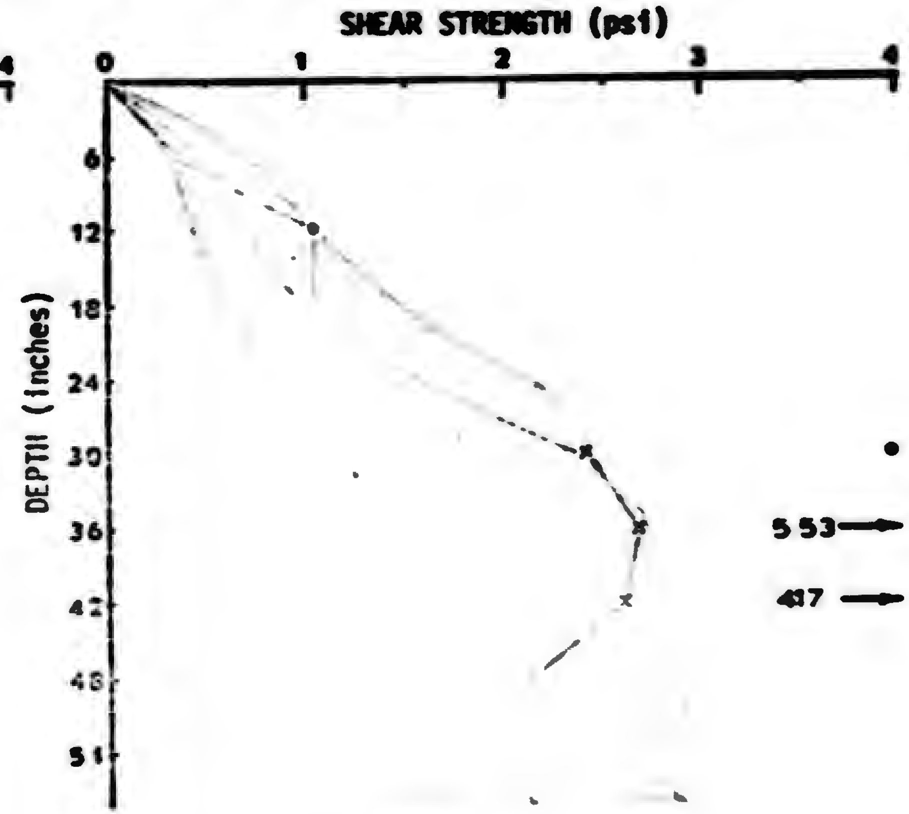
APPENDIX B

SHEAR STRENGTH PROFILES OF THE TEST PIT

The shear strength profiles at each drop station are illustrated together with the adjusted profile used in the penetration prediction computation. The profiles are in the same order as listed in Table VII.

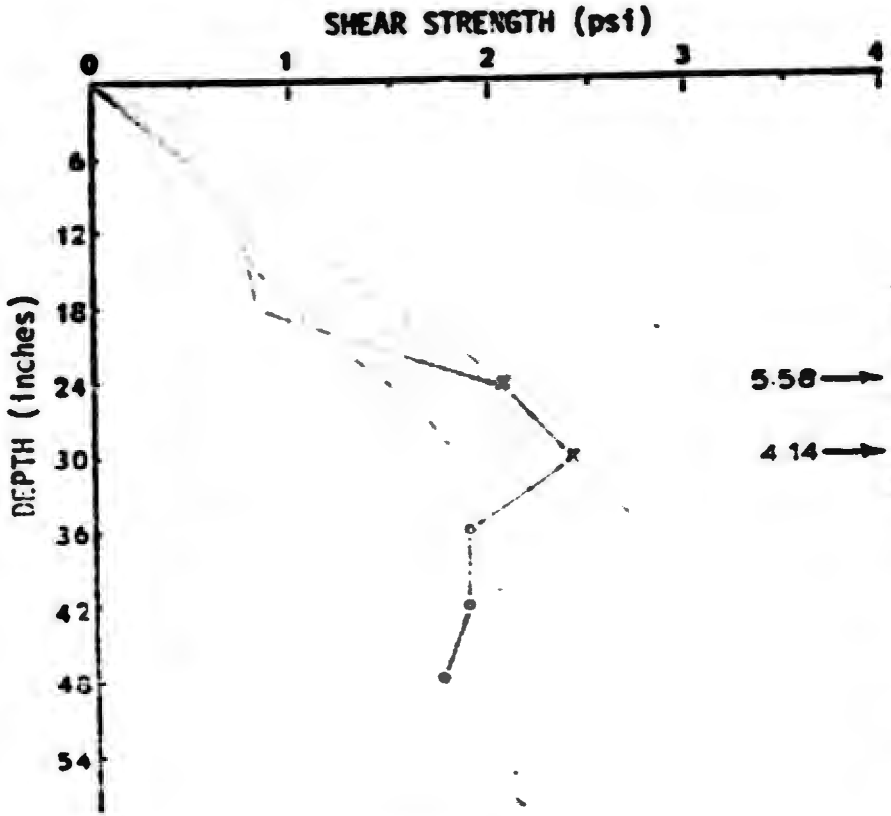


SPHERE
Velocity 0.0 fps
Station 6

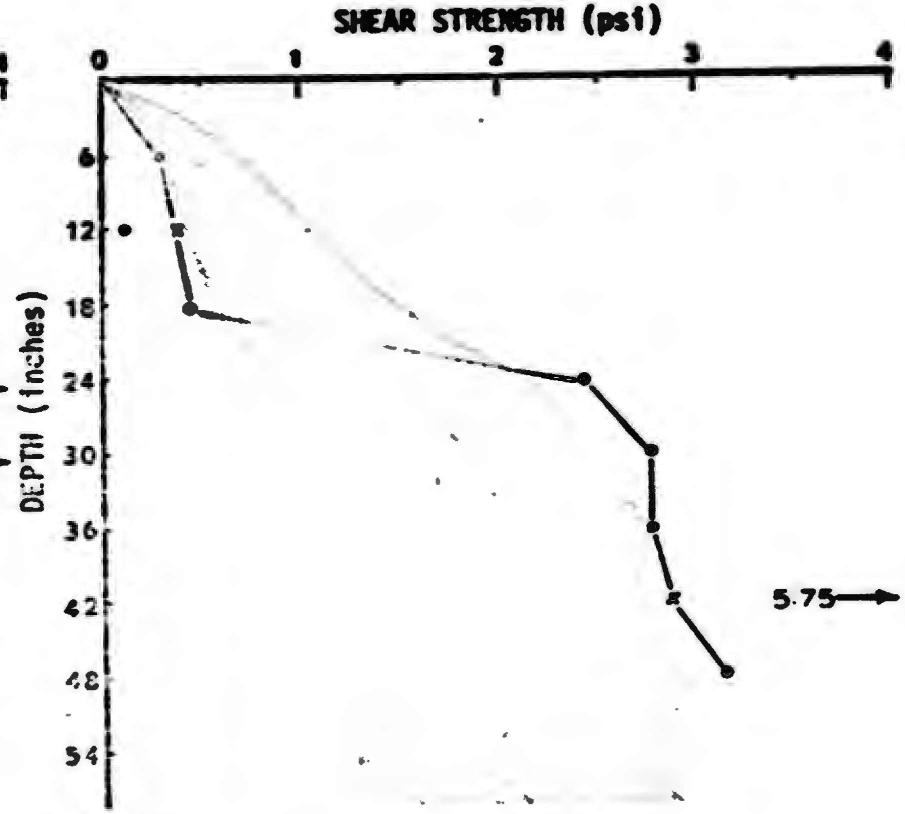


SPHERE
Velocity 5.0 fps
Station 7

• observed ------ mean ——— shear strength used
× adjusted [shaded box] one standard deviation from mean

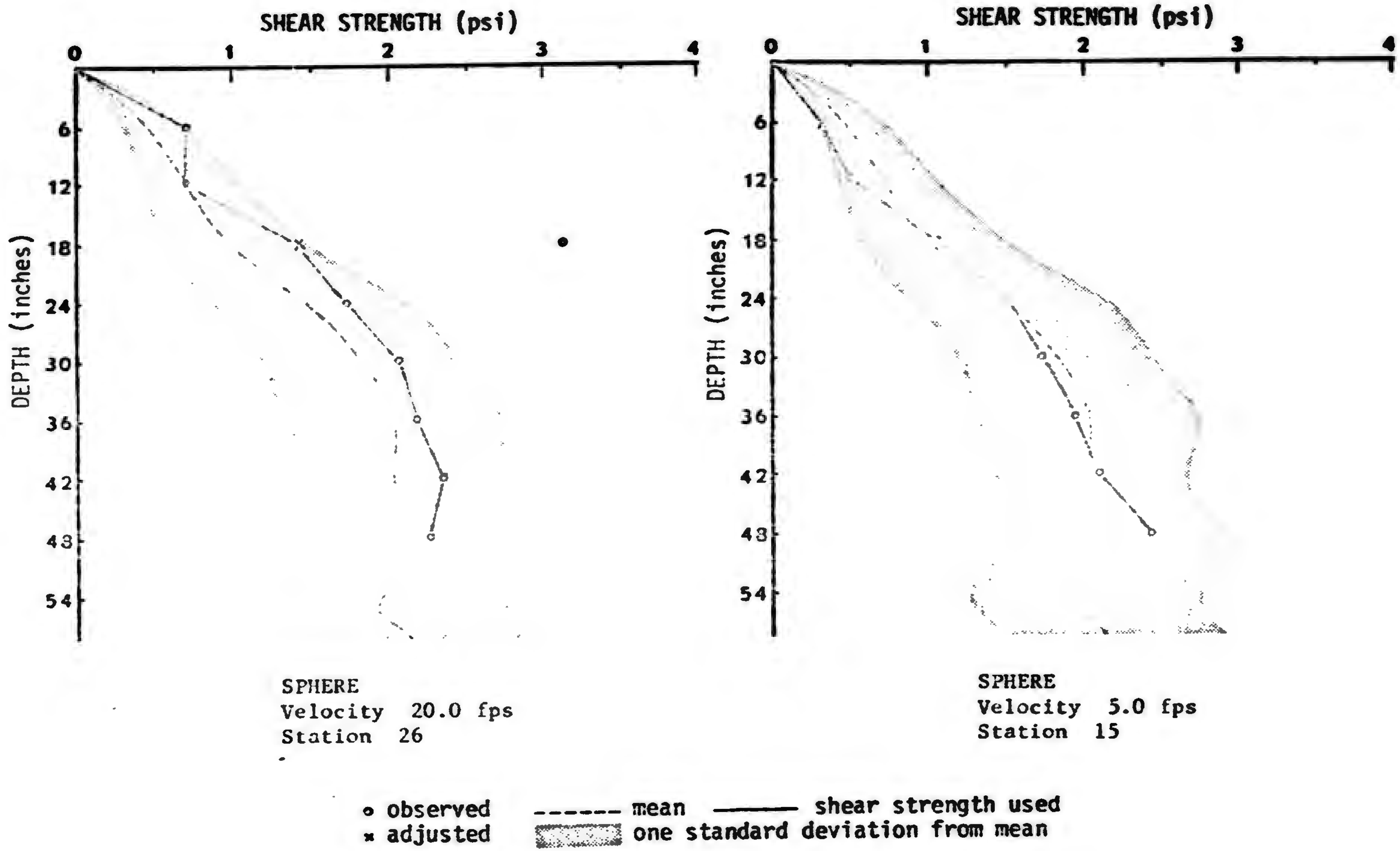


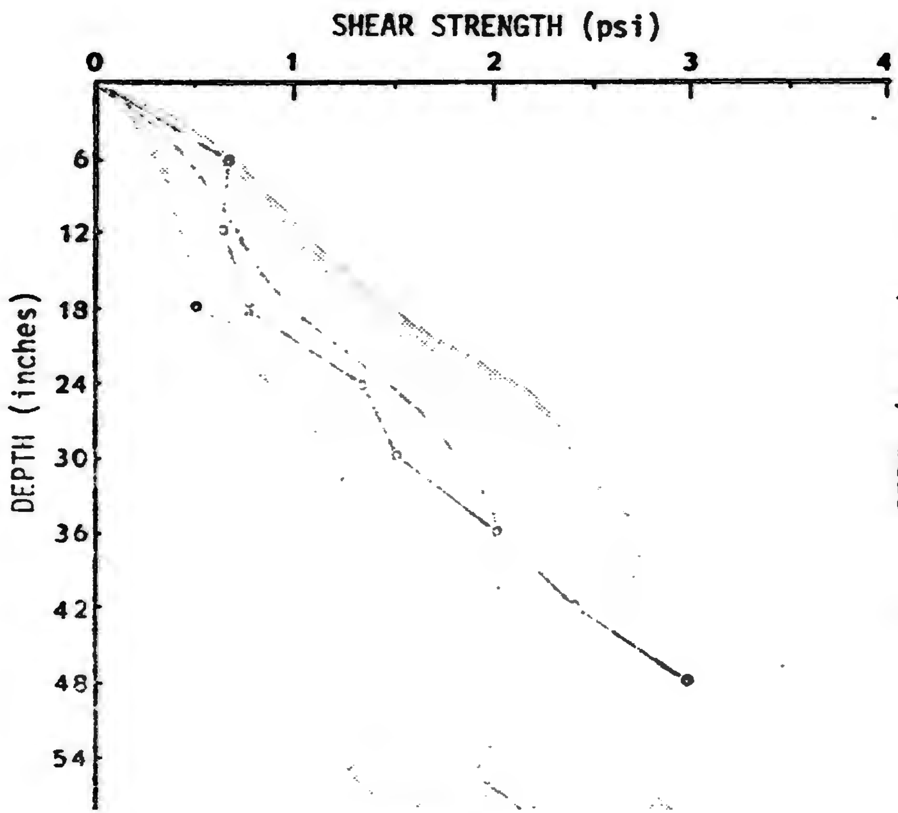
SPHERE
Velocity 10.0 fps
Station 9



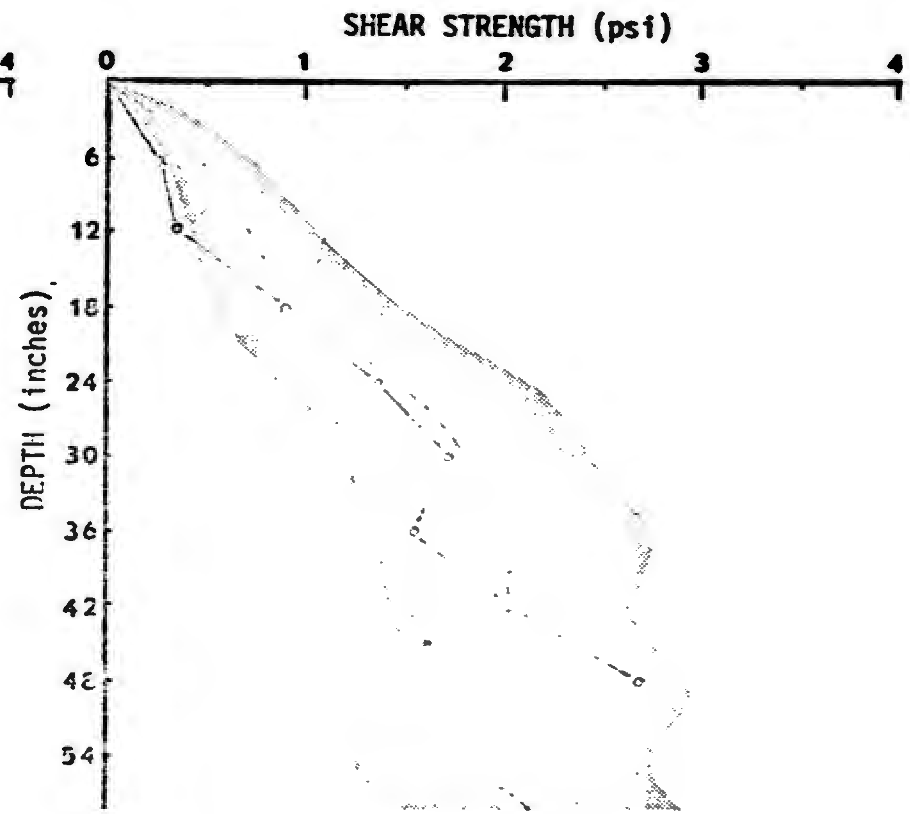
SPHERE
Velocity 15.0 fps
Station 20

∘ observed ------ mean ——— shear strength used
× adjusted (shaded) one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
SPHERE
Velocity 20.0 fps
Station 26
SHEAR STRENGTH (psi)
DEPTH (inches)
SPHERE
Velocity 5.0 fps
Station 15
o observed
x adjusted
mean
shear strength used
one standard deviation from mean

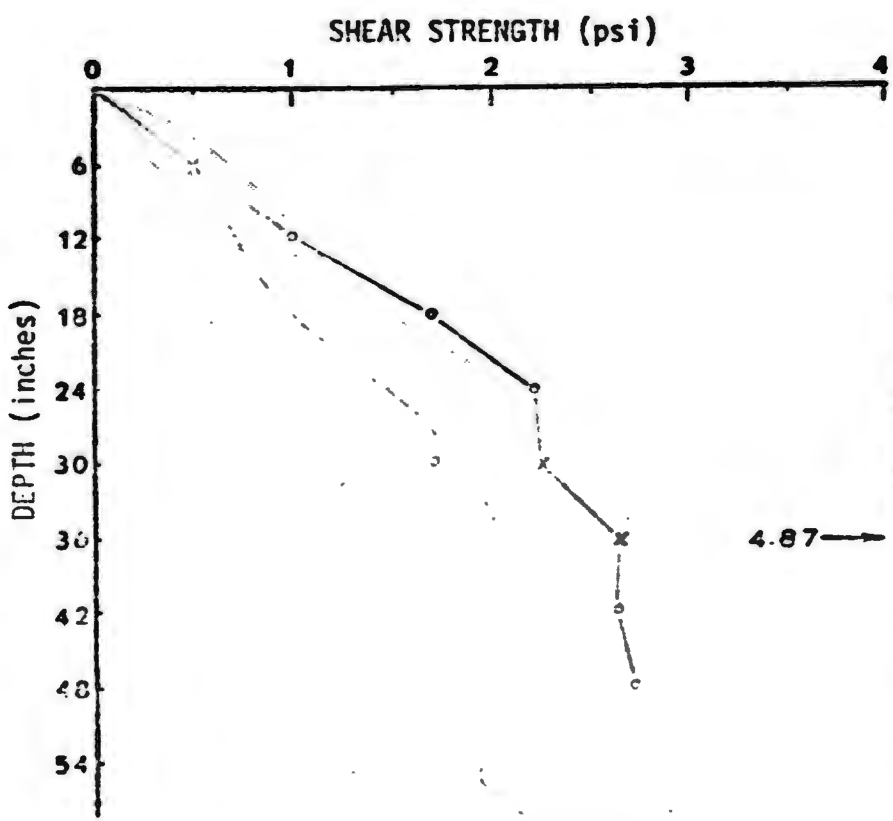


SPHERE
Velocity 10.0 fps
Station -

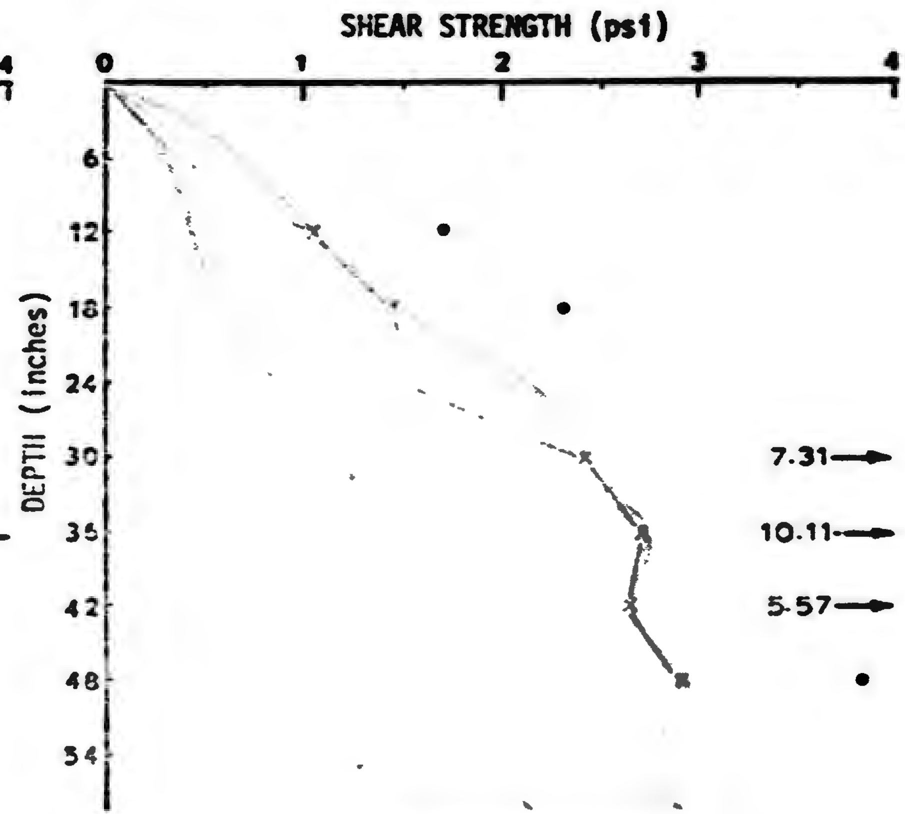


SPHERE
Velocity 15.0 fps
Station -

o observed ------ mean ——— shear strength used
x adjusted [shaded] one standard deviation from mean

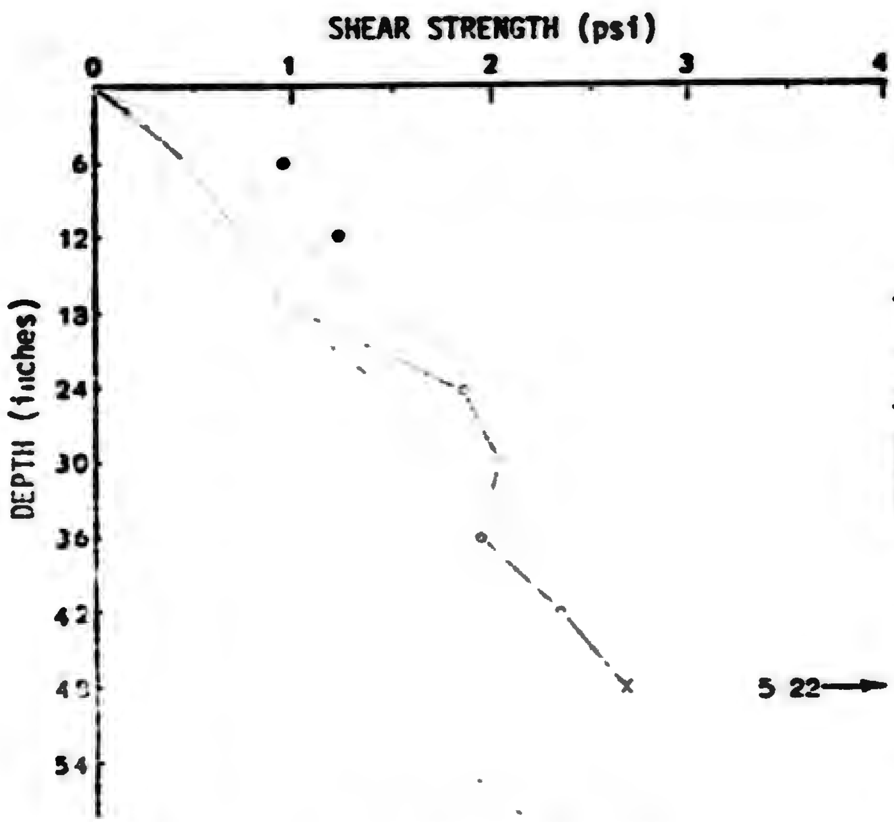


SPHERE
Velocity 20.0 fps
Station -

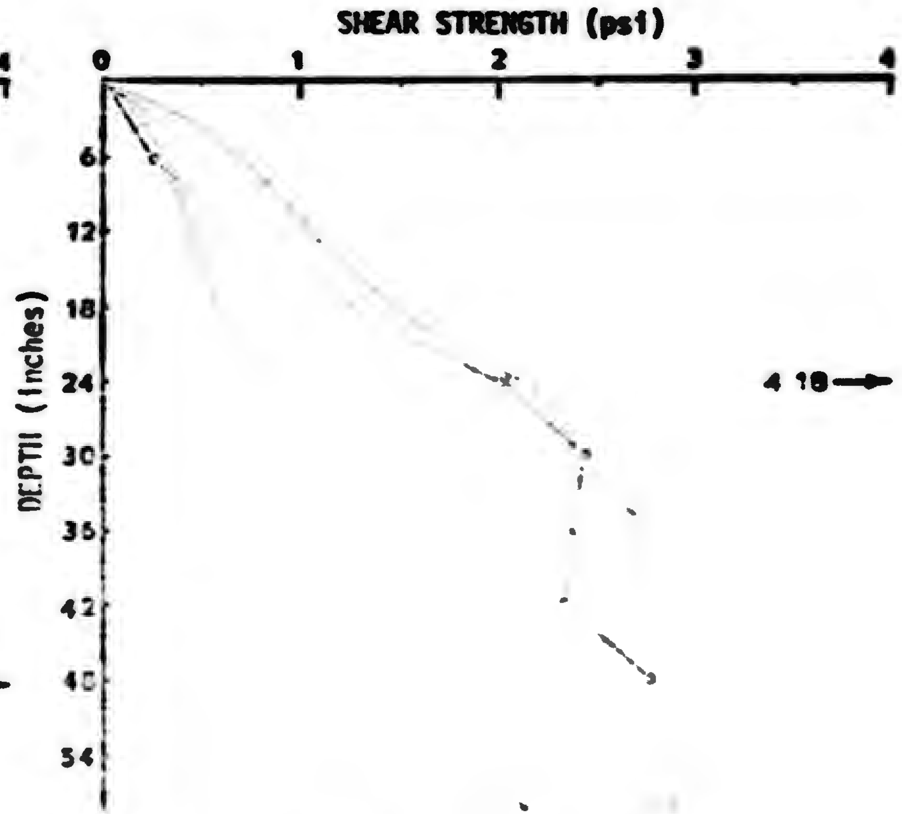


HORIZONTAL CYLINDER
Velocity 0.0 fps
Station 23

o observed ------ mean ——— shear strength used
x adjusted [shaded] one standard deviation from mean

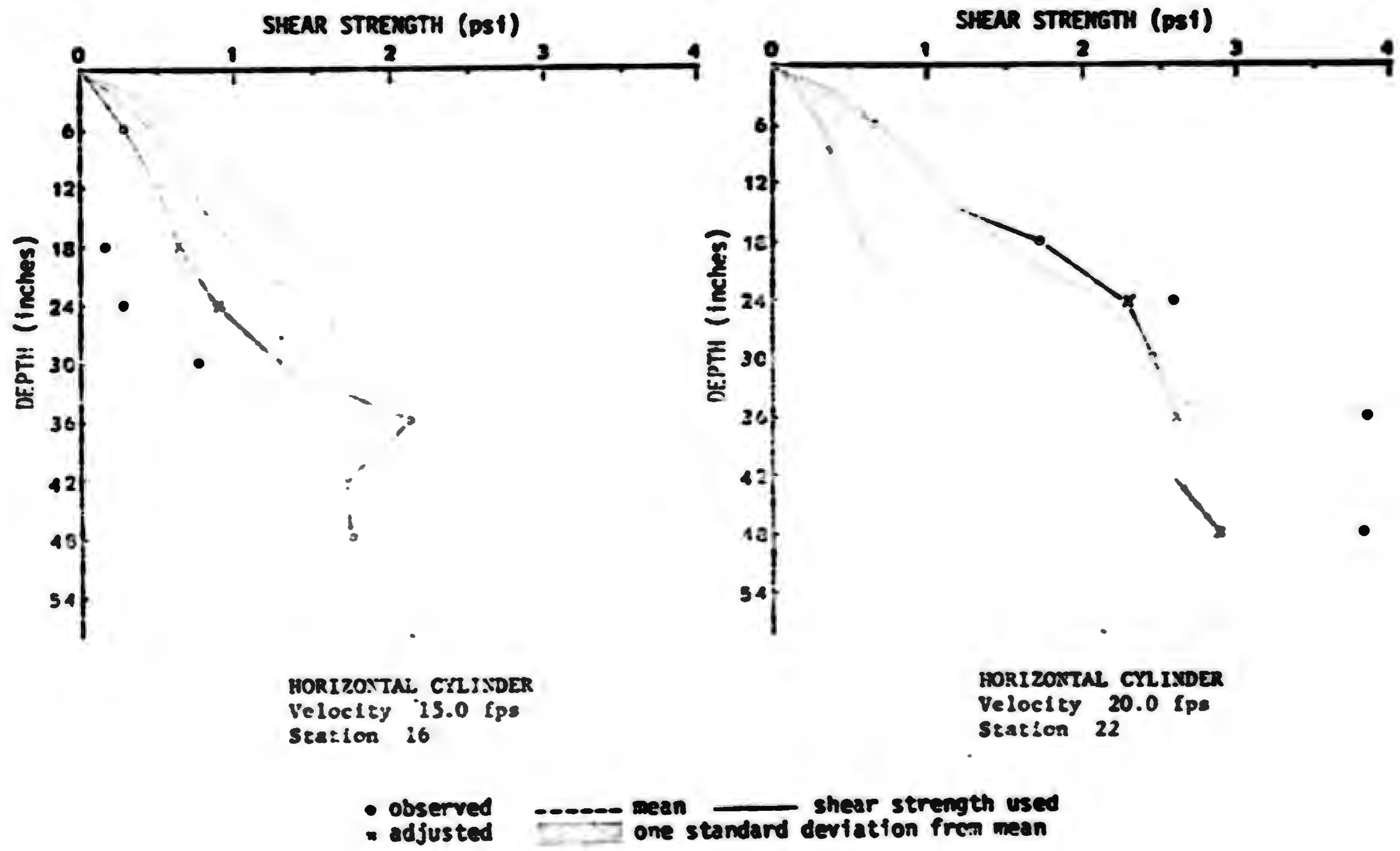


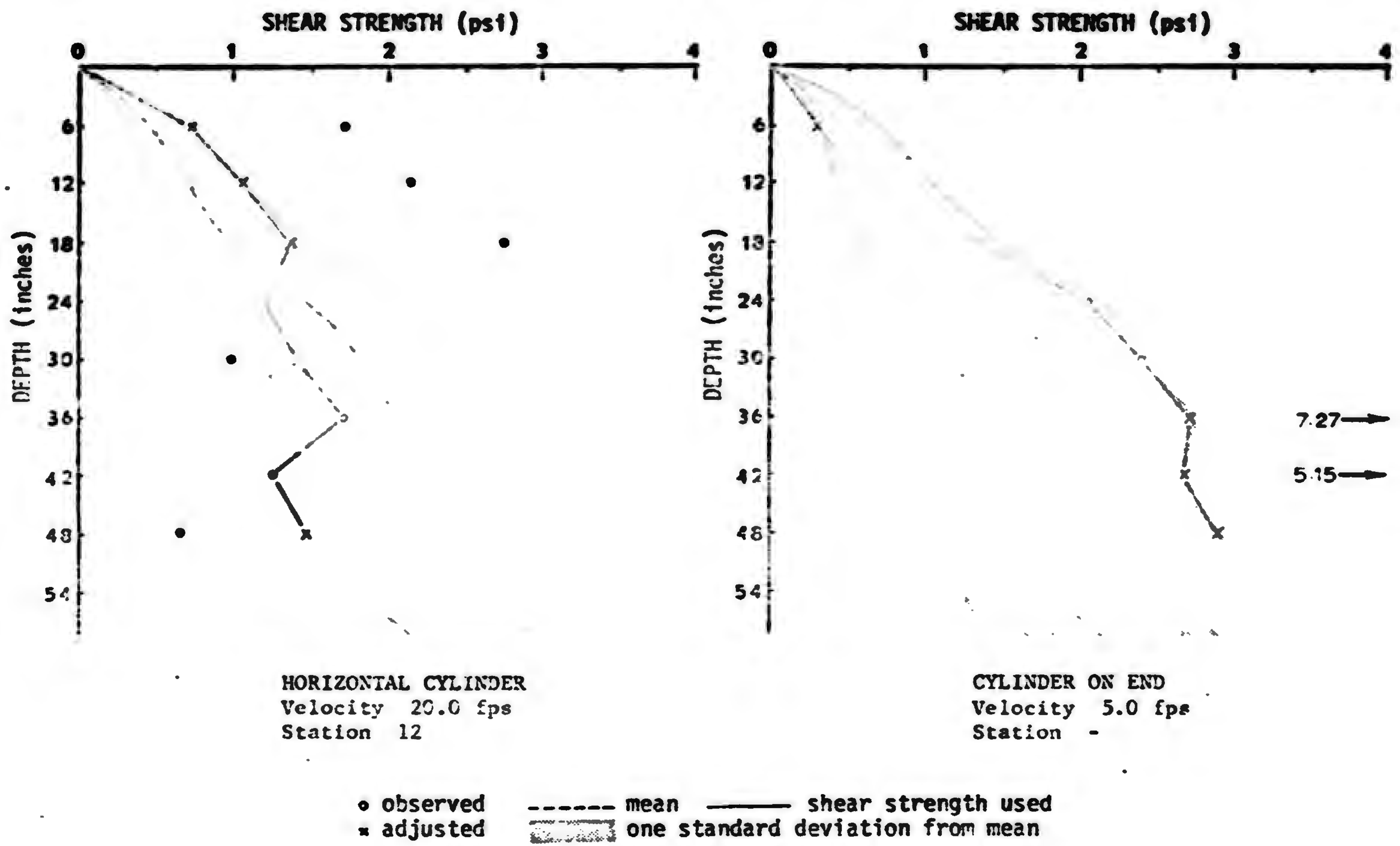
HORIZONTAL CYLINDER
Velocity 5.0 fps
Station 15

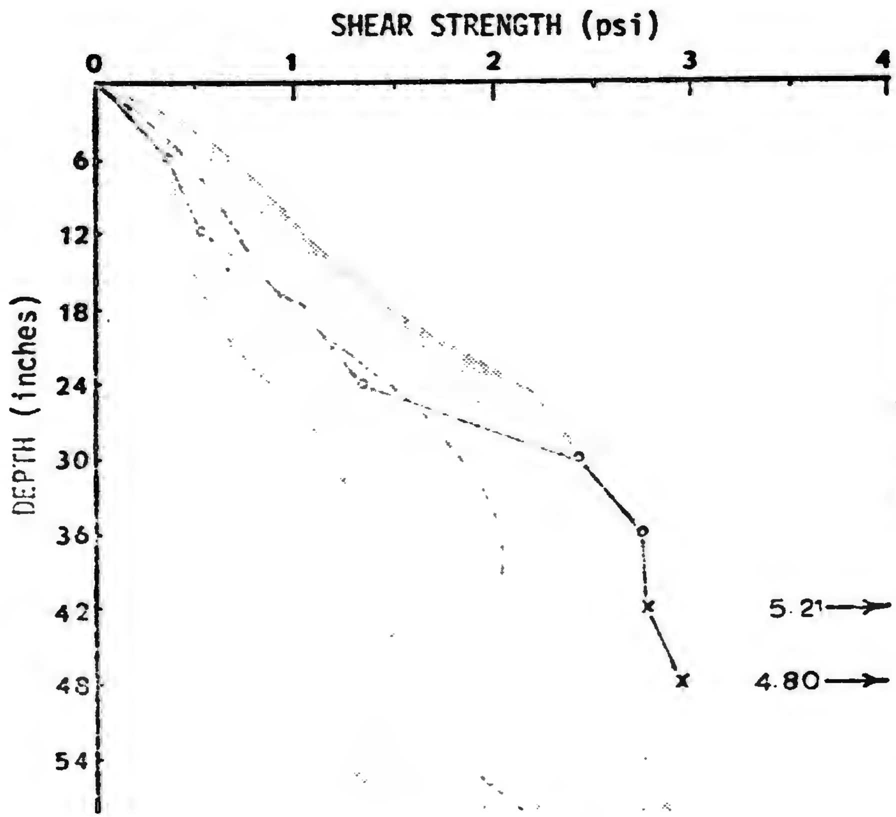


HORIZONTAL CYLINDER
Velocity 10.0 fps
Station 21

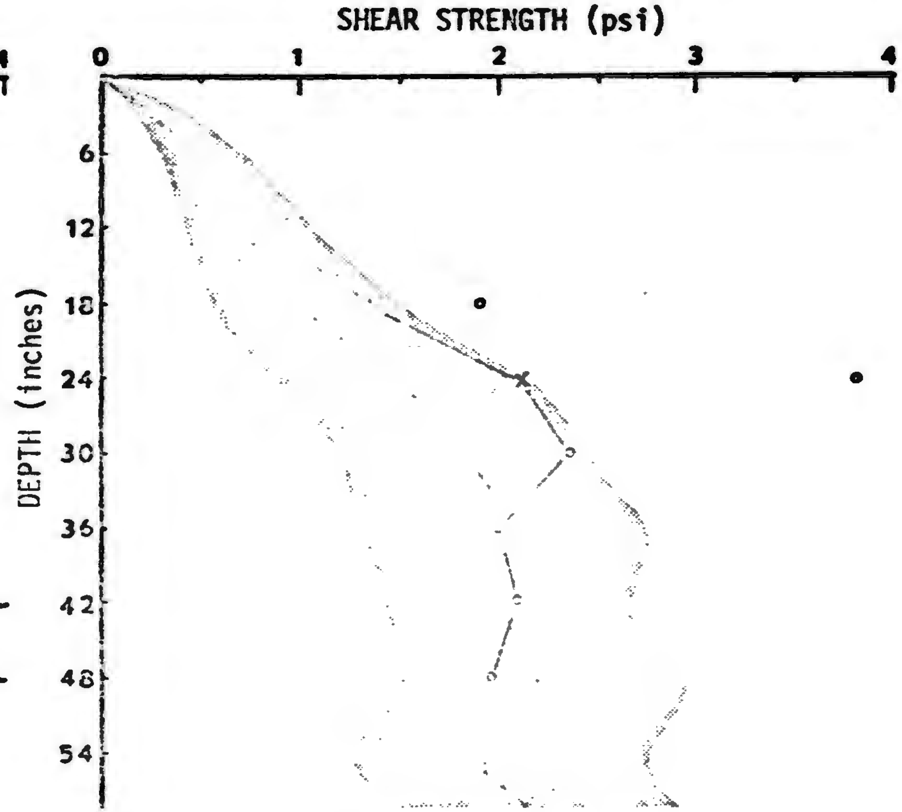
• observed ------ mean ——— shear strength used
x adjusted one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
HORIZONTAL CYLINDER
Velocity 15.0 fps
Station 16
SHEAR STRENGTH (psi)
HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 22
• observed
× adjusted
mean
shear strength used
one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 12
SHEAR STRENGTH (psi)
CYLINDER ON END
Velocity 5.0 fps
Station -
7.27
5.15
o observed
x adjusted
mean
shear strength used
one standard deviation from mean

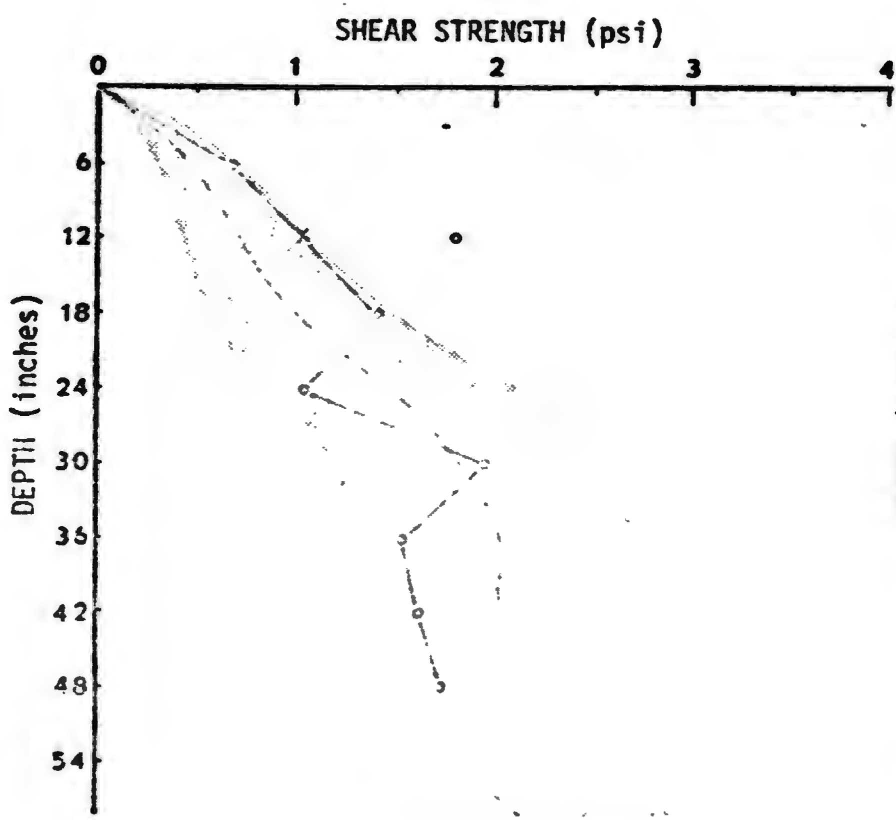


CYLINDER ON END
Velocity 10.0 fps
Station -

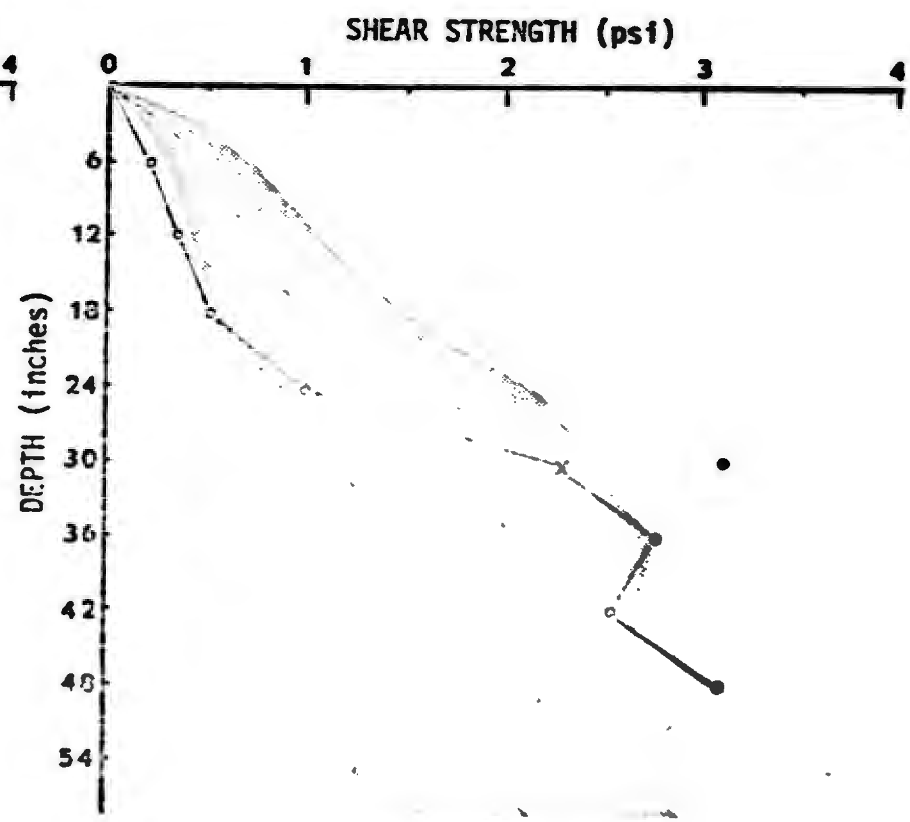


CYLINDER ON END
Velocity 15.0 fps
Station -

o observed ------ mean ——— shear strength used
x adjusted (shaded) one standard deviation from mean

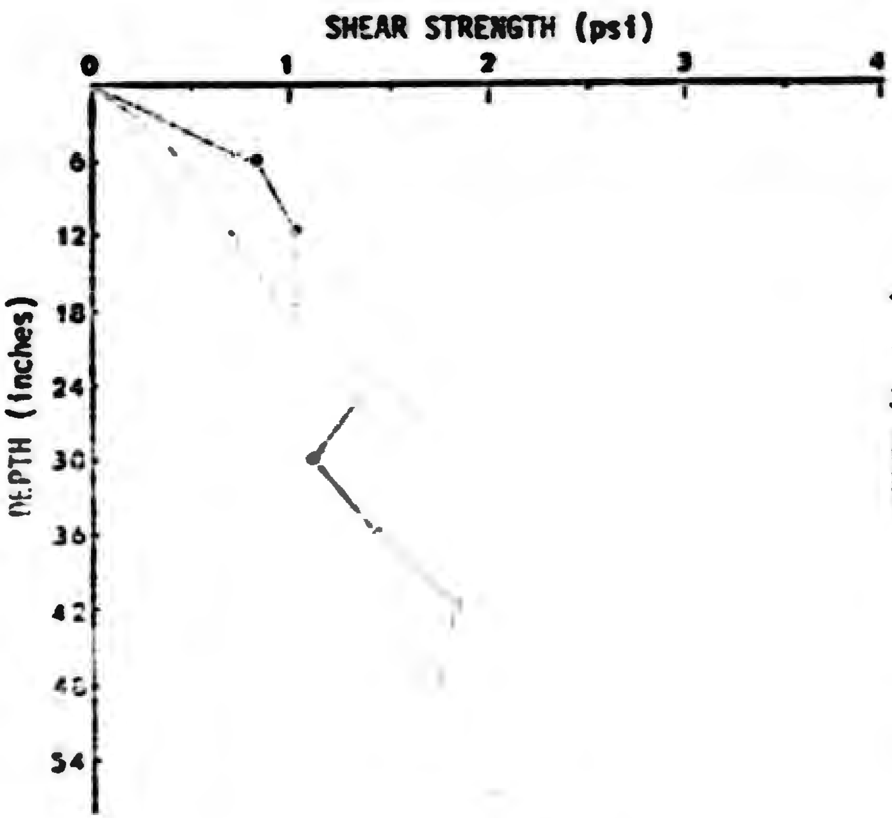


CYLINDER ON END
Velocity 20.0 fps
Station -

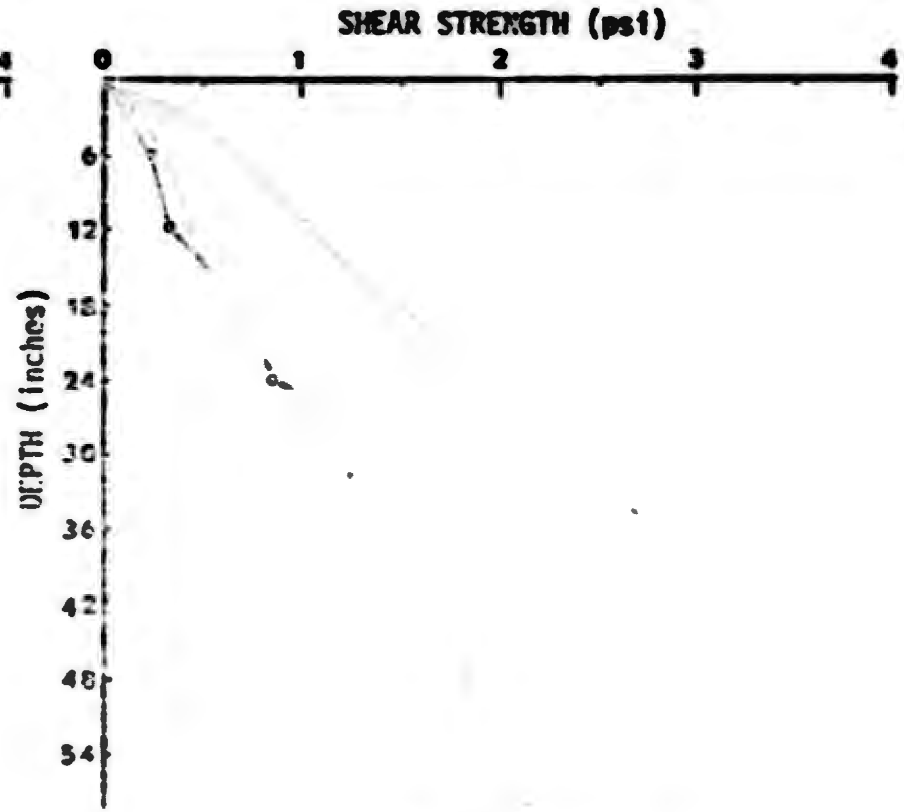


CYLINDER ON END
Velocity 0.0 fps
Station 22

• observed ------ mean ——— shear strength used
▪ adjusted [shaded] one standard deviation from mean

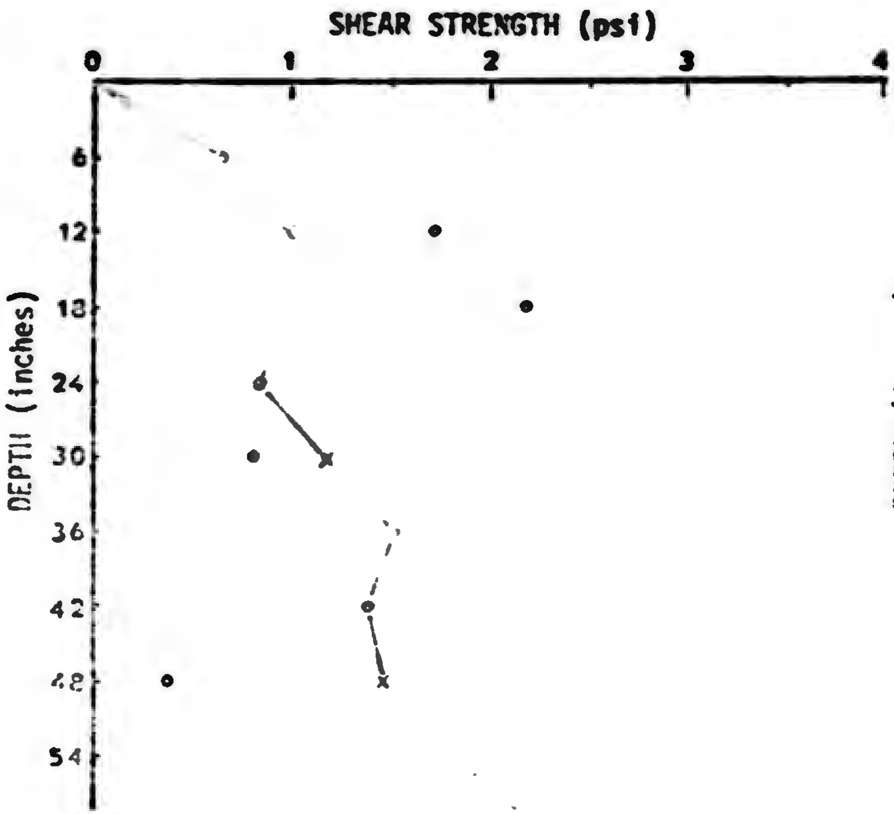


CYLINDER ON END
Velocity 5.0 fps
Station 14

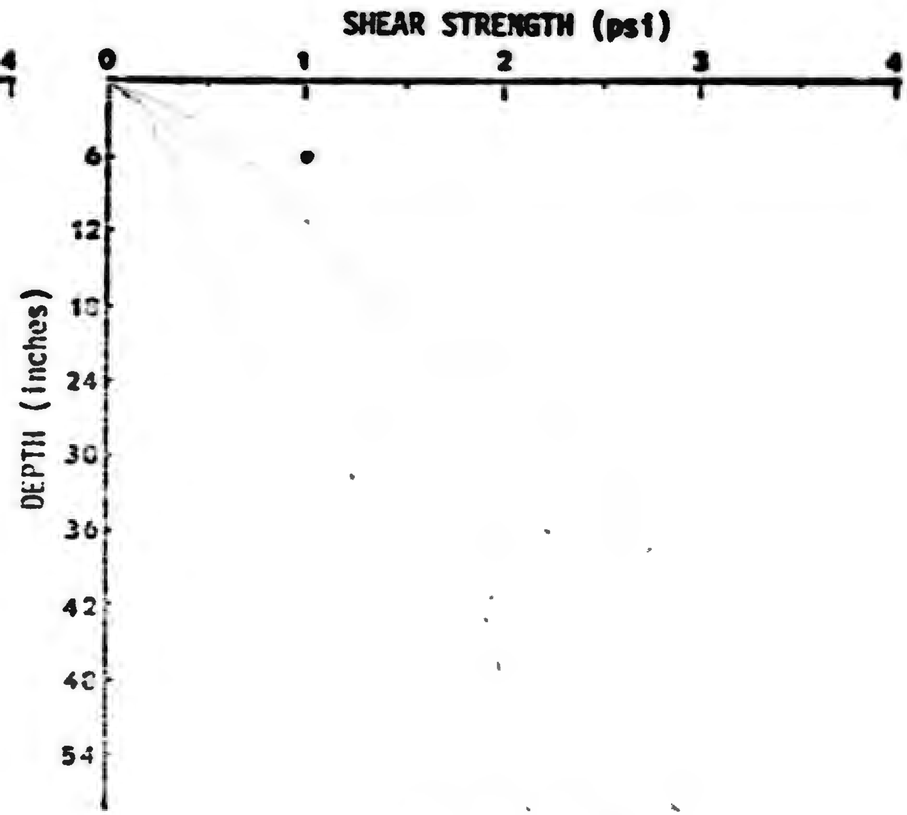


CYLINDER ON END
Velocity 10.0 fps
Station 16

• observed
▪ adjusted
------ mean
—— shear strength used
one standard deviation from mean

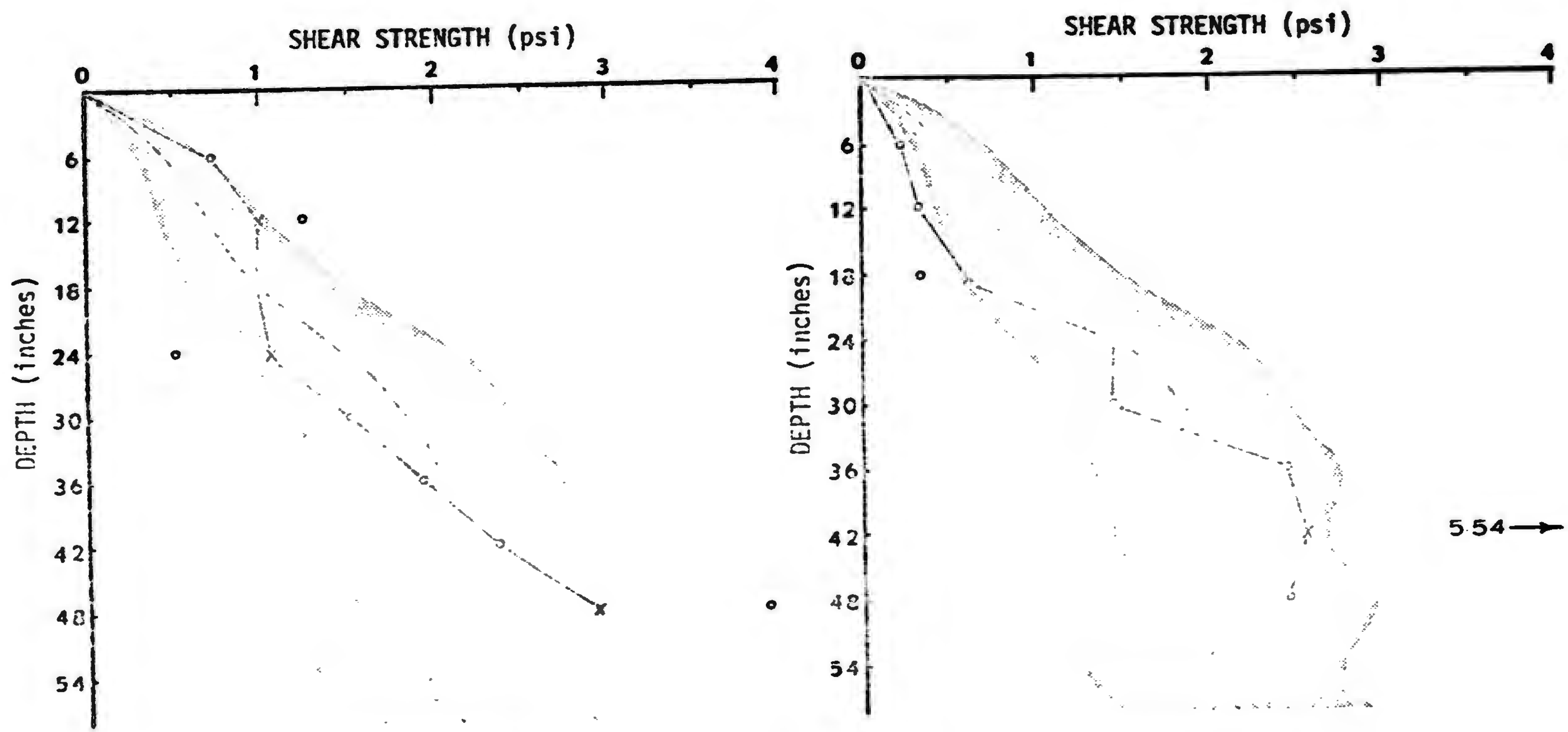


CYLINDER ON END
Velocity 15.0 fps
Station 12



CYLINDER ON END
Velocity 15.0 fps
Station 21

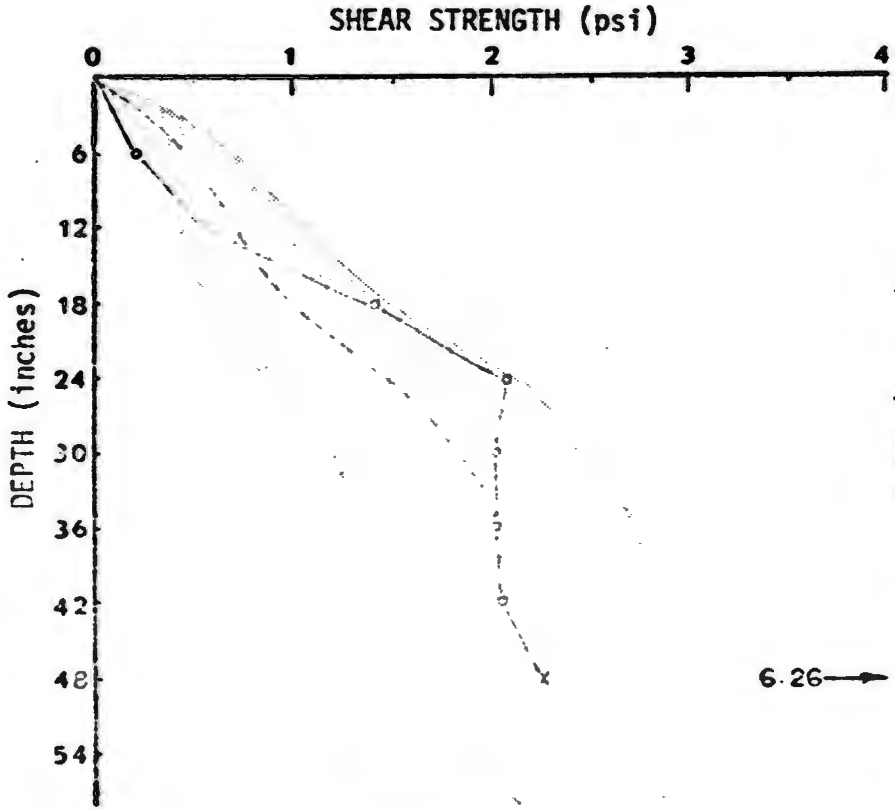
o observed ------ mean ——— shear strength used
x adjusted [shaded] one standard deviation from mean



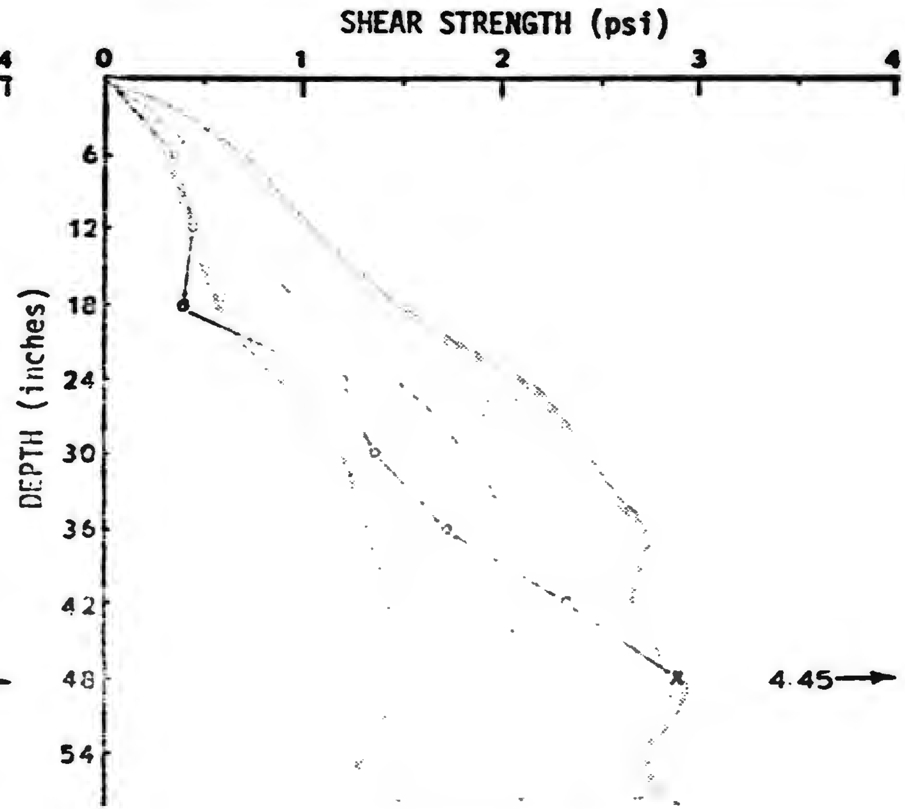
CYLINDER ON END
Velocity 20.0 fps
Station 11

CYLINDER ON END
Velocity 5.0 fps
Station 20

o observed
x adjusted
------ mean
——— shear strength used
one standard deviation from mean

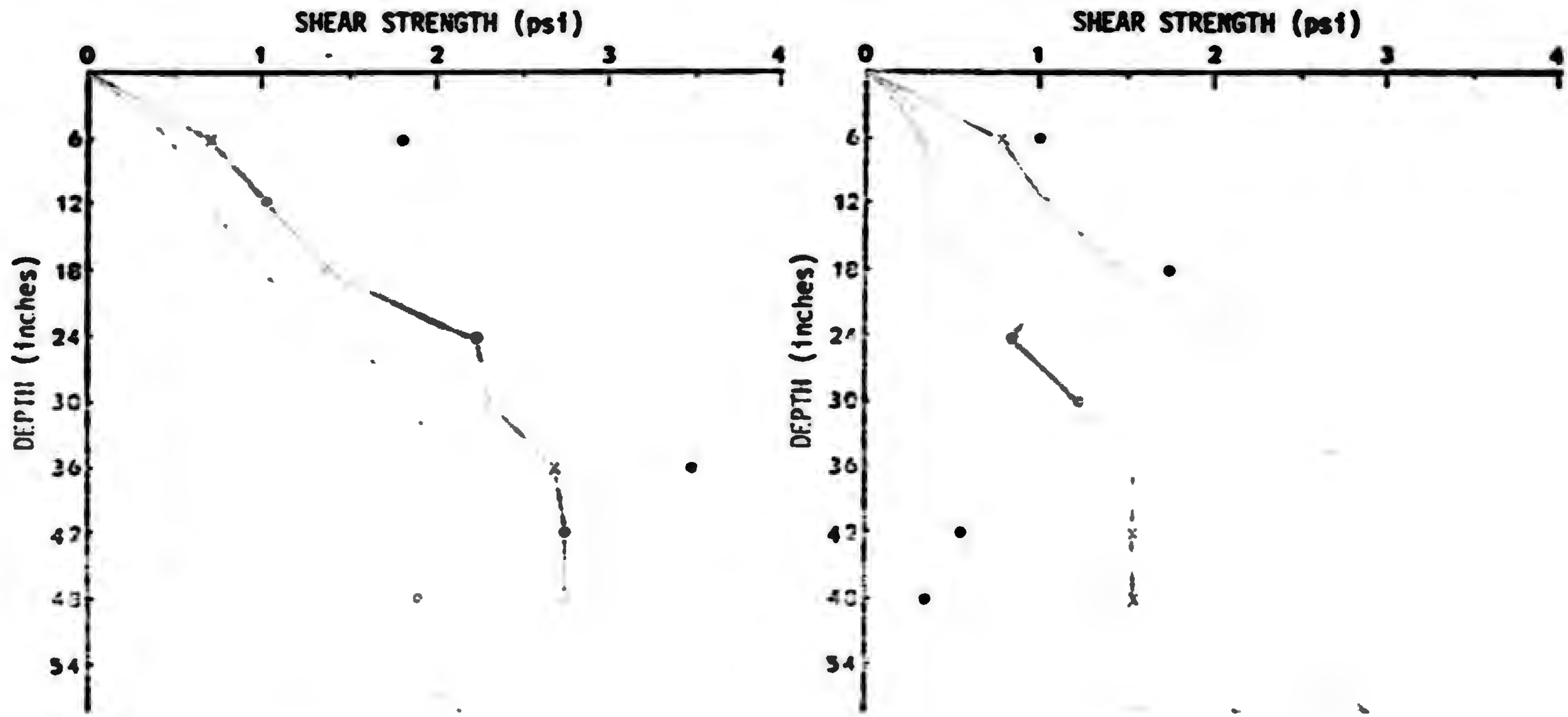


CYLINDER ON END
Velocity 10.0 fps
Station 25



CYLINDER ON END
Velocity 15.0 fps
Station 19

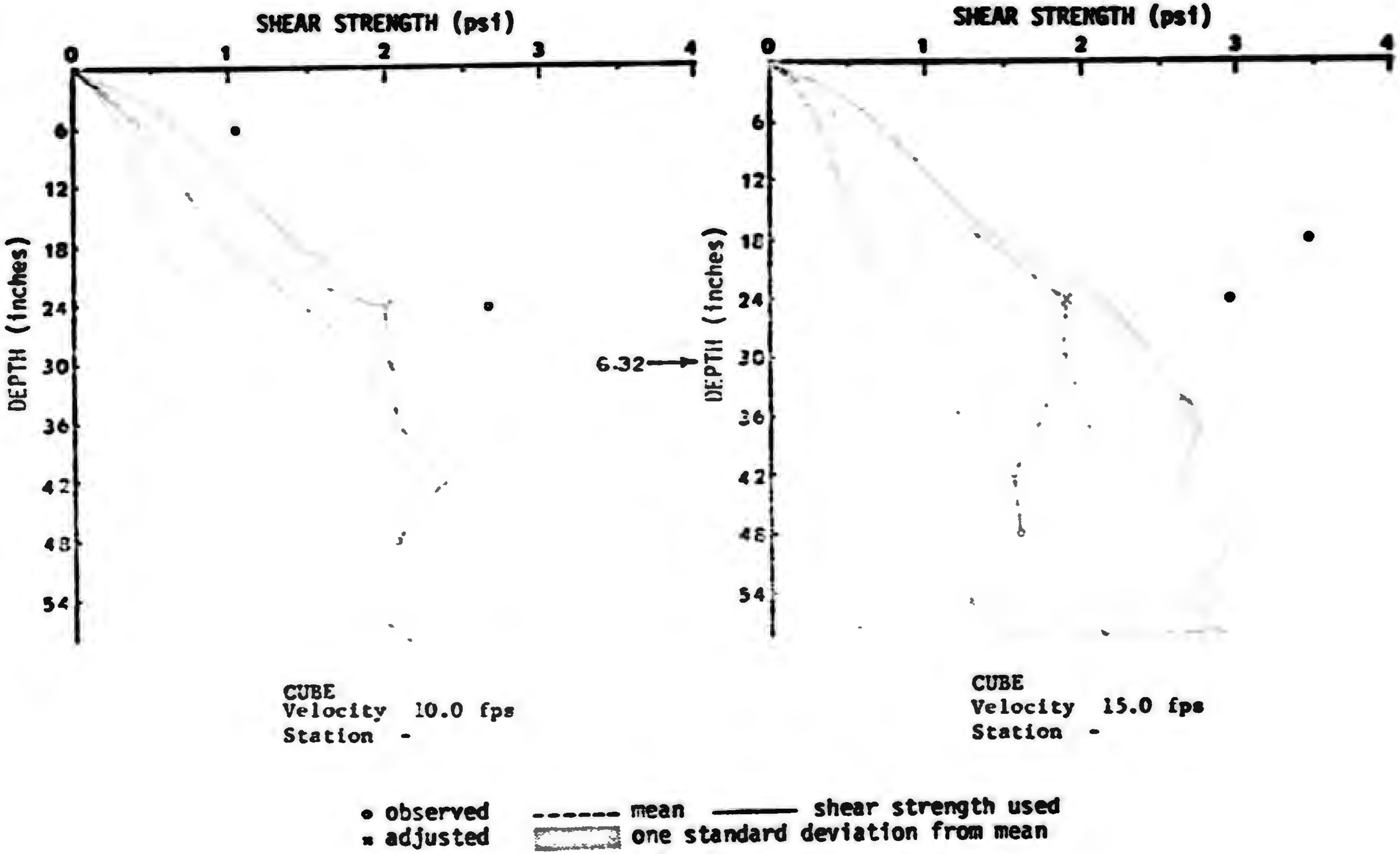
∘ observed ------ mean ——— shear strength used
× adjusted [shaded] one standard deviation from mean

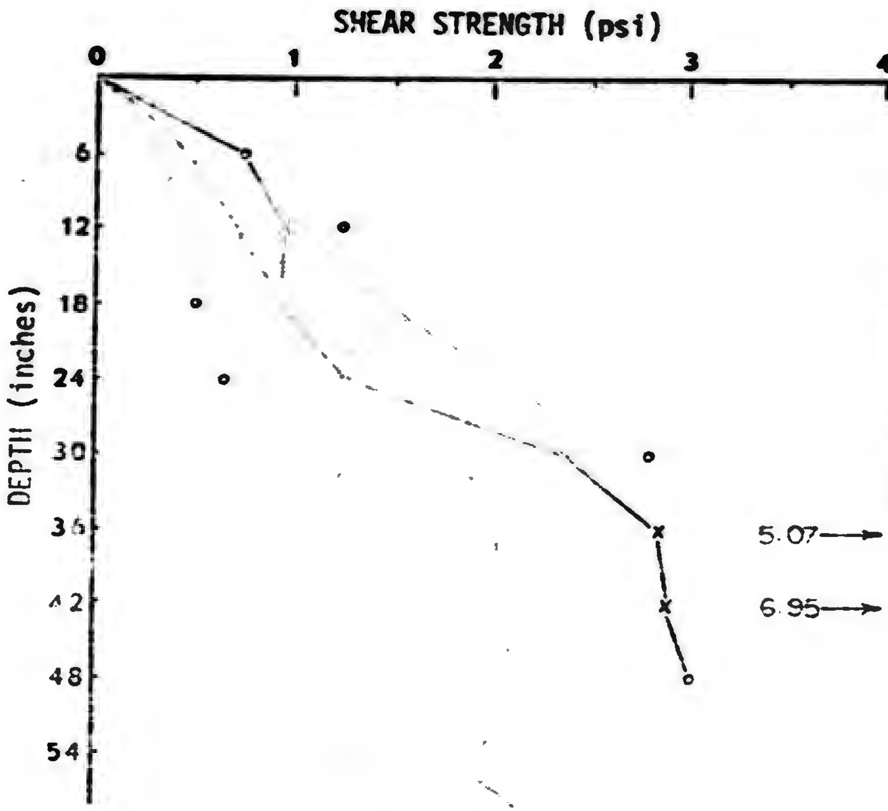


CYLINDER ON END
Velocity 20.0 ips
Station 35

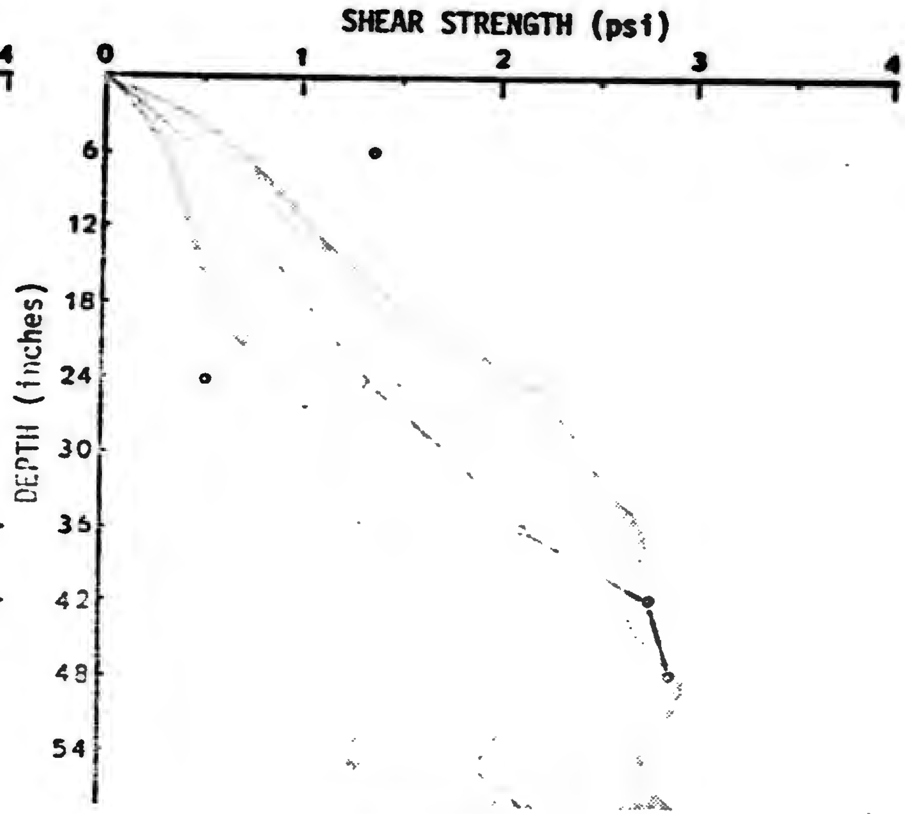
CUBE
Velocity 5.0 fps
Station -

• observed ------ mean ——— shear strength used
× adjusted one standard deviation from mean


SHEAR STRENGTH (psi)
0 1 2 3 4
DEPTH (inches)
6 12 18 24 30 36 42 48 54
6.32
CUBE
Velocity 10.0 fps
Station -
SHEAR STRENGTH (psi)
0 1 2 3 4
DEPTH (inches)
6 12 18 24 30 36 42 48 54
CUBE
Velocity 15.0 fps
Station -
• observed
× adjusted
------ mean
——— shear strength used
one standard deviation from mean

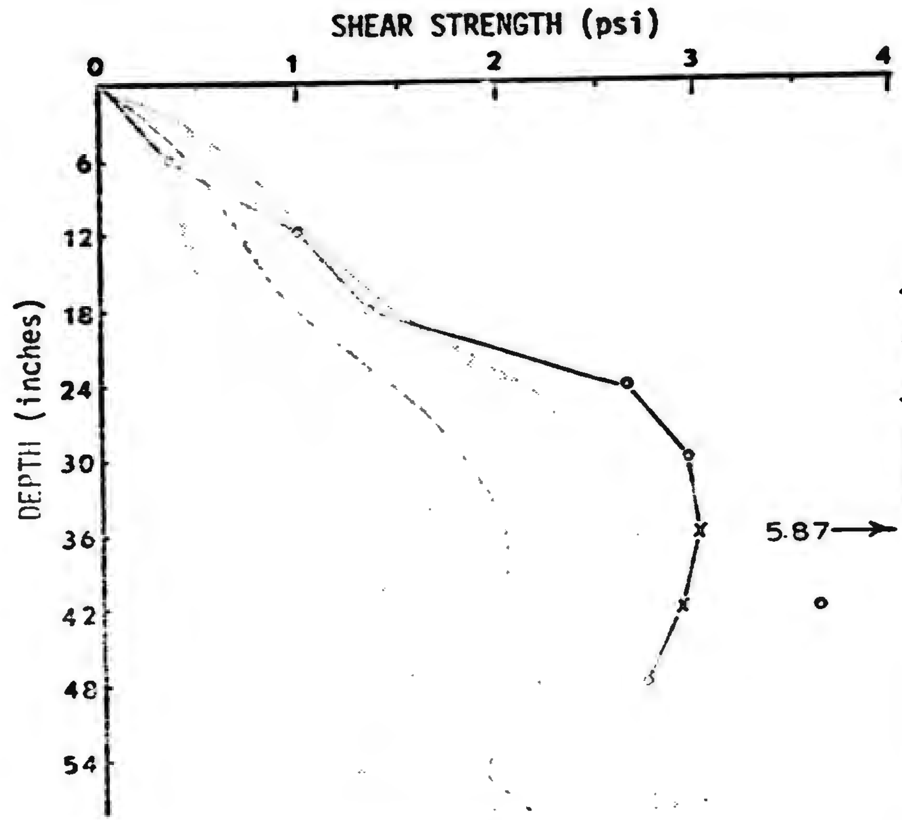


CUBE
Velocity 20.0 fps
Station -

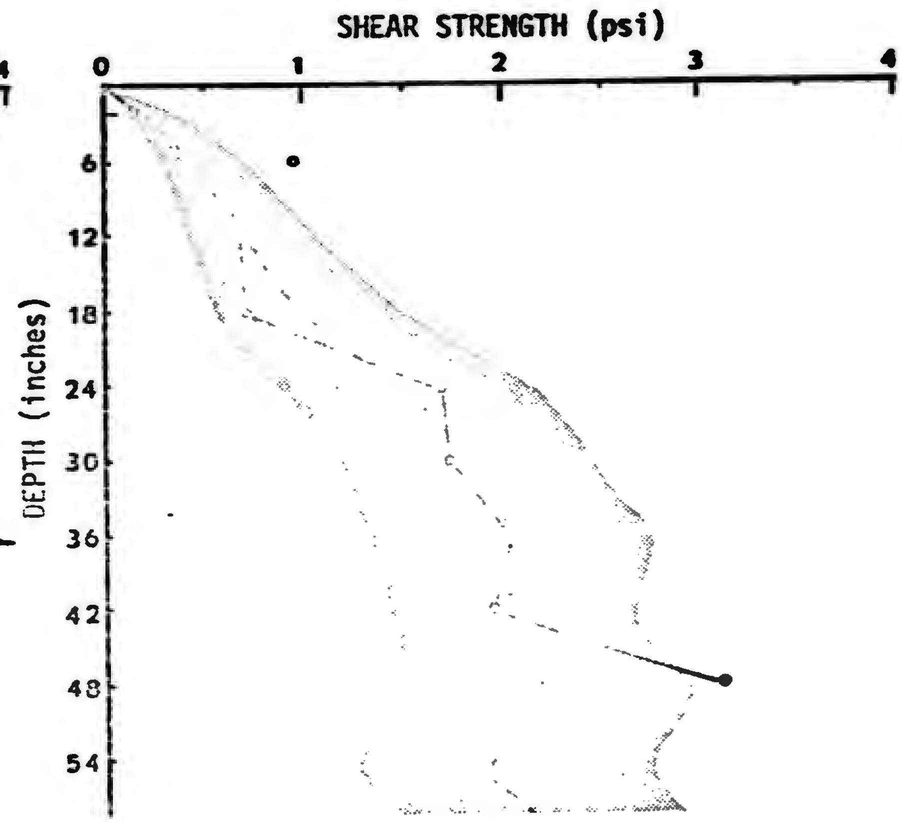


RECTANGLE
Velocity 0.0 fps
Station 24

o observed ------ mean ——— shear strength used
x adjusted [shaded] one standard deviation from mean

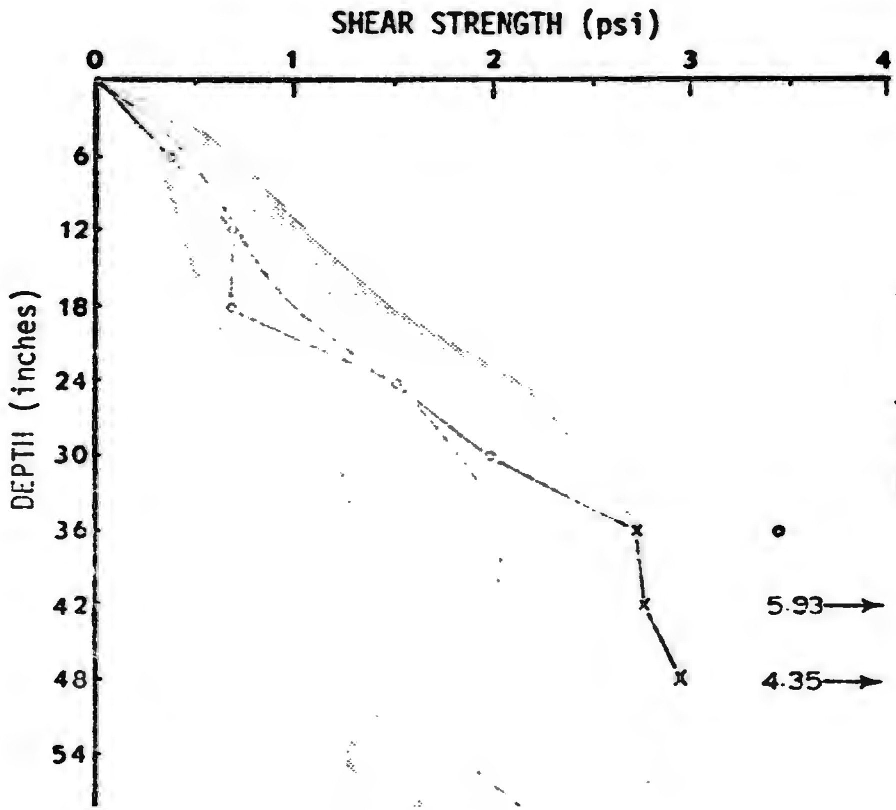


RECTANGLE
Velocity 5.0 fps
Station 13

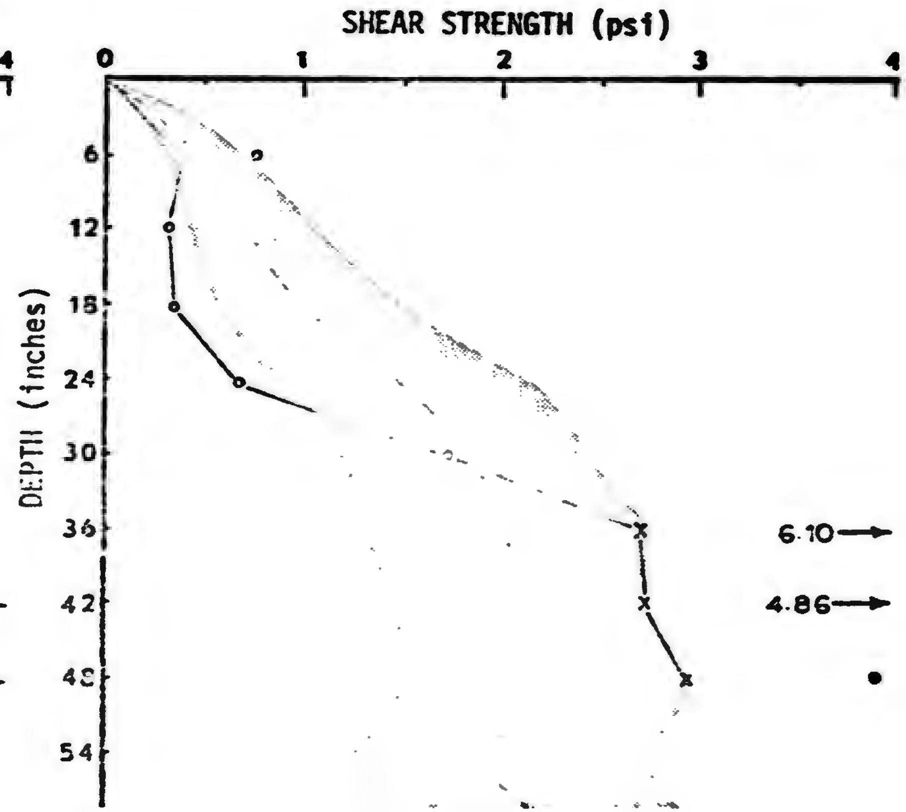


RECTANGLE
Velocity 10.0 fps
Station 11

o observed ------ mean ——— shear strength used
x adjusted [shaded] one standard deviation from mean

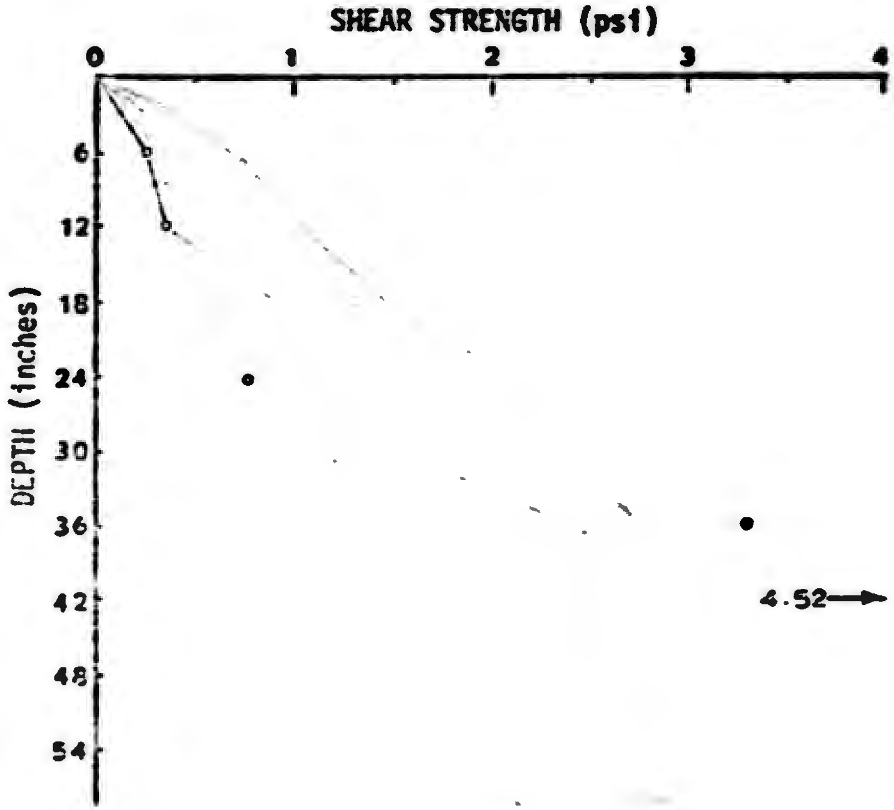


RECTANGLE
Velocity 15.0 fps
Station 17



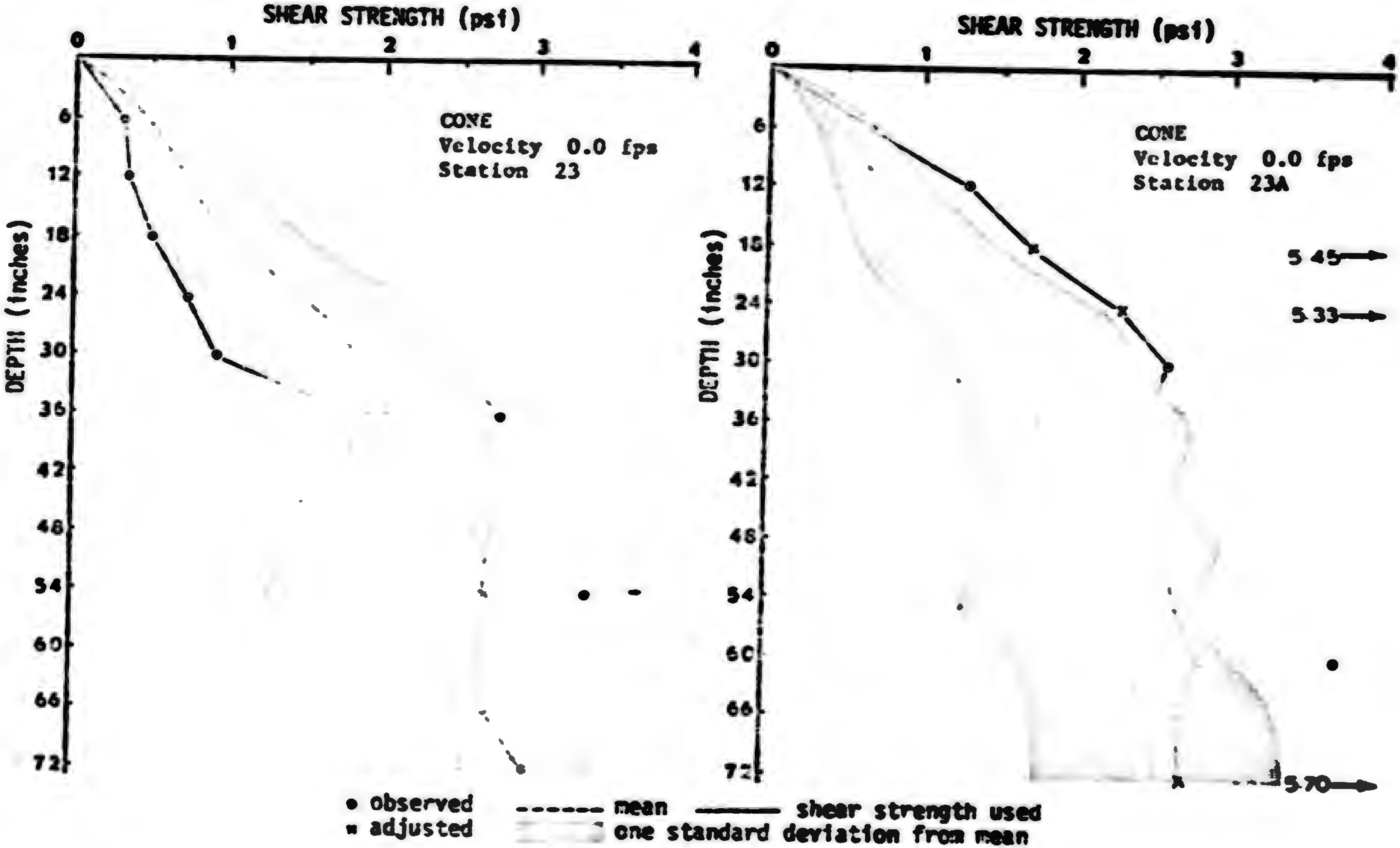
RECTANGLE
Velocity 15.0 fps
Station 19

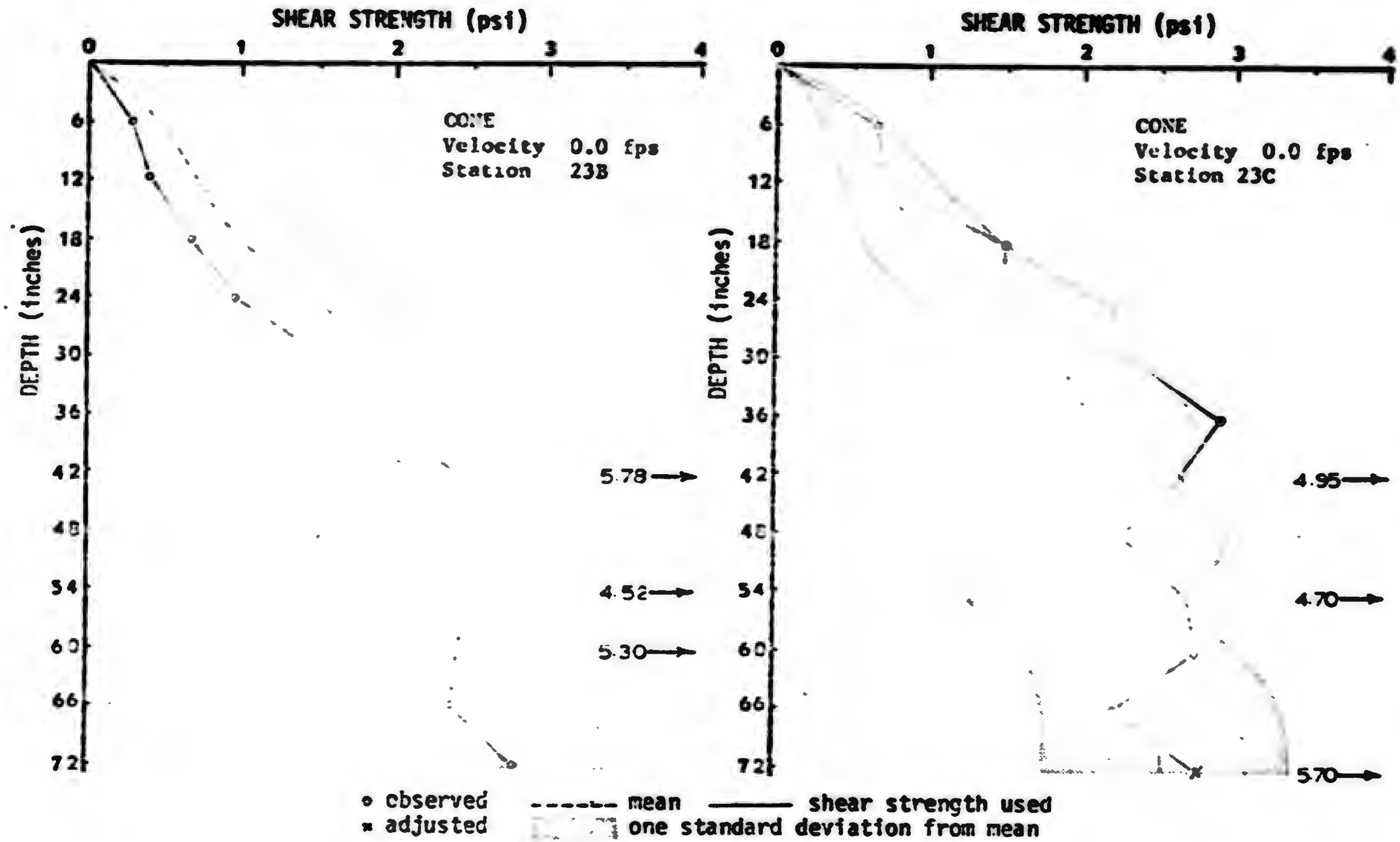
o observed ------ mean ——— shear strength used
x adjusted [shaded] one standard deviation from mean

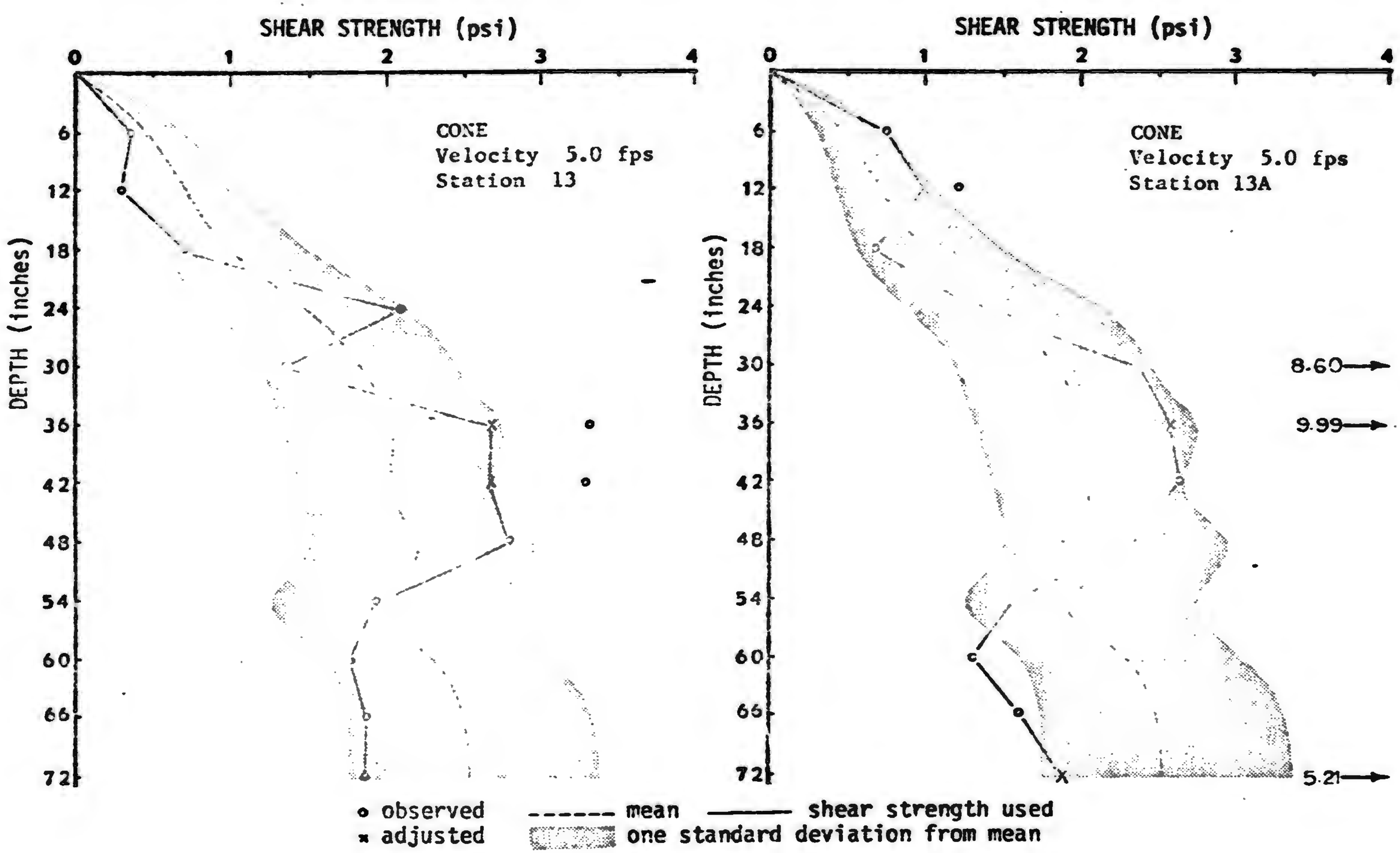


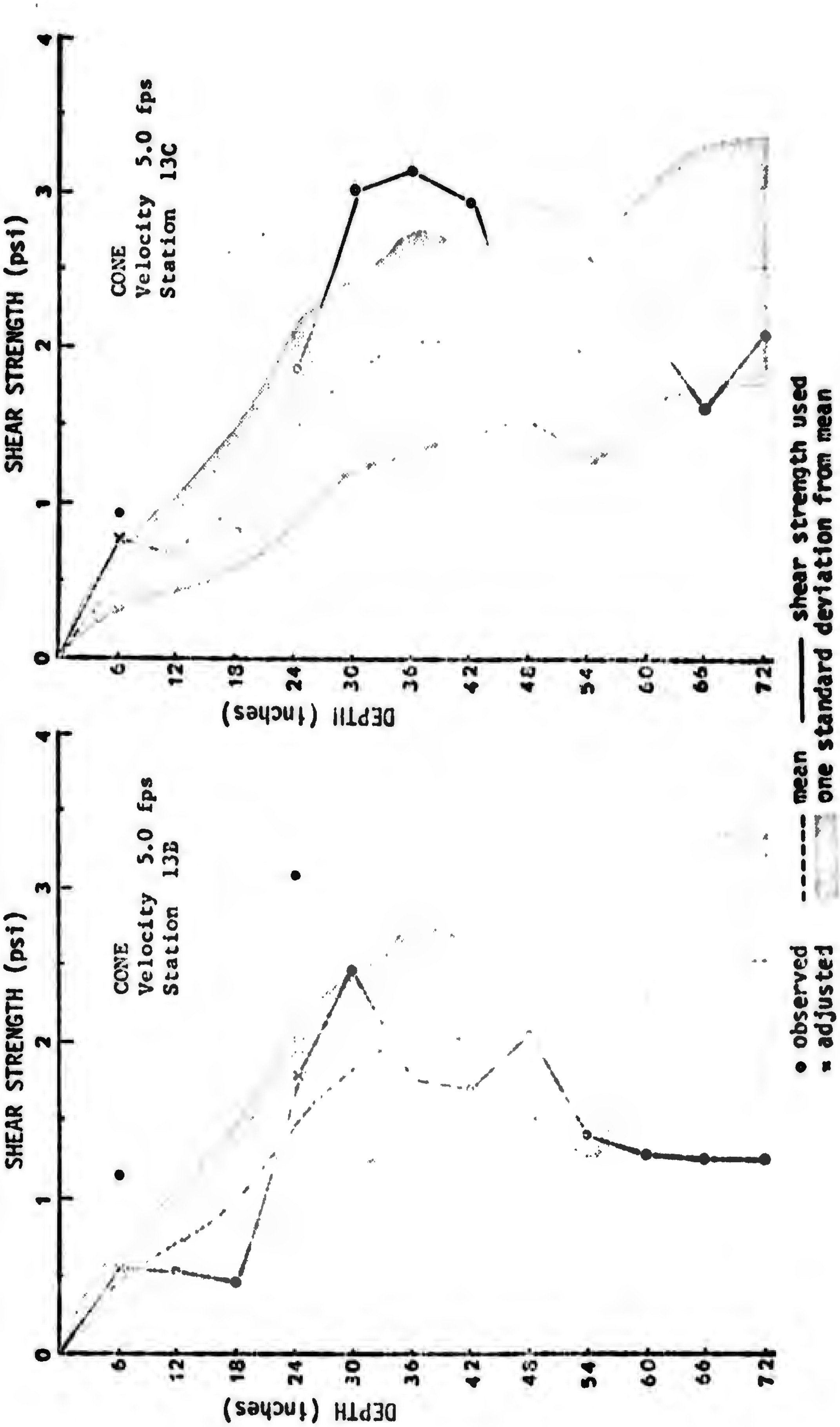
RECTANGLE
Velocity 20.0 fps
Station 18

• observed ------ mean ——— shear strength used
× adjusted one standard deviation from mean

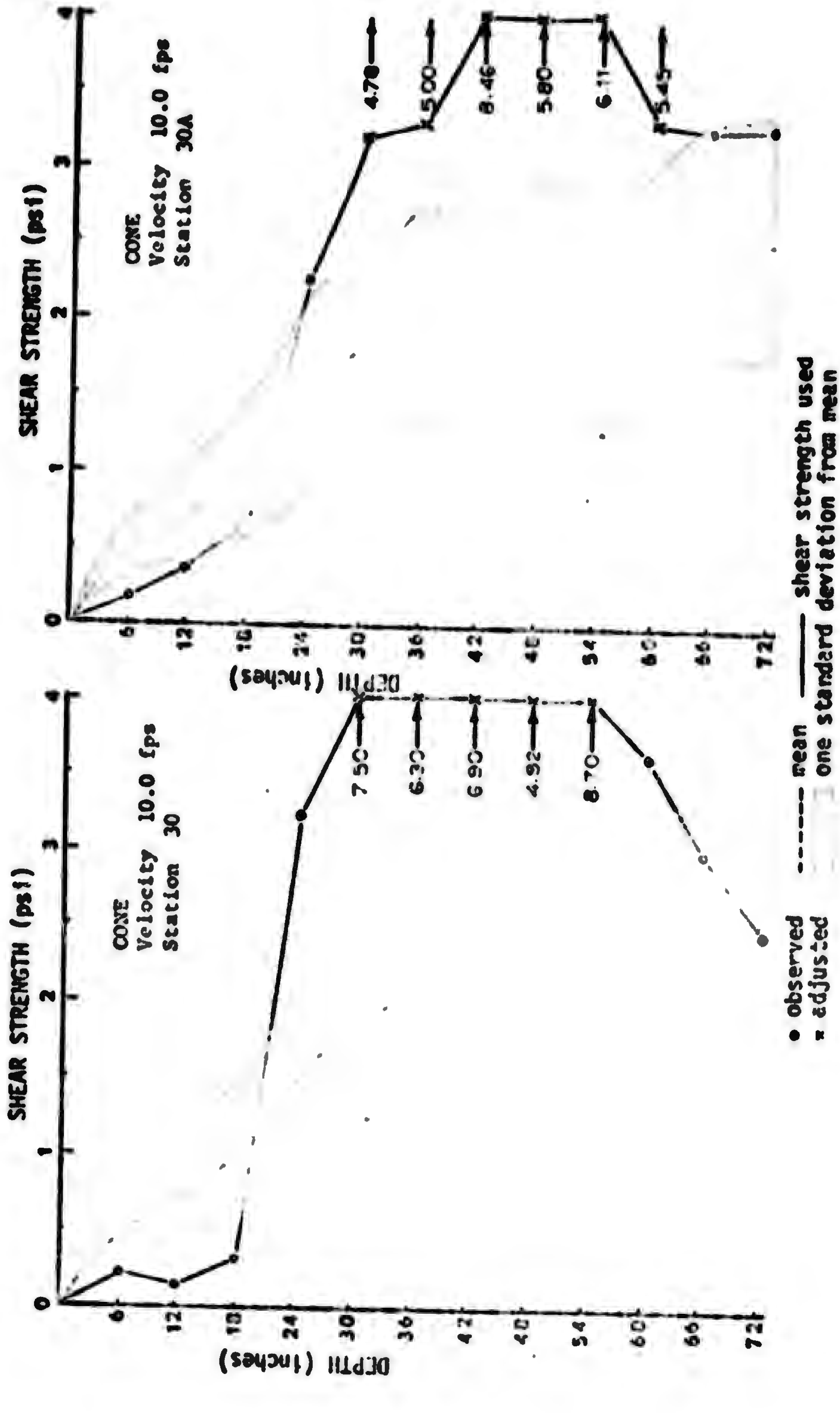

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23
SHEAR STRENGTH (psi)
CONE
Velocity 0.0 fps
Station 23A
5.45
5.33
5.70
observed
adjusted
mean
shear strength used
one standard deviation from mean

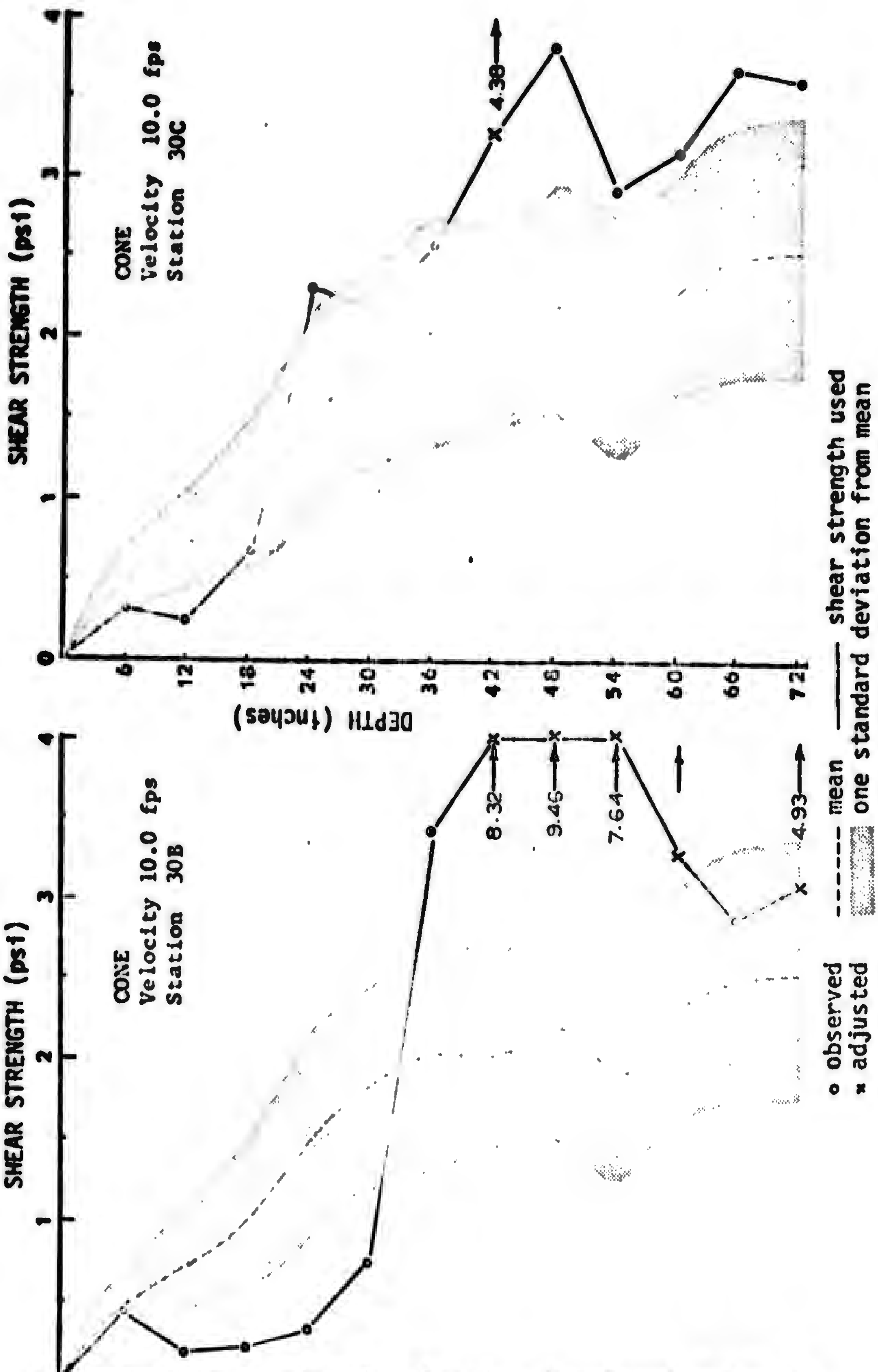

SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23B
5.78
4.52
5.30
SHEAR STRENGTH (psi)
0
1
2
3
4
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
CONE
Velocity 0.0 fps
Station 23C
4.95
4.70
5.70
o observed
x adjusted
mean
shear strength used
one standard deviation from mean

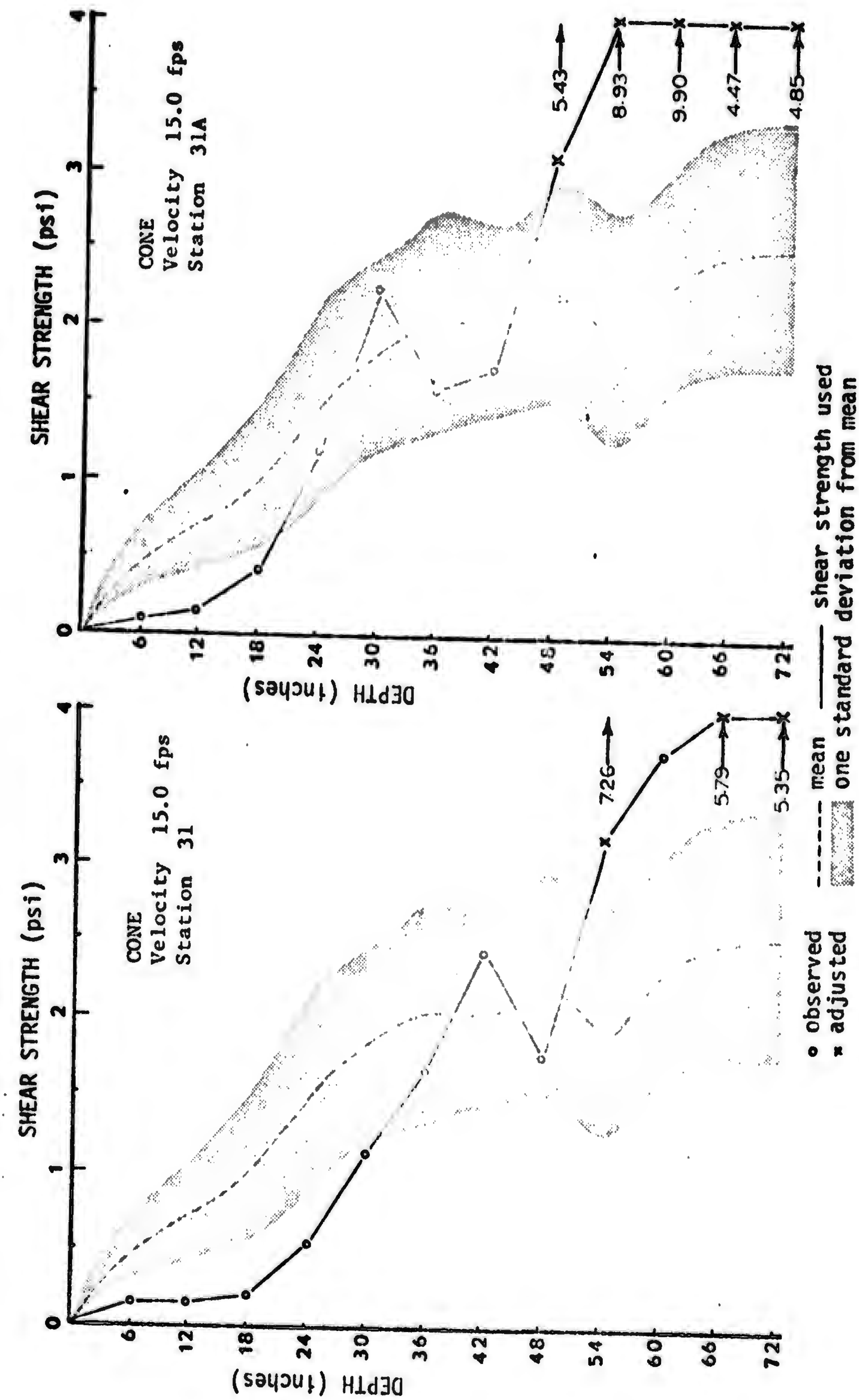

SHEAR STRENGTH (psi)
0 1 2 3 4
DEPTH (inches)
6 12 18 24 30 36 42 48 54 60 66 72
CONE
Velocity 5.0 fps
Station 13
SHEAR STRENGTH (psi)
0 1 2 3 4
DEPTH (inches)
6 12 18 24 30 36 42 48 54 60 66 72
CONE
Velocity 5.0 fps
Station 13A
8.60
9.99
5.21
o observed
x adjusted
mean
shear strength used
one standard deviation from mean

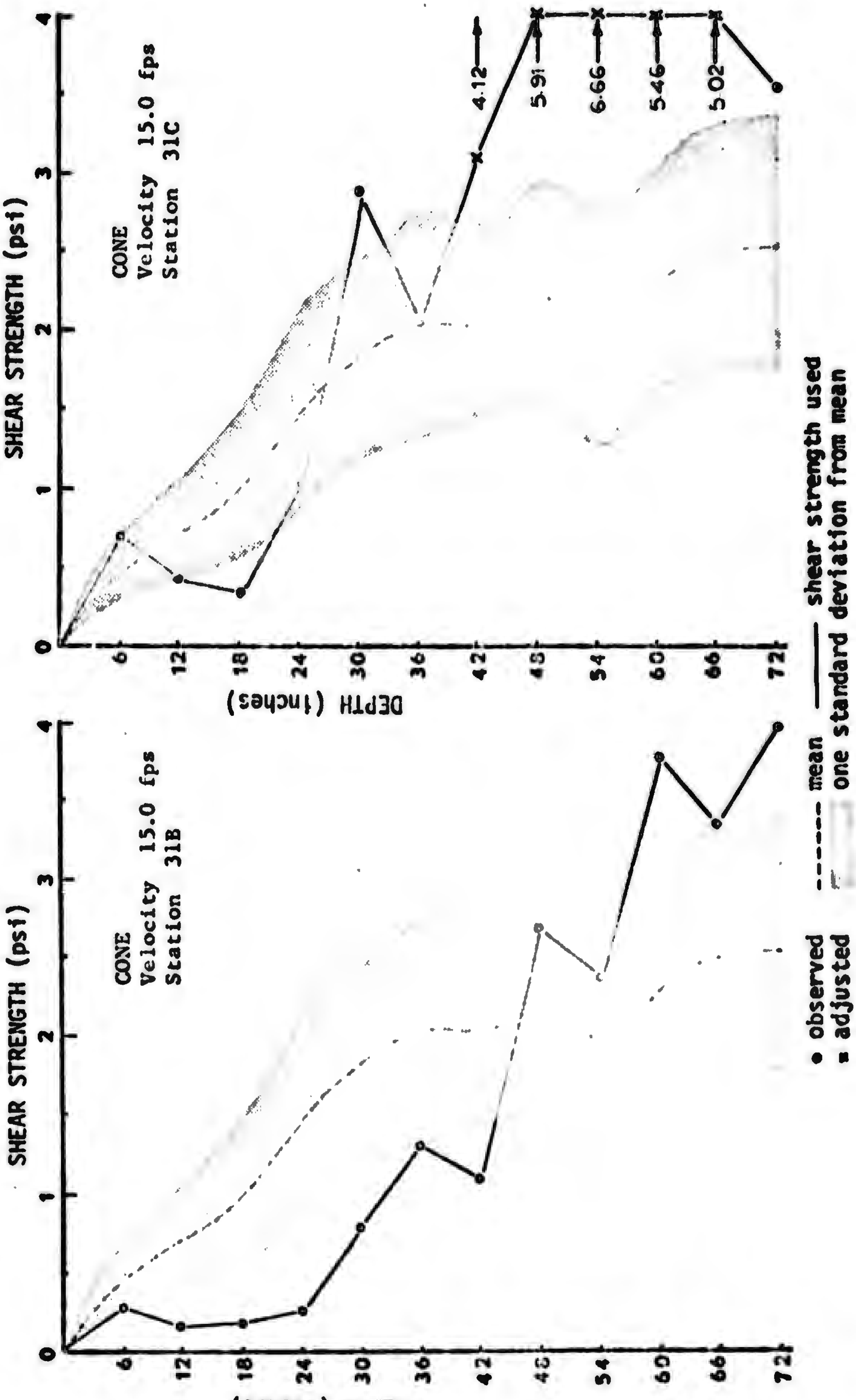


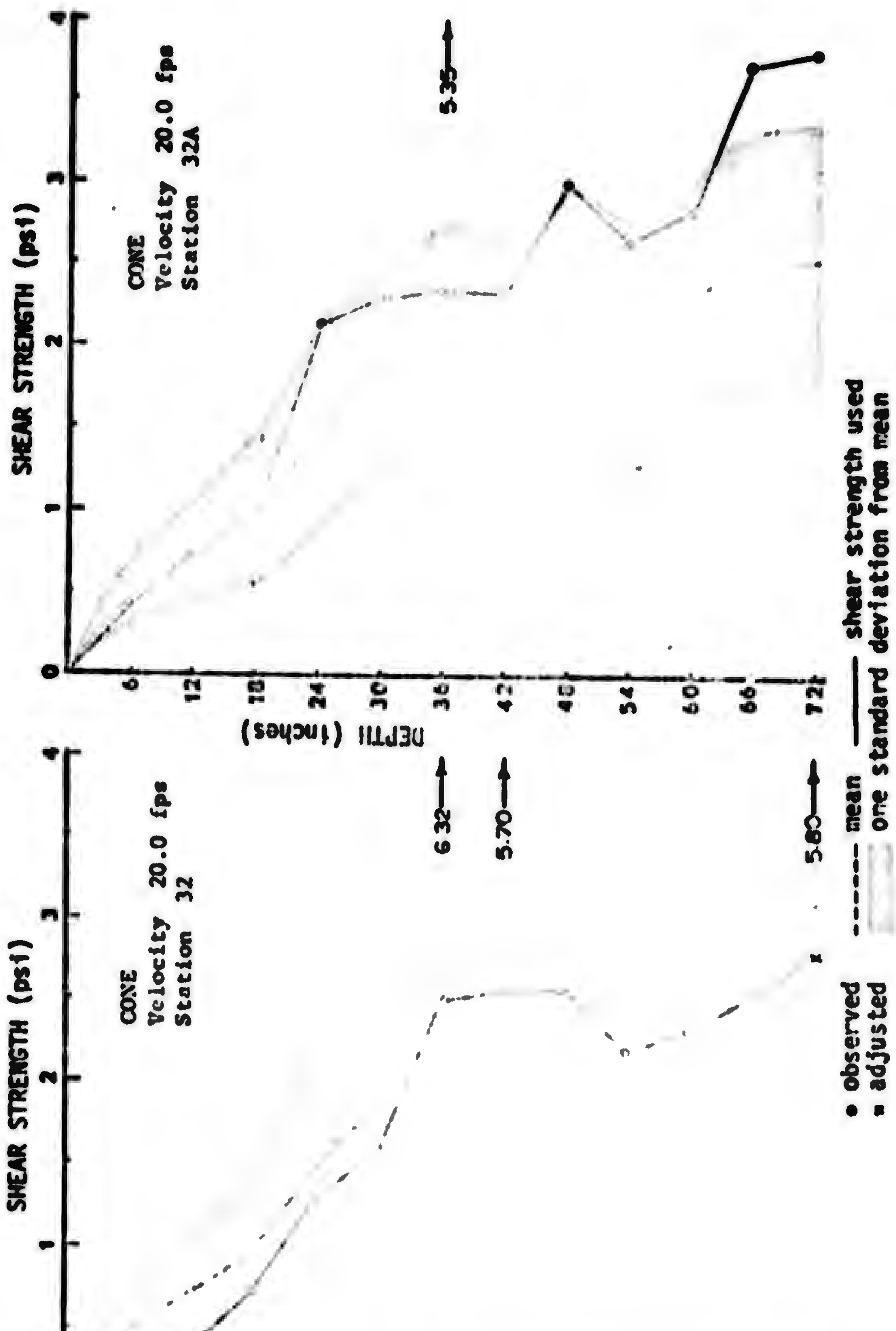
SHEAR STRENGTH (psi)
CONE
Velocity 5.0 fps
Station 13C
DEPTH (inches)
SHEAR STRENGTH (psi)
CONE
Velocity 5.0 fps
Station 13B
DEPTH (inches)
• observed
× adjusted
mean
one standard deviation from mean
shear strength used

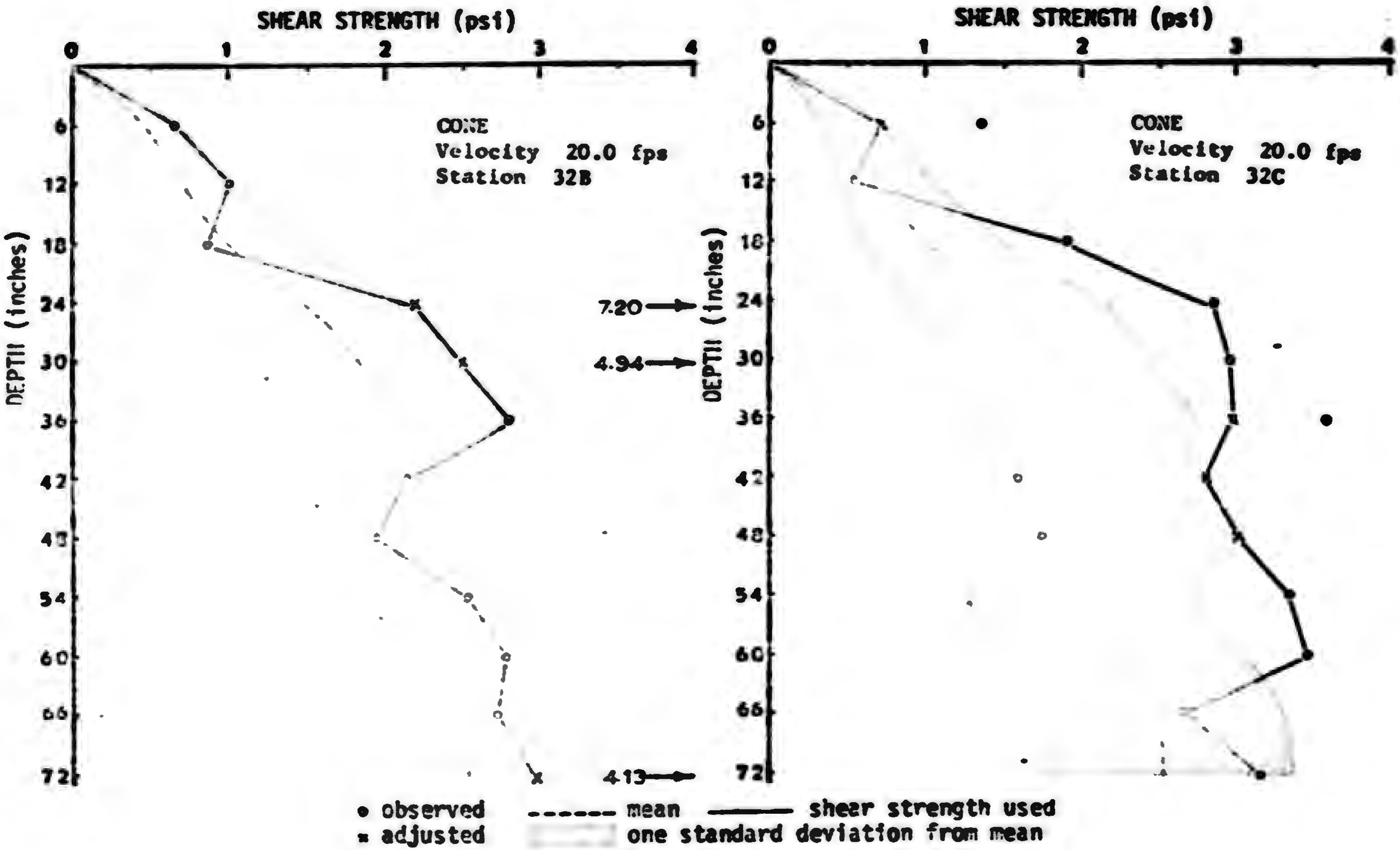

SHEAR STRENGTH (psi)
DEPTH (inches)
CONE
Velocity 10.0 fps
Station 30
7.50
6.30
6.90
4.92
8.70
CONE
Velocity 10.0 fps
Station 30A
4.78
5.00
8.46
5.80
6.11
5.45
• observed
x adjusted
------ mean
—— shear strength used
one standard deviation from mean


SHEAR STRENGTH (psi)
DEPTH (inches)
CONE
Velocity 10.0 fps
Station 30B
8.32
9.45
7.64
4.93
CONE
Velocity 10.0 fps
Station 30C
4.38
o observed
x adjusted
------ mean
—— shear strength used
one standard deviation from mean


CONE
Velocity 15.0 fps
Station 31A
SHEAR STRENGTH (psi)
DEPTH (inches)
5.43
8.93
9.90
4.47
4.85
CONE
Velocity 15.0 fps
Station 31
SHEAR STRENGTH (psi)
DEPTH (inches)
7.26
5.79
5.35
o observed
x adjusted
- - - - - mean
——— shear strength used
one standard deviation from mean


SHEAR STRENGTH (psi)
0
1
2
3
4
CONE
Velocity 15.0 fps
Station 31C
DEPTH (inches)
6
12
18
24
30
36
42
48
54
60
66
72
4.12
5.91
6.66
5.46
5.02
SHEAR STRENGTH (psi)
CONE
Velocity 15.0 fps
Station 31B
DEPTH (inches)
• observed
x adjusted
mean
one standard deviation from mean
shear strength used


SHEAR STRENGTH (psi)
DEPTH (inches)
CONE
Velocity 20.0 fps
Station 32A
5.35
SHEAR STRENGTH (psi)
DEPTH (inches)
CONE
Velocity 20.0 fps
Station 32
6.32
5.70
5.80
0
1
2
3
4
6
12
18
24
30
36
42
48
54
60
66
72
• observed
x adjusted
------ mean
one standard deviation from mean
shear strength used


SHEAR STRENGTH (psi)
0 1 2 3 4
DEPTH (inches)
6 12 18 24 30 36 42 48 54 60 66 72
CONE
Velocity 20.0 fps
Station 32B
7.20
4.94
4.13
SHEAR STRENGTH (psi)
0 1 2 3 4
DEPTH (inches)
6 12 18 24 30 36 42 48 54 60 66 72
CONE
Velocity 20.0 fps
Station 32C
• observed
x adjusted
------ mean
—— shear strength used
one standard deviation from mean

APPENDIX C: COMPUTATION OF SPHERE PENETRATION

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS( ) ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )  PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( )  SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
```

```
C
C SUMSUB( )WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OR BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(50),US(50),SUMSUB(50),E(100),V(100)
C     RESET DIMENSIONS FOR LARGE OBJECTS
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/50
     3*0.0/,US/50*0.0/,SUMSUB/50*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT SPHERE
      RAD=1.192
      WT=561.
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C     FOR A SPHERE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
      CD=0.3
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF SPHERE
      Y=DX/2.
      YMAX=2*RAD
      Z=RAD/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=PI*(RAD**2-(RAD-Y)**2)
      DO 100 I=2,N
      AREA(I)=PI*(RAD**2-(RAD-(I-1)*DX-Y)**2)
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
```

```
      DO 200 I=N,100
      AREA(I)=AREA(N)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVUL=(2./3.)*PI*RAD**3
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVCL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
      PRINT,CVOL,HAFVOL,ERROR
C
C
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS AND
C     DISPLACED MASS FROM SECTION TO SECTION
C     APPROXIMATE BY USING ONE HALF ON AN ELIPTICAL FORM. AMASS BECOMES
C     CONSTANT WHEN MAX AREA HAS BEEN REACHED
C
      SUMVOL=0.0
      K=N+1
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      B=(I-1)*DX-Y
      A=RAD**2-(RAD-B)**2
      AS=SQRT(A)
      EE=1-(B**2)/A
      D=SQRT(EE)
C
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
      SI=ARSIN(D)
      SQRE=SQRT(1-D**2)
C     ADD DISPLACED VOL AT THE SAME TIME
      AMASS(I-1)=BWD*((2./3.)*PI*AS**3*((D-SI*SQRE)/(SI-D*SQRE)))
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
```

```
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
C
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
  400 CONTINUE
C
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF SPHERE
C
      HAMAS=BWD*(PI*RAD**3)
      ERROR=HAMAS-AMASS(N)
      PRINT,HAMAS,AMASS(N),ERROR
C
C
C     AMASS REMAINS THE SAME AFTER MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
      PRINT,CDMASS,AMASS(N)
C
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
```

```
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA*PI/3.)*(RAD*X**3-X**4/4.)
      PRINT,AWB
C
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
```

```
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2200)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
      SLOPE1=SS05/.5
      BINT1=0.0
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE SPHERE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
C     TION DEPTH MINUS ONE HALF THE PENETRATION DEPTH UP TO THE MAX RAD
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE MAX RAD IS REACHED THE DEPTH EQUALS PENETRATION DEPTH
C     MINUS ONE HALF THE RADIUS
      IF((I*DX-Y).GT.RAD) DEPTH=I*DX-Y-RAD/2.
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
```

```
C
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASSI=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASSI-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
```

```
C      SECTION TO COMPUTE THE WORK DONE BY DRAG
C      APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C      FIRST TIME OVER THE SECTION, AS DONE ABOVE
       VAVG=(V(I)+V(I+1))/2.
       IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
       WDRAG=.5*BUD*CD*AREA(I)*DX*VAVG**2
C
       VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
      2S(I))
       IF (VELOSQ.LE.0.0)GO TO 1000
       V(I+1)=SQRT(VELOSQ)
C
C      CALCULATE E AT NEXT SECTION
       E(I+1)=BMASS*V(I+1)**2/2.
C
C      CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
       EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C      COMPUTE PENETRATION DEPTH
       XXX=I*DX
C
C      PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C      SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C      WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C      AND DRAG
C
       WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000  CONTINUE
 1000  CONTINUE
 2050  FORMAT(I5)
 2060  FORMAT(' ',I3)
 2100  FORMAT(F5.1,8F5.2)
 2200  FORMAT('1',9X,'SPHERE'//9X,'RADIUS = ',F7.3/9X,'WEIGHT = ',F7.1,'
      2LPS'/9X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
      3 COEFFICIENT = ',F5.2///)
 2300  FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
      2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500  FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
      2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
      3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
      4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
      5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
      6ORCES'//)
 2600  FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
       STOP
       END
```

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.30 0.38 0.78 0.70 1.34 1.63 1.53 1.55

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	1.787	1.930	27.832	0.074	0.121	0.020	0.003
2	0.10	2.432	3.240	53.726	0.653	1.352	0.100	0.031
3	0.15	2.971	5.400	76.958	1.775	2.653	0.256	0.135
4	0.20	3.315	7.560	95.946	3.402	3.928	0.486	0.248
5	0.25	3.605	9.720	113.323	5.406	5.017	0.785	0.373
6	0.30	3.8[illegible]0	11.880	125.8[illegible]	8.070	5.801	1.151	0.510
7	0.35	3.920	14.040	134.579	10.936	6.705	1.580	0.641
8	0.40	3.9[illegible]	16.200	13[illegible].415	14.206	6.[illegible]	2.058	0.759
9	0.45	4.014	18.360	1[illegible]0.492	17.792	5.711	2.612	0.858
10	0.50	3.978	20.[illegible]0	137.949	21.658	4.796	3.209	0.929
11	0.55	3.890	22.680	131.955	25.764	3.453	3.856	0.959
12	0.60	3.751	24.840	122.700	30.074	1.710	4.548	0.975
13	0.65	3.558	27.000	110.773	34.5[illegible]	-0.398	5.282	0.963
14	0.70	3.304	29.[illegible]0	95.171	39.154	-2.879	6.055	0.872
15	0.75	2.977	31.320	77.296	43.847	-5.539	6.864	0.762
16	0.80	2.555	33.4[illegible]0	56.508	48.594	-8.480	7.705	0.613
17	0.85	1.981	35.6[illegible]	34.208	53.355	-11.607	8.574	0.425
18	0.90	1.037	37.[illegible]	9.375	59.093	-14.867	9.469	0.193

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.36 1.04 1.03 1.56 2.41 2.68 2.61 2.16

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	5.298	1.296	244.746	0.099	1.060	0.020	0.100
2	0.10	5.534	3.888	266.986	0.784	4.600	0.100	0.325
3	0.15	5.718	6.480	285.087	2.130	6.989	0.256	0.573
4	0.20	5.855	9.072	298.890	4.082	8.649	0.486	0.830
5	0.25	5.946	11.664	303.283	6.595	10.192	0.735	1.084
6	0.30	5.994	14.256	313.250	9.624	10.983	1.151	1.326
7	0.35	6.000	16.848	313.858	13.123	11.195	1.590	1.544
8	0.40	5.965	19.440	310.240	17.047	10.823	2.068	1.730
9	0.45	5.891	22.032	302.573	21.351	9.876	2.612	1.877
10	0.50	5.778	24.624	291.060	25.959	8.382	3.209	1.981
11	0.55	5.626	27.216	275.923	30.917	6.378	3.856	2.036
12	0.60	5.433	29.808	257.3[illegible]5	36.089	3.908	4.548	2.041
13	0.65	5.199	32.400	235.673	41.460	1.025	5.282	1.995
14	0.70	4.920	34.992	211.004	46.994	-2.217	6.055	1.896
15	0.75	4.589	37.584	183.590	52.617	-5.763	6.864	1.745
16	0.80	4.193	40.176	153.632	58.313	-9.555	7.705	1.545
17	0.85	3.730	42.768	121.320	64.026	-13.536	8.574	1.298
18	0.90	3.156	45.360	86.836	69.712	-17.652	9.469	1.005
19	0.95	2.403	47.952	50.351	75.325	-21.846	10.385	0.670
20	1.00	1.175	50.544	12.036	80.921	-26.059	11.320	0.283

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.49 0.77 0.85 2.07 2.43 1.19 1.19 1.77

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	10.135	1.764	895.509	0.121	3.878	0.020	0.383
2	0.10	10.199	5.292	906.996	1.067	14.349	0.100	1.146
3	0.15	10.216	8.820	909.886	2.899	20.019	0.256	1.885
4	0.20	10.192	12.348	905.645	5.556	23.669	0.486	2.580
5	0.25	10.131	15.876	894.873	8.977	25.845	0.785	3.216
6	0.30	10.036	19.404	878.129	13.093	26.762	1.151	3.782
7	0.35	9.903	22.932	855.917	17.852	26.553	1.580	4.268
8	0.40	9.749	26.460	828.697	23.203	25.330	2.068	4.669
9	0.45	9.560	29.988	795.897	29.061	23.195	2.612	4.980
10	0.50	9.342	33.516	760.915	35.374	20.250	3.209	5.198
11	0.55	9.094	37.044	721.115	42.092	16.590	3.856	5.323
12	0.60	8.817	40.572	677.829	49.121	12.311	4.548	5.355
13	0.65	8.510	44.100	631.362	56.432	7.506	5.282	5.297
14	0.70	8.170	47.628	581.991	63.951	2.263	6.055	5.151
15	0.75	7.797	51.156	529.970	71.617	-3.332	6.864	4.921
16	0.80	7.385	54.684	475.528	79.370	-9.[illegible]	7.705	4.613
17	0.85	6.931	58.212	418.878	87.147	-15.253	8.574	4.231
18	0.90	6.428	61.740	360.214	94.886	-21.424	9.469	3.782
19	0.95	5.853	65.268	299.717	102.526	-27.638	10.385	3.273
20	1.00	5.220	68.796	237.558	110.006	-33.826	11.320	2.709
21	1.05	4.475	71.548	174.587	116.038	-39.389	12.270	2.102
22	1.10	3.573	72.584	111.614	120.523	-44.196	13.231	1.465
23	1.15	2.364	75.600	48.726	124.634	-48.700	14.200	0.803

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.30 0.37 0.45 2.44 2.78 2.78 2.86 3.14

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	15.071	1.090	1980.215	0.074	8.576	0.020	0.854
2	0.10	15.048	3.240	1974.368	0.653	30.629	0.100	2.516
3	0.15	14.972	5.400	1954.411	1.775	41.890	0.256	4.076
4	0.20	14.856	7.560	1924.219	3.402	48.844	0.486	5.511
5	0.25	14.703	9.720	1886.209	5.496	52.972	0.735	6.805
6	0.30	14.536	11.[illegible]	[illegible].146	8.070	54.970	1.151	7.952
7	0.35	14.342	14.040	1793.470	10.[illegible]	55.260	1.5[illegible]	8.949
8	0.40	14.132	16.2[illegible]	1741.219	14.205	54.2[illegible]	2.0[illegible]	9.797
9	0.45	13.907	1[illegible]	[illegible].292	17.[illegible]2	52.0[illegible]	2.61[illegible]	10.500
10	0.50	13.670	20.[illegible]	[illegible].254	21.659	49.0[illegible]	3.209	11.064
11	0.55	13.423	22.[illegible]	1570.[illegible]80	25.744	45.[illegible]	3.856	11.435
12	0.60	13.167	24.[illegible]	1511.[illegible]5	30.074	41.012	4.548	11.[illegible]02
13	0.65	12.903	27.0[illegible]	14[illegible]1.535	34.850	36.274	5.282	11.[illegible]1
14	0.70	12.631	29.1[illegible]0	139[illegible].078	39.154	31.233	6.055	12.071
15	0.75	12.359	31.[illegible]20	1[illegible]0.4[illegible]6	43.[illegible]67	25.[illegible]7	6.864	12.050
16	0.80	12.069	33.4[illegible]	12[illegible].723	4[illegible].50[illegible]	20.50[illegible]	7.705	11.936
17	0.85	11.776	35.[illegible]	1[illegible].[illegible]23	[illegible].355	14.9[illegible]	8.574	11.737
18	0.90	11.473	37.[illegible]	114[illegible].715	5[illegible].023	9.435	9.469	11.460
19	0.95	11.174	39.550	1[illegible].[illegible]79	62.77[illegible]	3.916	10.385	11.115
20	1.00	10.[illegible]43	42.[illegible]20	10[illegible].[illegible]5	67.351	-1.525	11.320	10.707
21	1.05	10.538	43.452	[illegible].116	70.452	-6.263	12.270	10.249
22	1.10	10.235	4[illegible].[illegible]6	9[illegible].3[illegible]5	7[illegible].[illegible]5	-10.180	13.231	9.759
23	1.15	9.923	44.460	[illegible].[illegible]09	73.797	-13.839	14.200	9.237
24	1.20	9.627	44.[illegible]54	[illegible].673	74.[illegible]48	-17.814	16.636	8.695
25	1.25	9.3[illegible]5	45.[illegible]	7[illegible].627	75.731	-33.453	17.611	8.208
26	1.30	9.103	4[illegible].[illegible]19	[illegible].373	77.[illegible]98	-34.462	18.587	7.780
27	1.35	8.837	47.[illegible]17	6[illegible].919	79.064	-35.465	19.562	7.393
28	1.40	8.549	4[illegible].[illegible]25	6[illegible].270	83.731	-36.462	20.537	6.872
29	1.45	8.243	4[illegible]	592.634	82.398	-37.454	21.512	6.429
30	1.50	7.917	50.851	5[illegible]6.418	84.055	-38.440	22.487	5.954
31	1.55	7.567	51.[illegible]59	[illegible]	85.731	-39.470	23.462	5.466
32	1.60	7.191	52.857	4[illegible]0.871	87.398	-40.395	24.438	4.965
33	1.65	6.794	53.[illegible]68	4[illegible].279	89.203	-41.427	25.413	4.453
34	1.70	6.362	5[illegible].[illegible]0	35[illegible].4[illegible]	91.10[illegible]	-42.499	26.388	3.927
35	1.75	5.943	5[illegible].252	[illegible].2[illegible]	9[illegible].012	-43.564	27.363	3.387
36	1.80	5.299	57.404	2[illegible].837	94.917	-44.623	28.339	2.836
37	1.85	4.670	5[illegible].556	1[illegible]0.1[illegible]	96.822	-45.675	29.313	2.266
38	1.90	3.924	59.708	13[illegible].231	98.727	-46.721	30.288	1.686
39	1.95	2.973	60.860	77.059	100.632	-47.750	31.264	1.085
40	2.00	1.463	62.012	1[illegible].665	102.536	-48.780	32.239	0.469

SPHERE

RADIUS = 1.192
WEIGHT = 361.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.40 0.52 1.08 1.51 1.74 1.95 2.11 2.44

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	5.298	1.440	244.736	0.099	1.260	0.020	0.199
2	0.10	5.533	4.320	266.892	0.871	4.597	0.100	0.373
3	0.15	5.715	7.200	284.773	2.366	6.973	0.256	0.572
4	0.20	[illegible]	[illegible]	293.171	4.535	8.802	0.486	0.928
5	0.25	[illegible]	[illegible]	304.937	7.229	[illegible]	0.785	1.081
6	0.30	5.973	[illegible]	311.030	[illegible]	10.795	1.151	1.318
7	0.35	5.969	18.720	310.[illegible]	[illegible]	[illegible]	1.580	1.530
8	0.40	5.917	[illegible]	305.476	[illegible]	10.358	2.065	1.707
9	0.45	5.823	[illegible]	296.128	[illegible]	9.218	2.612	1.843
10	0.50	5.664	[illegible]	[illegible]	28.877	7.605	3.203	1.931
11	0.55	5.514	30.240	[illegible]	[illegible]	5.227	3.856	1.968
12	0.60	5.293	33.120	254.300	40.099	2.463	4.548	1.950
13	0.65	5.027	36.000	219.866	46.067	-0.743	5.292	1.877
14	0.70	4.655	[illegible]	192.239	52.205	-4.322	6.055	1.748
15	0.75	4.305	41.760	161.641	59.453	-8.244	[illegible]	1.564
16	0.80	[illegible]	[illegible]	[illegible]	66.732	-12.417	7.705	1.327
17	0.85	3.255	47.520	92.373	71.140	-16.791	8.574	1.038
18	0.90	2.491	50.400	54.103	77.458	-21.393	9.469	0.700
19	0.95	1.252	53.280	13.656	83.895	-25.890	10.385	0.364

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.69 0.66 0.77 1.39 1.56 2.05 2.44 3.01

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	10.134	2.486	893.460	0.171	3.878	0.020	0.383
2	0.10	10.196	7.452	906.4[illegible]	1.502	14.333	0.100	1.146
3	0.15	10.207	12.420	908.217	4.0[illegible]	19.939	0.256	1.833
4	0.20	10.172	17.[illegible]	907.049	7.924	23.435	0.4[illegible]	2.57[illegible]
5	0.25	10.033	22.356	898.141	12.641	25.325	0.783	3.197
6	0.30	9.772	27.374	867.079	18.445	25.822	1.151	3.744
7	0.35	9.911	32.292	829.134	25.152	25.013	1.580	4.199
8	0.40	9.60[illegible]	37.260	804.879	32.67[illegible]	23.008	2.068	4.556
9	0.45	9.345	4[illegible].223	764.678	40.[illegible]22	19.407	2.612	4.808
10	0.50	9.061	47.[illegible]96	71[illegible].94[illegible]	49.[illegible]13	15.815	3.209	4.950
11	0.55	8.75[illegible]	52.156	6[illegible].059	59.[illegible]58	10.[illegible]37	3.856	4.991
12	0.60	8.371	57.132	61[illegible]	69.171	5.084	4.548	[illegible]
13	0.65	7.959	62.106	5[illegible].[illegible]32	79.459	-1.335	5.2[illegible]	4.711
14	0.70	7.483	67.0[illegible]	4[illegible].169	90.053	-8.311	6.055	4.415
15	0.75	6.943	72.036	420.227	100.849	-15.730	6.854	4.017
16	0.80	6.375	77.054	348.794	111.756	-23.511	7.703	3.523
17	0.85	5.607	81.972	274.143	122.717	-31.529	8.574	2.940
18	0.90	4.748	86.940	195.921	133.615	-39.688	9.467	2.273
19	0.95	3.650	91.938	116.179	144.374	-47.992	10.385	1.528
20	1.00	1.956	96.876	33.359	154.906	-56.047	11.320	0.694

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.28 0.36 0.91 1.39 1.74 1.57 2.05 2.70

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	15.071	1.008	1980.220	0.069	8.576	0.020	0.854
2	0.10	15.049	3.024	1974.415	0.610	30.630	0.100	2.516
3	0.15	14.973	5.040	1954.567	1.657	41.907	0.256	4.077
4	0.20	14.857	7.056	1924.576	3.175	48.867	0.486	5.512
5	0.25	14.711	9.072	1885.881	5.130	53.023	0.785	6.807
6	0.30	14.543	11.088	1843.275	7.485	55.065	1.151	7.956
7	0.35	14.349	13.104	1795.148	10.307	55.434	1.580	8.956
8	0.40	14.142	15.120	1743.6[illegible]2	13.259	54.462	2.069	9.808
9	0.45	13.921	17.136	[illegible]	16.406	52.409	2.612	10.517
10	0.50	13.633	19.152	1623.552	20.214	49.491	3.209	11.089
11	0.55	13.445	21.168	1575.216	24.047	45.884	3.856	11.529
12	0.60	13.196	23.184	1518.137	23.069	41.734	4.548	11.847
13	0.65	12.939	25.200	1459.440	32.247	37.169	5.282	12.049
14	0.70	12.674	27.216	1400.457	36.543	32.290	6.055	12.144
15	0.75	12.404	29.232	1341.390	40.924	27.188	6.864	12.140
16	0.80	12.128	31.248	1282.397	45.354	21.740	7.705	12.044
17	0.85	11.847	33.264	1223.593	49.793	15.612	8.574	11.865
18	0.90	11.560	35.280	1165.096	54.220	11.262	9.469	11.610
19	0.95	11.268	37.296	1106.934	58.576	5.943	10.385	11.287
20	1.00	10.970	39.312	1049.200	62.961	0.699	11.320	10.904
21	1.05	10.570	40.408	992.590	65.840	-3.920	12.270	10.469
22	1.10	10.371	41.194	937.767	67.455	-7.811	13.231	9.998
23	1.15	10.073	41.760	884.704	68.846	-11.434	14.200	9.501
24	1.20	9.772	42.336	832.583	70.002	-15.452	16.636	8.979
25	1.25	9.547	43.292	794.637	71.583	-31.703	17.611	8.509
26	1.30	9.308	44.444	755.337	73.489	-32.830	18.587	8.105
27	1.35	9.054	45.596	714.695	75.393	-33.950	19.562	7.687
28	1.40	8.764	46.748	672.720	77.298	-35.064	20.537	7.254
29	1.45	8.497	47.900	629.416	79.202	-36.172	21.512	6.808
30	1.50	8.190	49.052	584.799	81.107	-37.274	22.487	6.348
31	1.55	7.862	50.204	533.868	83.012	-38.369	23.462	5.874
32	1.60	7.509	51.356	491.634	84.917	-39.458	24.438	5.387
33	1.65	7.101	55.433	439.577	93.312	-43.486	25.413	4.856
34	1.70	6.603	64.353	380.173	106.408	-49.624	26.388	4.282
35	1.75	5.996	72.273	313.463	119.503	-55.727	27.363	3.620
36	1.80	5.241	80.193	239.490	132.599	-61.794	28.338	2.879
37	1.85	4.261	88.113	158.297	145.695	-67.825	29.313	2.059
38	1.90	2.832	96.033	69.935	158.790	-73.814	30.288	1.148

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.52 1.04 1.74 2.29 2.30 2.69 2.70 2.79

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	20.032	1.872	3498.678	0.129	15.153	0.020	1.513
2	0.10	19.943	5.616	3467.680	1.132	53.382	0.100	4.431
3	0.15	19.785	9.360	3412.919	3.076	72.336	0.256	7.139
4	0.20	19.577	13.104	3341.465	5.896	83.521	0.486	9.597
5	0.25	19.330	16.849	3257.707	9.526	89.709	0.785	11.786
6	0.30	19.052	20.592	3164.624	13.931	92.179	1.151	13.698
7	0.35	18.750	24.336	3065.244	18.955	91.755	1.580	15.334
8	0.40	18.423	28.080	2960.852	24.623	89.045	2.068	16.702
9	0.45	18.070	31.824	2853.105	30.840	84.527	2.612	17.810
10	0.50	17.738	35.569	2743.143	37.540	78.525	3.209	18.674
11	0.55	17.374	39.312	2631.932	44.658	71.532	3.856	19.306
12	0.60	17.001	43.056	2519.846	52.129	63.626	4.548	19.723
13	0.65	16.618	46.800	2407.680	59.837	55.084	5.282	19.939
14	0.70	16.227	50.544	2295.748	67.866	46.089	6.055	19.972
15	0.75	15.828	54.288	2184.309	76.002	36.788	6.864	19.835
16	0.80	15.422	58.032	2073.572	84.229	27.308	7.705	19.545
17	0.85	15.008	61.776	1963.639	92.492	17.762	8.574	19.115
18	0.90	14.585	65.520	1854.760	100.695	8.247	9.469	18.559
19	0.95	14.155	69.264	1746.837	108.803	-1.150	10.385	17.892
20	1.00	13.716	73.008	1640.193	116.741	-10.354	11.320	17.127
21	1.05	13.266	76.752	1534.458	124.443	-19.296	12.270	16.276
22	1.10	12.807	80.496	1429.998	131.844	-27.908	13.231	15.353
23	1.15	12.335	84.240	1326.726	138.878	-36.136	14.200	14.369
24	1.20	11.846	87.984	1223.921	145.481	-44.597	16.636	13.334
25	1.25	11.425	94.199	1122.014	155.757	-71.763	17.611	12.349
26	1.30	10.950	101.697	1045.341	168.138	-77.416	18.587	11.414
27	1.35	10.416	109.175	945.938	180.520	-83.037	19.562	10.408
28	1.40	9.815	116.663	836.344	192.901	-88.627	20.537	9.331
29	1.45	9.132	124.151	727.098	205.282	-94.184	21.512	8.195
30	1.50	8.349	131.639	607.777	217.664	-99.709	22.487	6.968
31	1.55	7.434	134.127	481.801	230.045	-105.202	23.462	5.680
32	1.60	6.330	146.615	344.329	242.426	-110.662	24.438	4.320
33	1.65	4.896	155.606	200.013	257.293	-117.215	25.413	2.874
34	1.70	2.622	165.486	59.947	273.960	-124.523	26.388	1.290

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.71 0.71 1.45 1.74 2.09 2.21 2.38 2.30

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	20.032	2.556	3496.631	0.175	15.152	0.020	1.513
2	0.10	19.942	7.668	3467.232	1.546	53.367	0.100	4.431
3	0.15	19.721	12.7[illegible]0	3411.424	4.203	72.259	0.256	7.137
4	0.20	19.567	17.992	3339.043	8.051	83.299	0.496	9.590
5	0.25	19.311	23.00[illegible]	[illegible]1.507	13.007	89.224	0.785	11.768
6	0.30	19.021	28.116	[illegible]154.273	18.920	91.286	1.151	13.662
7	0.35	18.701	33.228	30[illegible]7.293	25.881	90.242	1.590	15.269
8	0.40	18.359	38.[illegible]40	29[illegible]9.217	33.620	85.529	2.068	16.595
9	0.45	17.993	43.452	2822.459	42.109	81.402	2.612	17.647
10	0.50	17.60[illegible]	48.564	2703.256	51.257	74.371	3.209	18.439
11	0.55	17.237	53.676	2581.424	60.976	65.069	3.856	18.981
12	0.60	16.793	58.788	2457.089	71.176	56.761	4.548	19.291
13	0.65	1[illegible].357	63.900	23[illegible]2.611	81.763	46.657	5.292	19.383
14	0.70	15.[illegible]	69.012	2205.623	92.653	36.046	6.055	19.274
15	0.75	15.445	74.124	20[illegible]0.057	103.772	25.001	6.854	18.978
16	0.80	14.967	79.235	1953.179	115.095	13.708	7.705	18.512
17	0.85	14.473	84.[illegible]8	182[illegible].194	126.274	2.299	8.574	17.892
18	0.90	13.961	89.460	1699.256	137.428	-9.107	9.469	17.133
19	0.95	13.433	94.572	1572.511	148.553	-20.401	10.395	16.251
20	1.00	12.879	99.684	1446.068	159.396	-31.486	11.320	15.261
21	1.05	12.315	102.240	1322.361	165.769	-40.473	12.270	14.191
22	1.10	11.750	102.240	120[illegible].591	167.458	-47.048	13.231	13.080
23	1.15	11.1[illegible]1	102.240	1089.920	168.553	-52.885	14.200	11.953
24	1.20	10.603	102.240	9[illegible]0.122	169.053	-58.661	16.636	10.818
25	1.25	10.094	102.240	[illegible]85.379	169.053	-76.638	17.611	9.766
26	1.30	9.559	102.240	7[illegible]5.528	169.053	-76.645	18.587	8.806
27	1.35	8.991	102.240	704.869	169.053	-76.652	19.562	7.846
28	1.40	8.385	102.240	613.102	169.053	-76.659	20.537	6.885
29	1.45	7.733	102.240	521.327	169.053	-76.665	21.512	5.924
30	1.50	7.019	102.240	429.545	169.053	-76.671	22.487	4.962
31	1.55	6.274	102.240	337.757	169.053	-76.677	23.462	3.999
32	1.60	5.311	102.240	245.963	169.053	-76.691	24.438	3.034
33	1.65	4.129	10[illegible].420	14[illegible].615	179.272	-81.320	25.413	2.032
34	1.70	2.188	11[illegible].076	41.748	196.891	-89.273	26.388	0.011

APPENDIX D: COMPUTATION OF A CYLINDER PENETRATING HORIZONTALLY

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C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CYLINDER ON ITS SIDE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS( ) ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )  PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( )  SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C DIM      LENGTH OF CYLINDER
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
```

```
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB( )WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(100),US(100),SUMSUB(100),E(100),V(100)
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,US/100*0.0/,WB/100*0.0/,WBSUB/10
     30*0.0/,US/100*0.0/,SUMSUB/100*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT HORIZONTAL CYLINDER
      RAD=.94791
      WT=540.75
      DIM=33.834/12.
      BMD=37.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CYLINDER USE A COEFFICIENT OF DRAG EQUAL TO 0.68
      CD=0.68
C
C
C     SET INCREMENT
      DX=.05
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF SPHERE
      Y=DX/2.
      YMAY=2*RAD
      Z=RAD/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      DIM2=2.*(RAD**2-(RAD-Y)**2)
      AREA(1)=DIM*DIM2
      DO 100 I=2,N
      AREA(I)=DIM*2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)
```

```
C     PRINT,AREA(I)
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
C     PRINT,AREA(I)
  200 CONTINUE
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*DIM/2.
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
      PRINT,CVOL,HAFVOL,ERROR
C
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE BY USING ONE HALF OF A PROLATE ELLIPSOID.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
      DO 400 I=2,K
C     CHANGE THE PROJECTED RECTANGULAR AREA INTO A ELLIPSE OF THE
C     EQUIVALENT AREA KEEPING THE RATIO OF MAXIMUM AND MINIMUM
C     DIMENSIONS THE SAME FOR THE RECTANGLE AND ELLIPSE
      AA=DIM
      BB=2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)
C     THE ELLIPSE DIMENSIONS ARE
      A=SQRT(DIM**2/PI)
      R=AA/BB
      B=A/R
```

```
      REA=PI*A*B
C     PRINT,A,B,REA
C     NOW FORM THE APPROXIMATE PROLATE ELLIPSOID USING DIMENSIONS OF
C     EQUIVALENT ELLIPSE AND PENETRATION DEPTH
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
C     EK IS A VARIABLE OF HYPERBOLIC FORM FOR THE ADDED MASS EQUATION
C     APPROXIMATE EK BY A SERIES OF STRAIGHT LINES
      IF(R.LE.1.0) GO TO 400
      IF((R.LE.1.50).AND.(R.GT.1.00)) GO TO 12
      IF((R.LE.2.00).AND.(R.GT.1.50)) GO TO 13
      IF((R.LE.2.51).AND.(R.GT.2.00)) GO TO 14
      IF((R.LE.2.99).AND.(R.GT.2.51)) GO TO 15
      IF((R.LE.3.99).AND.(R.GT.2.99)) GO TO 16
      IF((R.LE.4.99).AND.(R.GT.3.99)) GO TO 17
      IF((R.LE.6.01).AND.(R.GT.4.99)) GO TO 18
      IF((R.LE.6.97).AND.(R.GT.6.01)) GO TO 19
      IF(R.GT.6.97) GO TO 20
   12 EK=.2420*R+.2580
      GO TO 21
   13 EK=.1620*R+.3790
      GO TO 21
   14 EK=.1196*R+.4628
      GO TO 21
   15 EK=.0833*R+.5629
      GO TO 21
   16 EK=.0570*R+.6326
      GO TO 21
   17 EK=.0350*R+.7204
      GO TO 21
   18 EK=.0226*R+.7825
      GO TO 21
   19 EK=.0156*R+.8241
      GO TO 21
   20 EK=.0050*R+.8703
      GO TO 21
C
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
C     ADD DISPLACED VOL AT THE SAME TIME
   21 AMASS(I-1)=EK*(2./3.)*BWD*PI*A*B**2
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
C     PRINT,AA,BB,A,B,R,EK,AMASS(I-1)
  400 CONTINUE
C
```

```
C
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF ELLIPSOID
C
      HAMAS=BWD*(EK*(2./3.)*PI*A*B**2+PI*RAD**2*DIM/2.)
      ERROR=HAMAS-AMASS(N)
      PRINT,HAMAS,AMASS(N),ERROR
C
C     AMASS REMAINS THE SAME AFTER MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
      PRINT,CDMASS,AMASS(N)
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
```

```
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
C     PRINT,WB(I)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION.
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,DIM,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
```

```
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CYLINDER TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH MINUS ONE HALF THE PENETRATION DEPTH
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE MAX RAD IS REACHED THE DEPTH EQUALS PENETRATION DEPTH
C     MINUS ONE HALF THE RADIUS
      IF((I*DX-Y).GT.RAD) DEPTH=I*DX-Y-RAD/2.
C
```

```
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LE.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
```

```
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(V0+V(I+1))/2.
      WDRAG=.5*RHOW*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'CYLINDER'//9X,'RADIUS = ',F7.3/9X,'LENGTH =',F7.3,
     2' FEET'/9X,'WEIGHT = ',F7.1,' LBS'/9X,'BULK WET DENSITY = ',F5.2,'
     3 SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
```

IMPACT VELOCITY EQUALS 0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE -

0.42 1.08 1.48 1.57 2.44 2.72 2.69 2.93

CYLINDER
RADIUS = 0.940
LENGTH = 2.819 FEET
WEIGHT = 540.8 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.68

CONDITIONS AT THE END OF SECTION — WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	1.719	1.512	24.823	0.149	2.029	0.029	0.009
2	0.10	2.253	4.526	42.655	3.502	5.037	0.295	0.381
3	0.15	2.558	7.560	54.977	7.431	5.769	0.803	0.713
4	0.20	2.720	10.584	62.186	12.135	5.251	1.431	1.007
5	0.25	2.764	13.608	64.201	17.432	4.245	2.147	1.209
6	0.30	2.703	16.632	61.391	23.199	2.404	2.936	1.309
7	0.35	2.579	19.875	54.132	29.242	-0.120	3.787	1.289
8	0.40	2.254	[illegible]	42.694	35.714	-3.139	4.693	1.138
9	0.45	1.80	25.704	27.406	42.459	-6.634	5.645	0.956
10	0.50	1.011	28.723	9.591	49.207	-10.522	6.638	0.429

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.51 0.75 1.09 1.83 2.04 1.96 2.38 2.70

CONDITIONS AT THE END OF SECTION — WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	5.102	1.836	218.740	0.179	17.876	0.029	0.311
2	0.10	5.169	5.508	224.576	4.253	14.112	0.295	2.540
3	0.15	5.174	9.180	[illegible]	9.023	13.551	0.803	3.296
4	0.20	5.127	12.852	220.922	14.735	11.073	1.431	3.816
5	0.25	5.017	16.524	211.516	21.167	8.992	2.147	4.137
6	0.30	4.846	20.196	197.349	28.170	5.839	2.936	4.259
7	0.35	4.613	23.868	179.853	35.630	1.922	3.787	4.195
8	0.40	4.311	27.540	156.157	43.457	-2.358	4.693	3.947
9	0.45	3.927	31.212	129.592	51.551	-7.120	5.645	3.521
10	0.50	3.440	34.884	99.472	59.873	-12.281	6.638	2.927
11	0.55	2.804	38.556	66.092	68.336	-17.759	7.667	2.173
12	0.60	1.931	42.228	29.734	76.886	-23.474	8.726	1.259

CYLINDER

RADIUS = 0.948
LENGTH = 2.819 FEET
WEIGHT = 5?0.8 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.68

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.26 0.68 1.24 2.04 2.44 2.38 2.33 2.75

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	9.741	0.936	[illegible]	0.021	65.433	0.029	1.190
2	0.10	[illegible]	[illegible]	774.137	2.140	42.072	0.285	9.060
3	0.15	9.420	[illegible]	[illegible]	4.600	38.943	0.803	11.143
4	0.20	[illegible]	[illegible]	[illegible]	7.512	32.483	1.431	12.532
5	0.25	9.058	[illegible]	[illegible]	10.791	29.765	2.147	13.472
6	0.30	[illegible]	10.296	659.434	14.361	25.835	2.936	14.056
7	0.35	8.650	12.129	[illegible]	18.164	[illegible]	3.787	14.359
8	0.40	[illegible]	[illegible]	607.275	[illegible]	17.305	4.593	14.456
9	0.45	[illegible]	15.912	[illegible]	25.984	13.120	5.645	[illegible]
10	0.50	7.954	[illegible]	[illegible]	30.524	8.963	6.639	[illegible]
11	0.55	7.637	19.656	[illegible]	34.979	4.699	7.667	[illegible]
12	0.60	[illegible]	[illegible]	[illegible]	39.197	0.385	8.726	13.042
13	0.65	[illegible]	[illegible]	[illegible]	43.570	-3.915	9.912	12.614
14	0.70	[illegible]	25.272	[illegible]	47.930	-8.139	10.921	11.549
15	0.75	[illegible]	27.144	[illegible]	52.243	-12.408	12.047	10.801
16	0.80	[illegible]	29.016	[illegible]	56.503	-16.553	13.199	9.893
17	0.85	6.829	30.859	[illegible]	60.655	-20.646	14.343	8.905
18	0.90	[illegible]	32.760	249.072	[illegible]	-24.526	15.506	7.879
19	0.95	[illegible]	34.632	[illegible]	68.565	-27.166	18.421	6.802
20	1.00	[illegible]	37.565	175.499	74.375	-36.655	19.589	5.713
21	1.05	[illegible]	43.514	133.579	86.349	-42.700	20.757	4.553
22	1.10	3.195	49.662	85.813	98.323	-48.554	21.924	3.209
23	1.15	1.761	55.710	32.236	110.297	-54.501	23.092	1.656

CYLINDER

RADIUS = 0.948
LENGTH = 2.819 FEET
WEIGHT = 540.8 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.68

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.29 0.52 0.62 0.90 1.30 2.16 1.74 1.76

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	[illegible]	1.044	[illegible]	0.102	144.684	0.029	2.654
2	[illegible]	[illegible]	[illegible]	[illegible]	2.418	88.046	0.265	19.889
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	79.546	0.803	24.129
4	0.20	[illegible]	[illegible]	[illegible]	8.379	64.781	1.431	26.821
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.147	28.557
6	[illegible]	[illegible]	[illegible]	[illegible]	16.018	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	20.260	42.226	3.787	30.075
8	0.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.693	30.180
9	[illegible]	[illegible]	[illegible]	[illegible]	29.317	[illegible]	5.645	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.617	6.638	[illegible]
11	[illegible]	[illegible]	21.924	[illegible]	[illegible]	15.074	7.657	[illegible]
12	[illegible]	[illegible]	[illegible]	[illegible]	43.710	8.711	8.726	27.782
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.538	9.812	26.705
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-3.438	10.921	25.496
15	[illegible]	[illegible]	30.276	[illegible]	58.278	-9.206	12.047	24.184
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-14.760	13.189	22.781
17	0.85	[illegible]	[illegible]	[illegible]	67.653	-20.213	14.343	21.310
18	0.90	[illegible]	[illegible]	643.204	72.150	-25.209	15.504	19.754
19	0.95	[illegible]	[illegible]	[illegible]	76.477	-30.866	18.421	18.201
20	1.00	[illegible]	[illegible]	[illegible]	82.815	-46.465	19.599	16.715
21	1.05	[illegible]	45.141	[illegible]	89.372	-49.658	20.757	15.318
22	1.10	[illegible]	48.453	441.797	95.929	-52.804	21.924	13.828
23	1.15	[illegible]	51.765	[illegible]	102.487	-55.904	23.092	12.247
24	1.20	6.257	55.077	[illegible]	109.044	-58.950	24.259	10.575
25	1.25	5.649	58.389	265.193	115.601	-61.968	25.427	8.814
26	1.30	4.932	61.701	[illegible]	122.158	-64.932	26.595	6.952
27	1.35	4.050	65.013	[illegible]	128.716	-67.849	27.762	5.018
28	1.40	2.853	[illegible]	[illegible]	135.273	-70.711	28.930	2.966

RADIUS = 0.948
LENGTH = 2.819 FEET
WEIGHT = 540.8 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.68

CYLINDER

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.68 0.73 1.74 2.30 2.45 2.60 2.58 2.90

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	19.293	2.448	3127.998	0.239	255.626	0.029	4.705
2	0.10	18.774	7.344	2962.121	5.670	151.921	0.285	35.034
3	0.15	18.250	12.240	2799.098	12.031	134.984	0.803	42.237
4	0.20	17.761	17.136	2651.059	19.647	107.355	1.431	46.639
5	0.25	17.259	22.032	2503.344	28.223	95.071	2.147	49.304
6	0.30	16.757	26.928	2359.854	37.560	79.358	2.936	50.659
7	0.35	16.260	31.824	2221.854	47.506	62.639	3.787	51.100
8	0.40	15.758	36.720	2086.797	57.935	49.667	4.693	50.798
9	0.45	15.251	41.616	1954.582	68.742	34.981	5.645	49.987
10	0.50	14.737	46.512	1825.073	79.831	21.599	6.638	48.490
11	0.55	14.215	51.408	1699.117	91.115	8.547	7.667	46.665
12	0.60	13.684	56.304	1573.555	102.514	-4.155	8.726	44.513
13	0.65	13.141	61.200	1451.228	113.952	-16.483	9.812	42.082
14	0.70	12.565	66.096	1330.983	125.355	-28.418	10.921	39.422
15	0.75	12.012	70.992	1212.677	136.651	-39.932	12.047	36.575
16	0.80	11.421	75.888	1096.184	147.769	-51.006	13.189	33.578
17	0.85	10.807	80.784	981.556	158.636	-61.779	14.343	30.466
18	0.90	10.165	85.680	868.384	169.180	-71.743	15.504	27.269
19	0.95	9.483	90.576	755.782	179.326	-82.104	18.421	23.996
20	1.00	8.816	97.335	653.104	193.836	-104.586	19.589	20.816
21	1.05	8.095	98.655	550.646	195.321	-104.362	20.757	17.777
22	1.10	7.305	99.375	448.407	196.747	-104.139	21.924	14.743
23	1.15	6.420	100.095	346.385	198.172	-103.918	23.092	11.713
24	1.20	5.395	100.815	244.591	199.598	-103.697	24.259	8.681
25	1.25	4.125	101.535	142.998	201.023	-103.470	25.427	5.639
26	1.30	2.227	102.255	41.679	202.449	-103.202	26.595	2.515

CYLINDER

RADIUS = 0.948
LENGTH = 2.819 FEET
WEIGHT = 540.8 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.68

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.74 1.09 1.45 1.22 1.43 1.74 1.30 1.50

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	19.293	2.644	3127.970	0.260	255.624	0.029	4.705
2	0.10	18.773	7.992	2951.698	6.170	151.837	0.285	35.031
3	0.15	18.246	13.320	2797.852	13.093	134.746	0.803	42.225
4	0.20	17.753	18.648	2648.566	21.380	106.900	1.431	46.607
5	0.25	17.245	23.976	2499.184	30.713	94.316	2.147	49.240
6	0.30	16.735	29.304	2353.604	40.874	78.239	2.936	50.561
7	0.35	16.228	34.632	2213.100	51.698	61.108	3.787	50.932
8	0.40	15.714	39.960	2076.180	63.049	46.660	4.693	50.557
9	0.45	15.193	45.288	1939.736	74.804	32.470	5.645	49.559
10	0.50	14.662	50.616	1805.667	86.875	18.541	6.638	49.052
11	0.55	14.121	55.944	1675.843	99.155	4.914	7.667	46.125
12	0.60	13.[illegible]	61.272	1547.177	111.560	-8.392	8.726	43.849
13	0.65	13.001	66.600	1420.391	124.007	-21.320	9.812	41.284
14	0.70	12.414	71.928	1295.472	136.415	-33.870	10.921	38.480
15	0.75	11.811	77.256	1172.273	148.700	-46.001	12.047	35.481
16	0.80	11.181	82.584	1050.677	160.807	-57.687	13.189	32.325
17	0.85	10.524	87.912	930.737	172.633	-69.049	14.343	29.050
18	0.90	9.830	93.240	812.080	184.107	-79.601	15.504	25.684
19	0.95	9.0[illegible]	98.568	693.831	195.140	-90.527	18.421	22.242
20	1.00	8.323	105.[illegible]	583.557	211.190	-112.323	19.589	18.864
21	1.05	7.474	111.705	469.412	221.158	-116.767	20.757	15.534
22	1.10	6.467	116.745	351.453	231.137	-120.151	21.924	12.085
23	1.15	5.229	121.795	229.745	241.115	-123.971	23.092	8.508
24	1.20	3.524	126.825	104.367	251.094	-127.708	24.259	4.769

APPENDIX E: COMPUTATION OF A CYLINDER PENETRATING END-ON

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A FLAT ENDED CYLINDER
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS()  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )  PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
```

```
C SUMSUB( )WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )    KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(100),US(100),SUMSUB(100),E(100),V(100)
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/10
     30*0.0/,US/100*0.0/,SUMSUB/100*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT  CYLINDER IMPACTING WITH FLAT END
      RAD=.94791
      WT=561.75
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CYLINDER END ON USE A DRAG COEFFICIENT OF .9
      CD=0.9
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF CYLINDER
      Y=DX/2.
      YMAX=2.777
      Z=YMAX/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=PI*(RAD**2)
      DO 100 I=2,N
      AREA(I)=AREA(1)
  100 CONTINUE
C     FOR THIS ANALYSIS THE AREA IS CONSTANT FOR THE REMAINING
C     PENETRATION THEREFORE SET SUCCEEDING AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
```

```
C       PRINT,AREA(I)
  200   CONTINUE
C
C       COMPUTE THE VOLUME OF EACH SECTION
C       VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
        DO 300 I=1,100
        VOL(I)=AREA(I)*DX
  300   CONTINUE
C
C       CHECK VOLUME CALCULATIONS
        HAFVOL=PI*RAD**2*YMAX
        CVOL=VOL(1)
        DO 350 I=2,N
        CVOL=CVOL+VOL(I)
  350   CONTINUE
C
        ERROR=CVOL-HAFVOL
C       PRINT,CVOL,HAFVOL,ERROR
C
C
C
C       CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C       DISPLACED MASS FROM SECTION TO SECTION.
C       APPROXIMATE BY USING ONE HALF OF A CIRCULAR DISK, AMASS BECOMES
C       CONSTANT WHEN MAX AREA HAS BEEN REACHED.
C
        SUMVOL=0.0
        K=N+1
        DO 400 I=2,K
C       SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
        AMASS(I-1)=BWD*(4./3.)*RAD**3
C
C       SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C       IS NO CONTRIBUTION FROM THE DISPLACED MASS
  400   CONTINUE
C
C       AMASS REMAINS THE SAME AFTER MAX AREA
C
        DO 450 I=N,100
        AMASS(I)=AMASS(N)
C       PRINT,AMASS(N)
  450   CONTINUE
C
C       COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
        DMASS(1)=0.0
        DO 500 I=2,N
        DMASS(I)=AMASS(I)-AMASS(I-1)
```

```
C     PRINT,DMASS(N)
  500 CONTINUE
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
```

```
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA*PI*RAD**2*X**2/2.)
      PRINT,AWB,X
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
```

```
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CYLINDER TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH
      DEPTH=I*DX-Y
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
```

```
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
      WDRAG=.5*BMD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
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C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'CYLINDER  FLAT END IMPACTING'//9X,'RADIUS = ',
     2F7.3/9X,'WEIGHT = ',F7.1,' LBS'/
     39X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
     4 COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.30 0.61 1.39 2.09 2.44 2.72 2.70 2.90

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	4.829	2.160	203.599	2.250	35.974	0.308	4.203
2	0.10	4.990	6.480	217.359	6.777	2.431	0.925	4.193
3	0.15	5.094	10.800	226.560	11.295	1.626	1.542	4.423
4	0.20	5.147	15.120	231.278	15.813	0.834	2.159	4.562
5	0.25	5.150	19.440	231.590	20.331	0.055	2.776	4.613
6	0.30	5.106	23.760	227.569	24.850	-0.710	3.392	4.576
7	0.35	5.012	28.080	213.249	29.368	-1.463	4.009	4.453
8	0.40	4.867	32.400	206.822	33.886	-2.203	4.626	4.2[illegible]
9	0.45	4.669	36.720	190.236	38.404	-2.930	5.243	3.956
10	0.50	4.403	41.040	167.604	42.972	-3.646	5.860	3.584
11	0.55	4.074	45.432	144.929	47.515	-4.360	6.476	3.131
12	0.60	3.649	49.896	116.216	52.184	-5.073	7.093	2.595
13	0.65	3.073	54.360	83.536	56.853	-5.774	7.710	1.979
14	0.70	2.319	59.824	46.952	61.521	-6.462	8.327	1.276
15	0.75	0.870	63.238	6.602	66.190	-7.131	8.944	0.445

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.36 0.54 1.04 1.36 2.44 2.78 2.80 2.96

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	9.264	2.592	749.511	2.711	132.433	0.308	16.151
2	0.10	9.287	7.776	752.958	8.133	0.609	0.925	14.973
3	0.15	9.276	12.960	751.259	13.554	-0.300	1.542	14.990
4	0.20	9.235	[illegible]	744.499	18.976	-1.194	2.159	14.906
5	0.25	[illegible]	[illegible]	733.764	24.398	-2.073	2.776	14.722
6	0.30	[illegible]	[illegible]	[illegible]	29.819	-2.938	3.392	14.439
7	0.35	8.920	[illegible]	694.722	35.241	-3.788	4.009	14.060
8	0.40	[illegible]	[illegible]	[illegible]	40.663	-4.623	4.626	13.585
9	0.45	8.547	[illegible]	637.724	46.085	-5.444	5.243	13.017
10	0.50	8.306	[illegible]	602.340	51.506	-6.252	5.860	12.357
11	0.55	8.035	53.335	[illegible]	55.573	-6.844	6.476	11.618
12	0.60	7.738	55.723	522.716	58.283	-7.425	7.093	10.824
13	0.65	[illegible]	[illegible]	479.710	60.994	-7.699	7.710	9.957
14	0.70	[illegible]	[illegible]	[illegible]	63.705	-7.957	8.327	9.108
15	0.75	6.662	[illegible]	387.4[illegible]0	65.416	-8.328	8.944	8.188
16	0.80	6.225	[illegible]	339.346	69.127	-8.683	9.560	7.227
17	0.85	5.736	[illegible]	287.225	71.838	-9.033	10.177	6.226
18	0.90	5.170	71.[illegible]	[illegible]	74.549	-9.376	10.794	5.185
19	0.95	4.530	73.[illegible]72	[illegible]	77.260	-9.713	11.411	4.103
20	1.00	3.743	76.464	122.340	79.970	-10.044	12.028	2.981
21	1.05	2.657	81.360	61.634	85.091	-10.726	12.644	1.795

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.52 0.78 1.38 2.12 2.38 2.01 2.11 1.97

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	13.785	3.744	1659.988	3.916	293.131	0.308	36.057
2	0.10	13.723	11.232	1644.113	11.747	-2.628	0.925	32.918
3	0.15	13.632	18.720	1622.360	19.578	-3.842	1.542	32.553
4	0.20	13.512	26.208	1593.871	27.410	-5.035	2.159	32.052
5	0.25	13.362	33.696	1559.742	35.241	-6.209	2.776	31.418
6	0.30	13.182	41.184	1517.034	43.073	-7.362	3.392	30.652
7	0.35	12.972	48.672	1468.979	50.904	-8.497	4.009	29.758
8	0.40	12.729	55.160	1414.579	58.735	-9.612	4.626	28.736
9	0.45	12.453	63.648	1353.976	66.567	-10.708	5.243	27.589
10	0.50	12.143	71.136	1287.271	74.398	-11.786	5.860	26.320
11	0.55	11.803	76.752	1216.218	80.272	-12.555	6.476	24.947
12	0.60	11.440	80.496	1142.540	84.187	-13.018	7.093	23.504
13	0.65	11.057	84.240	1064.220	88.103	-13.475	7.710	22.009
14	0.70	10.635	87.984	987.491	92.019	-13.923	8.327	20.463
15	0.75	10.199	91.728	906.128	95.934	-14.364	8.944	18.866
16	0.80	9.705	95.472	822.442	99.850	-14.797	9.560	17.220
17	0.85	9.184	99.216	736.284	103.766	-15.223	10.177	15.525
18	0.90	8.614	102.960	647.756	107.681	-15.642	10.794	13.782
19	0.95	7.937	106.704	556.497	111.597	-16.054	11.411	11.992
20	1.00	7.298	110.448	463.748	115.513	-16.459	12.028	10.154
21	1.05	6.477	116.640	366.192	121.988	-17.237	12.644	8.246
22	1.10	5.480	125.280	262.153	131.025	-18.383	13.261	6.223
23	1.15	4.169	133.920	151.752	140.061	-19.507	13.878	4.055
24	1.20	2.007	142.560	35.179	149.097	-20.595	14.495	1.667

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.69 1.04 1.43 1.06 1.97 1.57 1.65 1.76

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	18.328	4.968	2932.592	5.196	518.167	0.308	63.928
2	0.10	18.204	14.904	2893.084	15.587	-6.981	0.925	58.057
3	0.15	18.052	24.840	2844.961	25.979	-8.503	1.542	57.184
4	0.20	17.872	34.776	2789.373	36.371	-9.999	2.159	56.140
5	0.25	17.662	44.712	27[illegible].455	46.762	-11.470	2.776	54.929
6	0.30	17.424	54.548	26[illegible].352	57.154	-12.917	3.392	53.553
7	0.35	17.155	64.584	2569.197	67.546	-14.340	4.009	52.016
8	0.40	16.855	74.520	2480.131	77.937	-15.737	4.626	50.319
9	0.45	16.522	84.456	2383.289	88.329	-17.111	5.243	48.466
10	0.50	16.156	94.392	227[illegible].795	98.720	-18.463	5.860	46.459
11	0.55	15.762	101.840	2168.941	106.552	-19.410	6.476	44.322
12	0.60	15.344	106.920	2055.971	111.823	-19.961	7.093	42.101
13	0.65	14.907	111.960	1939.937	117.094	-20.502	7.710	39.818
14	0.70	14.442	117.000	1820.891	122.365	-21.034	8.327	37.474
15	0.75	13.950	122.040	1698.885	127.636	-21.557	8.944	35.071
16	0.80	13.427	127.080	1573.957	132.907	-22.072	9.560	32.609
17	0.85	12.871	132.120	1446.187	138.179	-22.578	10.177	30.089
18	0.90	12.276	137.160	1315.593	143.450	-23.075	10.794	27.513
19	0.95	11.637	142.200	1152.232	148.721	-23.564	11.411	24.880
20	1.00	10.947	147.240	1046.152	153.992	-24.044	12.028	22.192
21	1.05	10.194	152.568	907.145	159.564	-24.562	12.644	19.447
22	1.10	9.361	158.184	765.008	165.438	-25.115	13.261	16.640
23	1.15	8.426	163.800	619.795	171.311	-25.658	13.878	13.769
24	1.20	7.349	169.416	471.562	177.185	-26.192	14.495	10.832
25	1.25	6.059	175.032	320.367	183.058	-26.715	15.112	7.826
26	1.30	4.364	180.648	165.236	188.932	-27.225	15.728	4.733
27	1.35	1.049	186.264	9.614	194.805	-27.683	16.345	1.292

IMPACT VELOCITY EQUALS 0.0

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.21 0.35 0.52 1.10 2.30 2.79 2.56 3.10

CONDITIONS AT THE END OF SECTION / WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	[illegible]	1.512	22.170	1.581	3.917	0.308	0.110
2	0.10	2.159	[illegible]	40.702	4.744	3.274	0.925	0.612
3	0.15	2.577	[illegible]	55.731	7.907	2.655	1.542	0.955
4	0.20	2.777	[illegible]	[illegible]	11.069	2.048	2.159	1.223
5	[illegible]	[illegible]	[illegible]	75.527	14.232	1.450	2.776	1.422
6	[illegible]	[illegible]	[illegible]	[illegible]	17.395	0.863	3.392	1.553
7	[illegible]	[illegible]	[illegible]	[illegible]	20.557	0.285	4.009	1.619
8	[illegible]	[illegible]	[illegible]	[illegible]	23.720	-0.222	4.626	1.619
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-0.840	5.243	1.555
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.329	5.860	1.429
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-1.849	6.476	1.246
12	[illegible]	[illegible]	[illegible]	[illegible]	34.789	-2.224	7.093	1.014
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-2.592	7.710	0.740
14	0.70	[illegible]	[illegible]	15.359	39.006	-2.953	8.327	0.418

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.97 1.94 1.04 1.41 1.13 1.48 1.97 1.76

CONDITIONS AT THE END OF SECTION / WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	[illegible]	6.266	199.992	6.551	35.335	0.308	4.167
2	0.10	[illegible]	[illegible]	202.951	17.654	0.524	0.925	4.015
3	0.15	[illegible]	[illegible]	[illegible]	32.755	-1.527	1.542	3.959
4	0.20	[illegible]	[illegible]	[illegible]	45.950	-3.544	2.159	3.671
5	0.25	[illegible]	54.276	147.973	58.951	-5.527	2.776	3.155
6	0.30	[illegible]	63.904	[illegible]	72.064	-7.479	3.392	2.411
7	0.35	2.333	81.432	47.537	85.166	-9.339	4.009	1.431

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.725LUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.24 0.33 0.71 0.87 1.74 1.74 1.79 1.81

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	9.279	1.723	750.272	1.897	132.568	0.308	16.139
2	0.10	[illegible]	[illegible]	755.291	5.422	7.010	[illegible]	15.819
3	0.15	[illegible]	[illegible]	[illegible]	9.035	[illegible]	[illegible]	[illegible]
4	0.20	[illegible]	[illegible]	[illegible]	12.521	[illegible]	2.154	[illegible]
5	0.25	[illegible]	[illegible]	[illegible]	16.265	[illegible]	2.776	[illegible]
6	0.30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.392	[illegible]
7	0.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.004	[illegible]
8	0.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	0.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.249	[illegible]
10	0.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	0.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	0.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.093	[illegible]
13	0.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.710	[illegible]
14	0.70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	0.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	0.80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.560	[illegible]
17	0.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.177	10.497
18	0.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.883
19	0.95	7.151	[illegible]	[illegible]	[illegible]	-5.746	[illegible]	[illegible]
20	1.00	[illegible]	[illegible]	[illegible]	[illegible]	-5.943	[illegible]	[illegible]
21	1.05	[illegible]	[illegible]	[illegible]	[illegible]	-6.157	[illegible]	[illegible]
22	1.10	[illegible]	[illegible]	[illegible]	[illegible]	-6.652	12.644	[illegible]
23	1.15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	1.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	1.25	4.073	[illegible]	[illegible]	[illegible]	[illegible]	14.495	[illegible]
26	1.30	3.109	[illegible]	[illegible]	[illegible]	-10.671	[illegible]	[illegible]
27	1.35	[illegible]	83.04[illegible]	19.749	[illegible]	-11.425	16.345	[illegible]

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.66 1.00 1.07 0.87 1.20 1.57 1.43 1.50

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	13.781	4.752	1659.100	4.970	292.074	0.308	36.048
2	0.10	13.708	14.256	1640.575	14.910	-3.096	0.925	32.873
3	0.15	13.599	23.760	1614.449	24.850	-4.616	1.542	32.439
4	0.20	13.452	33.264	1579.264	34.789	-6.111	2.159	31.833
5	0.25	13.269	42.768	1536.965	44.729	-7.580	2.776	31.061
6	0.30	13.046	52.272	1495.891	54.669	-9.025	3.392	30.124
7	0.35	12.784	61.776	1435.779	64.609	-10.445	4.009	29.026
8	0.40	12.480	71.280	1373.764	74.549	-11.841	4.626	27.768
9	0.45	12.132	80.784	1294.979	84.488	-13.214	5.243	26.354
10	0.50	11.737	90.288	1202.576	94.428	-14.564	5.860	24.786
11	0.55	11.293	97.488	1114.652	101.958	-15.532	6.476	23.088
12	0.60	10.827	102.384	1023.391	107.079	-16.125	7.093	21.301
13	0.65	10.315	107.280	928.829	112.199	-16.708	7.710	19.447
14	0.70	9.756	112.176	831.022	117.320	-17.292	8.327	17.528
15	0.75	9.144	117.072	730.025	122.441	-17.845	8.944	15.545
16	0.80	8.467	121.968	625.593	127.561	-18.399	9.560	13.497
17	0.85	7.709	126.864	518.679	132.682	-18.944	10.177	11.386
18	0.90	6.840	131.760	408.438	137.802	-19.479	10.794	9.211
19	0.95	5.815	136.656	295.223	142.923	-20.004	11.411	6.972
20	1.00	4.529	141.552	179.097	148.043	-20.519	12.029	4.660
21	1.05	2.662	144.504	61.867	151.130	-20.714	12.644	2.256

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

CYLINDER FLAT END IMPACTING

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.50 0.75 1.18 1.37 1.53 2.26 1.91 2.02

CONDITIONS AT THE END OF SECTION — WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	13.786	3.600	1659.115	3.765	293.153	0.308	36.058
2	0.10	13.725	[illegible]	1644.619	11.295	-2.561	0.925	32.924
3	0.15	13.637	[illegible]	[illegible]	18.825	-3.731	1.542	32.569
4	0.20	[illegible]	[illegible]	[illegible]	[illegible]	-4.882	2.159	32.083
5	0.25	13.375	[illegible]	1561.942	33.886	-6.013	2.776	31.459
6	0.30	13.202	[illegible]	[illegible]	41.416	-7.125	3.392	30.729
7	0.35	[illegible]	[illegible]	1475.006	48.946	-8.218	4.009	29.862
8	0.40	12.764	[illegible]	[illegible]	55.476	-9.293	4.626	28.874
9	0.45	[illegible]	[illegible]	[illegible]	64.006	-10.350	5.243	27.766
10	0.50	[illegible]	[illegible]	[illegible]	71.537	-11.389	5.860	26.539
11	0.55	11.873	[illegible]	[illegible]	77.184	-12.131	6.476	25.212
12	0.60	11.525	77.400	1159.525	80.949	-12.579	7.093	23.818
13	0.65	11.152	81.000	[illegible]	84.714	-13.021	7.710	22.373
14	0.70	10.754	84.600	[illegible]	88.479	-13.454	8.327	20.879
15	0.75	10.327	88.200	[illegible]	92.245	-13.880	8.944	19.337
16	0.80	9.868	91.800	[illegible]	96.010	-14.300	9.560	17.746
17	0.85	9.373	95.400	766.942	99.775	-14.712	10.177	16.109
18	0.90	8.835	99.000	681.397	103.540	-15.117	10.794	14.424
19	0.95	[illegible]	107.600	593.579	107.305	-15.515	11.411	12.694
20	1.00	[illegible]	106.200	503.556	111.070	-15.906	12.028	10.919
21	1.05	6.955	[illegible]	410.214	116.190	-16.403	12.644	9.086
22	1.10	5.983	117.288	312.470	122.666	-17.271	13.261	7.173
23	1.15	4.909	123.480	210.406	129.142	-18.034	13.878	5.165
24	1.20	3.453	129.672	104.114	135.619	-19.781	14.495	3.048

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.73 1.00 0.99 1.08 1.52 1.91 2.39 2.95

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	18.327	5.256	2932.336	5.497	518.122	0.308	63.926
2	0.10	18.201	15.768	2892.072	16.491	-7.115	0.925	58.044
3	0.15	18.045	26.280	2842.699	27.485	-8.724	1.542	57.151
4	0.20	17.859	36.792	2784.369	38.479	-10.307	2.159	56.078
5	0.25	17.642	47.304	2717.238	49.473	-11.961	2.776	54.827
6	0.30	17.394	57.816	2641.445	60.467	-13.392	3.392	53.403
7	0.35	17.114	68.328	2557.146	71.461	-14.895	4.009	51.807
8	0.40	16.802	78.840	2464.477	82.455	-16.374	4.626	50.043
9	0.45	16.454	89.352	2362.592	93.449	-17.877	5.243	48.113
10	0.50	16.070	99.864	2254.598	104.443	-19.257	5.860	46.021
11	0.55	15.659	107.064	2140.582	111.974	-20.146	6.476	43.798
12	0.60	15.228	110.952	2024.536	116.040	-20.505	7.093	41.504
13	0.65	14.778	114.840	1905.493	120.106	-20.857	7.710	39.171
14	0.70	14.305	118.728	1784.466	124.172	-21.204	8.327	36.799
15	0.75	13.809	122.616	1664.550	128.239	-21.545	8.944	34.386
16	0.80	13.295	126.504	1540.717	132.305	-21.880	9.560	31.935
17	0.85	12.731	130.392	1415.018	136.371	-22.210	10.177	29.447
18	0.90	12.144	134.280	1297.485	140.439	-22.534	10.794	26.922
19	0.95	11.518	138.168	1159.149	144.504	-22.853	11.411	24.360
20	1.00	10.855	142.056	1027.241	148.570	-23.166	12.028	21.763
21	1.05	10.131	143.928	895.969	150.528	-23.160	12.644	19.147
22	1.10	9.371	143.784	746.706	150.377	-22.840	13.261	16.550
23	1.15	8.557	143.640	630.226	150.227	-22.525	13.878	13.988
24	1.20	7.669	143.496	513.409	150.076	-22.215	14.495	11.459
25	1.25	6.679	143.352	389.406	149.925	-21.910	15.112	8.962
26	1.30	5.537	143.208	267.176	149.775	-21.609	15.728	6.493
27	1.35	4.303	143.064	147.534	149.624	-21.311	16.345	4.040
28	1.40	1.782	142.920	27.726	149.474	-21.001	16.962	1.512

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.9 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.21 0.31 0.60 1.44 1.44 2.44 2.58 2.44

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	4.836	1.512	204.170	1.581	36.075	0.308	4.209
2	0.10	5.015	4.276	21[illegible].674	4.744	2.732	0.925	4.221
3	0.15	5.151	7.540	231.652	7.907	2.124	1.542	4.496
4	0.20	5.244	10.524	240.284	11.099	1.525	2.159	4.702
5	0.25	5.304	13.708	24[illegible]	14.232	0.937	2.776	4.843
6	0.30	5.326	[illegible]	247.611	17.345	0.359	3.392	4.915
7	0.35	5.313	[illegible]	249.419	[illegible]	-0.211	4.009	4.923
8	0.40	[illegible]	[illegible]	247.0[illegible]	23.720	-0.770	4.626	4.868
9	0.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.243	4.750
10	0.50	5.056	25.770	224.063	[illegible]	[illegible]	5.860	4.571
11	0.55	4.917	[illegible]	211.628	[illegible]	[illegible]	6.476	4.337
12	0.60	4.749	[illegible]	[illegible]	[illegible]	[illegible]	7.093	4.056
13	0.65	4.551	[illegible]	[illegible]	[illegible]	[illegible]	7.710	3.763
14	0.70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.327	3.429
15	0.75	4.067	35.720	144.435	36.404	[illegible]	8.944	3.065
16	0.80	3.768	38.170	123.[illegible]3	39.910	-3.352	9.560	2.671
17	0.85	3.419	[illegible]	102.0[illegible]	41.415	[illegible]	10.177	2.249
18	0.90	[illegible]	41.[illegible]	7[illegible].770	[illegible]	-4.118	10.794	1.796
19	0.95	[illegible]	42.[illegible]	54.[illegible]	[illegible]	-4.364	11.411	1.313
20	1.00	1.791	43.920	28.003	45.934	-4.606	12.028	0.798

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.21 0.57 1.46 2.11 2.05 2.07 2.09 2.30

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
1	0.05	9.272	1.512	[illegible]50.462	1.581	132.601	0.308	16.161
2	0.10	9.310	4.536	7[illegible].749	4.744	1.111	0.925	15.020
3	0.15	9.329	7.560	759.746	7.907	0.529	1.542	15.112
4	0.20	9.327	10.584	759.507	11.069	-0.042	2.159	15.140
5	0.25	9.305	13.608	756.087	14.232	-0.604	2.776	15.104
6	0.30	9.266	16.[illegible]2	749.539	17.395	-1.157	3.392	15.005
7	0.35	9.205	19.[illegible]6	739.916	20.557	-1.700	4.009	14.943
8	0.40	9.127	22.680	727.270	23.720	-2.234	4.626	14.622
9	0.45	9.029	25.704	711.551	26.883	-2.760	5.243	14.340
10	0.50	8.910	28.776	693.109	30.045	-3.276	5.860	13.999
11	0.55	8.765	32.832	670.743	34.338	-3.952	6.476	13.592
12	0.60	8.586	39.016	643.663	39.759	-4.785	7.093	13.098
13	0.65	8.372	43.200	611.950	45.181	-5.603	7.710	12.512
14	0.70	8.120	48.384	575.692	50.603	-6.408	8.327	11.834
15	0.75	7.828	53.568	534.935	56.024	-7.200	8.944	11.066
16	0.80	7.490	58.752	489.784	61.446	-7.978	9.560	10.209
17	0.85	7.102	63.936	440.304	66.868	-8.743	10.177	9.264
18	0.90	6.654	69.120	386.569	72.290	-9.495	10.794	8.234
19	0.95	6.135	74.304	328.648	77.711	-10.234	11.411	7.118
20	1.00	5.526	79.488	266.616	83.133	-10.961	12.028	5.919
21	1.05	4.752	88.488	197.192	92.545	-12.268	12.644	4.599
22	1.10	3.663	101.304	117.121	105.949	-14.146	13.261	3.084
23	1.15	1.749	114.120	26.679	119.353	-15.980	13.878	1.279

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.36 0.45 0.40 1.22 1.39 1.74 2.35 2.90

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	13.789	2.592	1660.002	2.711	293.310	0.308	36.068
2	0.10	13.740	7.776	1649.157	8.133	-2.093	0.925	32.968
3	0.15	13.670	12.960	1631.422	13.554	-2.957	1.542	32.683
4	0.20	13.579	18.144	1609.879	18.976	-3.807	2.159	32.302
5	0.25	13.469	23.328	1583.609	24.398	-4.642	2.776	31.825
6	0.30	13.335	28.512	1552.692	29.819	-5.463	3.392	31.255
7	0.35	13.183	33.696	1517.205	35.241	-6.270	4.009	30.594
8	0.40	13.008	38.950	1477.225	40.663	-7.064	4.626	29.841
9	0.45	12.811	44.064	1432.829	46.085	-7.844	5.243	29.000
10	0.30	12.591	49.248	1384.091	51.506	-8.612	5.860	28.072
11	0.55	12.356	52.488	1332.795	54.895	-9.063	6.476	27.075
12	0.60	12.112	53.764	1280.699	56.250	-9.205	7.093	26.044
13	0.55	11.853	55.080	1227.816	57.506	-9.344	7.710	24.998
14	0.70	11.597	56.376	1174.159	58.761	-9.481	8.327	23.936
15	0.75	11.325	57.672	1119.742	60.317	-9.615	8.944	22.859
16	0.80	11.043	58.968	1064.577	61.672	-9.747	9.560	21.767
17	0.85	10.749	60.264	1008.677	63.027	-9.877	10.177	20.660
18	0.90	10.443	61.560	952.054	64.383	-10.005	10.794	19.538
19	0.95	10.123	62.856	894.720	65.738	-10.130	11.411	18.402
20	1.00	9.790	64.152	836.688	67.094	-10.254	12.028	17.252
21	1.05	9.445	64.440	778.856	67.395	-10.218	12.644	16.097
22	1.10	9.095	63.720	722.112	66.642	-10.026	13.261	14.955
23	1.15	8.737	63.000	666.435	65.889	-9.839	13.878	13.834
24	1.20	8.371	62.280	611.808	65.136	-9.652	14.495	12.735
25	1.25	7.996	61.560	558.214	64.383	-9.470	15.112	11.656
26	1.30	7.610	60.840	505.635	63.630	-9.290	15.728	10.598
27	1.35	7.212	60.120	454.054	62.877	-9.114	16.345	9.559
28	1.40	6.793	59.400	403.455	62.124	-8.940	16.962	8.540
29	1.45	6.366	58.680	353.821	61.371	-8.770	17.579	7.541
30	1.50	5.912	57.960	305.137	60.618	-8.602	18.196	6.560
31	1.55	5.371	63.504	251.867	66.416	-9.412	18.812	5.540
32	1.60	4.643	75.312	189.574	78.765	-11.183	19.429	4.369
33	1.65	3.636	87.120	115.435	91.115	-12.923	20.046	2.999
34	1.70	1.934	98.928	32.665	103.464	-14.625	20.663	1.355

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.90

CYLINDER FLAT END IMPACTING

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.70 1.04 1.39 2.26 2.32 2.70 2.79 2.76

CONDITIONS AT THE END OF SECTION

WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	18.328	5.040	2932.529	5.271	518.154	0.308	63.928
2	0.10	18.203	15.120	2892.832	15.813	-7.014	0.925	59.054
3	0.15	18.059	25.200	2844.398	26.356	-8.559	1.542	57.175
4	0.20	17.868	35.280	2787.373	36.898	-10.076	2.159	56.124
5	0.25	17.657	45.360	2721.996	47.440	-11.568	2.776	54.904
6	0.30	17.415	55.440	2648.129	57.982	-13.035	3.392	53.516
7	0.35	17.145	65.520	2566.151	68.526	-14.478	4.009	51.904
8	0.40	16.842	75.600	2475.227	79.067	-15.896	4.626	50.250
9	0.45	16.505	85.680	2378.559	89.609	-17.291	5.243	48.378
10	0.50	16.135	95.760	2272.154	100.151	-18.661	5.860	46.349
11	0.55	15.726	103.248	2161.795	107.933	-19.605	6.476	44.190
12	0.60	15.316	108.144	2047.557	113.103	-20.130	7.093	41.949
13	0.65	14.877	113.040	1931.017	118.224	-20.645	7.710	39.648
14	0.70	14.404	117.936	1811.225	123.348	-21.156	8.327	37.270
15	0.75	13.903	122.832	1688.753	128.455	-21.652	8.944	34.874
16	0.80	13.382	127.728	1563.434	133.505	-22.143	9.560	32.409
17	0.85	12.822	132.624	1435.337	138.725	-22.626	10.177	29.877
18	0.90	12.225	137.520	1304.656	143.826	-23.099	10.794	27.296
19	0.95	11.582	142.416	1171.280	148.957	-23.565	11.411	24.662
20	1.00	10.890	147.312	1035.329	154.067	-24.023	12.028	21.973
21	1.05	10.175	152.208	896.758	159.263	-24.484	12.644	19.235
22	1.10	9.393	157.270	755.556	164.534	-24.940	13.261	16.452
23	1.15	8.371	162.365	611.771	169.805	-25.406	13.878	13.595
24	1.20	7.302	167.400	465.449	175.076	-25.854	14.495	10.692
25	1.25	6.027	172.440	318.640	180.347	-26.293	15.112	7.730
26	1.30	4.353	177.480	165.471	185.619	-26.721	15.728	4.690
27	1.35	1.174	182.520	17.023	190.990	-27.103	16.345	1.343

APPENDIX F: COMPUTATION OF THE PENETRATION OF A CUBE

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C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CUBE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX        INCREMENT SIZE
C
C BWD       BULK WET DENSITY OF SEDIMENT
C
C BMASS     OBJECT MASS
C
C AMASS( )  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )   PROJECTED AREA FOR SECTION ( )
C
C CNC       BEARING CAPACITY COEFFICIENT
C
C VOL( )    VOLUME OF SECTION ( )
C
C CFOOT     BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX       DEPTH OF PENETRATION
C
C SVOL( )   SUM OF VOLUMES TO SECTION INDICATED
C
C V( )      VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )     WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT        WEIGHT OF OBJECT
C
C G         ACCELERATION OF GRAVITY
C
C SPS       SHEAR STRENGTH OF SEDIMENT
C
C RAD       RADIUS OF AN EQUIVALENT CROSS SECTIONAL AREA
C
C DIM       LENGTH OF ONE SIDE
C
C WDRAG     WORK DONE BY DRAG FORCES
C
C WB( )     WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
```

```
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB( )WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OF BODY AT SECTION( )
C
      DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
     20),WB(100),WBSUB(50),US(50),SUMSUB(50),E(100),V(100)
C     RESET DIMENSIONS FOR LARGE OBJECTS
      DATA PI/3.141593/,G/32.1725/,AREA/100*0.0/,VOL/100*0.0/,AMASS/100*
     20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/100*0.0/,WB/100*0.0/,WBSUB/50
     3*0.0/,US/50*0.0/,SUMSUB/50*0.0/,E/100*0.0/,V/100*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT CUBE
      DIM=2.0
C     THE RADIUS OF AN EQUIVALENT CIRCULAR AREA IS.
      RAD=SQRT(DIM**2/PI)
      WT=702.75
      BWD=87.402/G
      CFOOT=1.3
      CNC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A CUBE USE A COEFFICIENT OF DRAG EQUAL TO 1.1
      CD=1.1
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF CUBE
      Y=DX/2.
      Z=DIM/DX
      N=Z+1
      AREA(1)=DIM**2
C
```

```
C      FOR THIS ANALYSIS THE AREA IS
C      CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C      AREAS AS FOLLOWS
       DO 200 I=1,100
       AREA(I)=AREA(1)
C      PRINT, AREA(I)
  200  CONTINUE
C
C
C
C      COMPUTE THE VOLUME OF EACH SECTION
C      VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
       DO 300 I=1,100
       VOL(I)=AREA(I)*DX
  300  CONTINUE
C
C      CHECK VOLUME CALCULATIONS
       HAFVOL=DIM**3
       CVOL=VOL(1)
       DO 350 I=2,N
       CVOL=CVOL+VOL(I)
  350  CONTINUE
C
       ERROR=CVOL-HAFVOL
C      PRINT,CVOL,HAFVOL,ERROR
C
C
C
C      CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C      DISPLACED MASS FROM SECTION TO SECTION.
C      APPROXIMATE BY USING ONE HALF OF A CIRCULAR DISK WITH AN
C      EQUIVALENT AREA
C      AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
       SUMVOL=0.0
       K=N+1
       DO 400 I=2,K
C      SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
       AMASS(I-1)=BWD*(4./3.)*RAD**3
C
C      SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C      IS NO CONTRIBUTION FROM THE DISPLACED MASS
C
  400  CONTINUE
C
       DO 450 I=N,100
       AMASS(I)=AMASS(N)
```

```
C     PRINT,AMASS(I)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
C     PRINT,DMASS(I)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
C     PRINT,CDMASS,AMASS(N)
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
C     PRINT,WS(I)
  600 CONTINUE
C
C
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=PWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
```

```
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C
      DO 760 I=N,100
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
C     PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA*DIM**2*X**2/2.)
C     PRINT,AWB,X
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) DIM,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
```

```
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CUBE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
C     TION DEPTH
      DEPTH=I*DX-Y
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
```

```
      IF(DEPTH.LE..5) GO TO 1
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WR(I))/(3MASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
```

```
C       SECTION TO COMPUTE THE WORK DONE BY DRAG
C       APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C       FIRST TIME OVER THE SECTION, AS DONE ABOVE
        VAVG=(V(I)+V(I+1))/2.
        IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
        WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
        VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
       2S(I))
        IF (VELOSQ.LE.0.0)GO TO 1000
        V(I+1)=SQRT(VELOSQ)
C
C       CALCULATE E AT NEXT SECTION
        E(I+1)=BMASS*V(I+1)**2/2.
C
C       CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
        EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C       COMPUTE PENETRATION DEPTH
        XXX=I*DX
C
C       PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C       SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C       WORK DONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C       AND DRAG
C
        WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000   CONTINUE
 1000   CONTINUE
 2050   FORMAT(I5)
 2060   FORMAT(' ',I3)
 2100   FORMAT(F5.1,8F5.2)
 2200   FORMAT('1',60X,'CUBE'//9X,'SIDE   = ',F7.3/9X,'WEIGHT = ',F7.1,'
       2LBS'/9X,'BULK WET DENSITY = ',F5.2,'SLUGS PER CUBIC FOOT'/9X,'DRAG
       3 COEFFICIENT = ',F5.2///)
 2300   FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
       2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F6.2//)
 2500   FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
       2N SECTION - FOOT POUNDS'///15X,'ITERATION',1X,'PENETRATION',4X,'VE
       3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
       4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
       5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',5X,'FORCES',4X,'F
       6ORCES'//)
 2600   FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
        STOP
        END
```

CUBE

SIDE = 2.000
WEIGHT = 702.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.10

IMPACT VELOCITY EQUALS 0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.48 0.85 1.30 1.70 2.00 1.75 1.40 1.20

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	1.475	2.456	23.756	5.122	5.660	0.437	0.162
2	0.10	1.865	10.348	37.985	15.365	3.390	1.311	0.842
3	0.15	1.984	17.280	43.012	25.609	1.198	2.185	1.119
4	0.20	1.891	24.192	39.047	35.853	-0.945	3.059	1.135
5	0.25	1.552	31.104	26.297	46.096	-3.038	3.933	0.896
6	0.30	0.676	38.016	4.937	56.340	-5.077	4.807	0.377

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.80 1.04 1.13 0.87 1.23 1.53 1.54 1.54

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	4.648	5.760	235.954	8.536	56.215	0.437	7.035
2	0.10	4.661	17.280	237.303	25.609	0.321	1.311	6.547
3	0.15	4.532	28.800	224.299	42.682	-3.101	2.185	6.385
4	0.20	4.250	40.320	197.231	59.754	-6.446	3.059	5.827
5	0.25	3.785	51.840	156.446	76.827	-9.717	3.933	4.880
6	0.30	3.060	63.360	102.246	93.899	-12.913	4.807	3.543
7	0.35	1.790	74.880	34.975	110.972	-16.027	5.681	1.783

CUBE

SIDE = 2.000
WEIGHT = 702.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.10

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.50 0.71 1.01 2.00 2.05 2.10 2.38 2.10

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	8.995	3.600	883.711	5.325	210.540	0.437	27.273
2	0.10	8.968	10.800	878.4[illegible]	16.006	-1.261	1.311	24.376
3	0.15	8.894	18.000	864.613	26.675	-3.430	2.185	24.104
4	0.20	8.774	25.200	840.718	37.346	-5.551	3.059	23.593
5	0.25	8.605	32.400	809.712	48.017	-7.625	3.933	22.817
6	0.30	8.387	39.600	768.135	58.687	-9.653	4.807	21.813
7	0.35	8.116	46.800	719.353	69.358	-11.636	5.681	20.576
8	0.40	7.788	54.000	667.37[illegible]	80.029	-13.575	6.555	19.110
9	0.45	7.384	61.200	597.4[illegible]	90.698	-15.472	7.429	17.421
10	0.50	6.931	68.400	524.[illegible]10	101.369	-17.326	8.303	15.512
11	0.55	6.396	73.512	446.850	109.945	-18.550	9.177	13.424
12	0.60	5.797	76.536	366.438	113.426	-19.159	10.051	11.229
13	0.65	5.095	77.550	283.532	117.908	-19.752	10.925	8.961
14	0.70	4.260	82.596	198.193	122.399	-20.337	11.799	6.618
15	0.75	3.181	85.6[illegible]	110.491	126.871	-20.895	12.673	4.190
16	0.80	1.372	88.632	20.573	131.353	-21.422	13.547	1.577

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CUBE

SIDE = 2.000
WEIGHT = 702.8 LBS
BULK WET DENSITY = 2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.10

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.61 0.72 1.40 1.90 1.88 1.74 1.55 1.60

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	13.390	4.392	1958.113	6.509	466.510	0.437	60.925
2	0.10	13.281	13.176	1926.263	19.527	-7.588	1.311	53.735
3	0.15	13.134	21.960	1884.022	32.545	-10.064	2.185	52.710
4	0.20	12.950	30.744	1831.620	45.563	-12.484	3.059	51.401
5	0.25	12.728	39.528	1769.281	58.580	-14.852	3.933	49.813
6	0.30	12.466	48.312	1697.225	71.598	-17.167	4.807	47.953
7	0.35	12.163	57.096	1615.667	84.616	-19.430	5.681	45.827
8	0.40	11.816	65.880	1524.818	97.634	-21.644	6.555	43.441
9	0.45	11.422	74.664	1424.583	110.652	-23.809	7.429	40.800
10	0.50	10.977	83.449	1316.063	123.670	-25.926	8.303	37.910
11	0.55	10.494	88.632	1202.815	131.353	-26.981	9.177	34.836
12	0.60	9.988	90.216	1089.498	133.700	-26.997	10.051	31.700
13	0.65	9.454	91.800	976.113	136.048	-27.013	10.925	29.562
14	0.70	8.887	93.384	862.643	138.395	-27.029	11.799	25.421
15	0.75	8.282	94.968	749.150	140.743	-27.044	12.673	22.278
16	0.80	7.629	96.552	635.576	143.090	-27.058	13.547	19.132
17	0.85	6.913	98.136	521.943	145.438	-27.072	14.421	15.983
18	0.90	6.114	99.720	408.256	147.795	-27.085	15.295	12.829
19	0.95	5.193	101.304	294.521	150.133	-27.097	16.169	9.667
20	1.00	4.068	102.888	180.751	152.480	-27.105	17.043	6.489
21	1.05	2.386	108.576	62.157	160.909	-28.254	17.917	3.159

CUBE

```
SIDE    =    2.000
WEIGHT  =    702.8   LBS
BULK WET DENSITY =  2.72SLUGS PER CUBIC FOOT
DRAG COEFFICIENT =  1.10
```

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.75 0.95 0.95 1.30 2.40 2.87 2.91 3.04

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	17.805	5.400	3462.389	8.003	824.897	0.437	108.038
2	0.10	17.628	16.200	3393.711	24.008	-16.362	1.311	94.845
3	0.15	17.417	27.000	3313.068	40.014	-19.213	2.185	92.779
4	0.20	17.173	37.800	3220.730	56.020	-21.999	3.059	90.386
5	0.25	16.894	48.600	3116.951	72.025	-24.725	3.933	87.673
6	0.30	16.579	59.400	3001.984	88.031	-27.390	4.807	84.646
7	0.35	16.228	70.200	2876.078	104.036	-29.996	5.681	81.313
8	0.40	15.838	81.000	2739.420	120.042	-32.544	6.555	77.680
9	0.45	15.407	91.800	2592.420	136.048	-35.036	7.429	73.755
10	0.50	14.932	102.600	2435.131	152.053	-37.474	8.303	69.543
11	0.55	14.475	109.440	2272.523	162.190	-38.740	9.177	65.115
12	0.60	13.898	112.320	2109.402	166.458	-38.863	10.051	60.608
13	0.65	13.343	115.200	1945.782	170.726	-38.982	10.925	56.086
14	0.70	12.772	118.080	1781.672	174.995	-39.099	11.799	51.551
15	0.75	12.169	120.960	1617.084	179.263	-39.212	12.673	47.001
16	0.80	11.530	123.840	1452.028	183.531	-39.324	13.547	42.438
17	0.85	10.853	126.720	1286.516	187.799	-39.432	14.421	37.861
18	0.90	10.129	129.600	1120.558	192.067	-39.538	15.295	33.271
19	0.95	9.347	132.480	954.165	196.335	-39.642	16.169	28.667
20	1.00	8.491	135.360	787.349	200.604	-39.743	17.043	24.049
21	1.05	7.546	136.800	621.826	202.739	-39.435	17.917	19.439
22	1.10	6.485	136.800	459.277	202.739	-38.727	18.791	14.884
23	1.15	5.238	136.800	299.646	202.738	-38.031	19.665	10.395
24	1.20	3.617	136.800	142.910	202.738	-37.342	20.539	5.938

CORE USAGE   OBJECT CODE=   8032 BYTES,ARRAY AREA=   4200 BYTES,TOTAL AREA AVAILABLE=   43104   BYTES

COMPILE TIME=   0.69 SEC,EXECUTION TIME=   0.66 SEC, WATFIV - VERSION 1 LEVEL 1 JANUARY 1970   DATE= 70/281

APPENDIX G: COMPUTATION OF THE PENETRATION OF A RECTANGULAR PARALLELEPIPED

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A RECTANGLE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX        INCREMENT SIZE
C
C BWD       BULK WET DENSITY OF SEDIMENT
C
C BMASS     OBJECT MASS
C
C AMASS()   ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( )   PROJECTED AREA FOR SECTION ( )
C
C CNC       BEARING CAPACITY COEFFICIENT
C
C VOL( )    VOLUME OF SECTION ( )
C
C CFOOT     BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OR AREA
C
C XXX       DEPTH OF PENETRATION
C
C SVOL( )   SUM OF VOLUMES TO SECTION INDICATED
C
C V( )      VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )     WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT        WEIGHT OF OBJECT
C
C G         ACCELERATION OF GRAVITY
C
C SPS       SHEAR STRENGTH OF SEDIMENT
C
C DIM       DIMENSIONS OF THE RECTANGLE BASE
C
C WDRAG     WORK DONE BY DRAG FORCES
C
C WB( )     WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
```

```
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OF BODY AT SECTION( )
C
      DIMENSION AREA(500),VOL(500),AMASS(500),DMASS(500),SVOL(500),WS(50
     20),WB(500),WBSUB(500),US(500),SUMSUB(500),E(500),V(500)
      DATA PI/3.141593/,G/32.1725/,AREA/500*0.0/,VOL/500*0.0/,AMASS/500*
     20.0/,DMASS/500*0.0/,SVOL/500*0.0/,WS/500*0.0/,WB/500*0.0/,WBSUB/50
     30*0.0/,US/500*0.0/,SUMSUB/500*0.0/,E/500*0.0/,V/500*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT RECTANGLE
      DIM1=2.0
      DIM2=3.0
      WT=1014.75
      BUD=87.402/G
      CFDCT=1.3
      CHC=5.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
      COH=43.2
C
C     FOR A RECTANGLE USE A COEFFICIENT OF DRAG EQUAL TO 1.0
      CD=1.0
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE BOTTOM OF RECTANGLE
      Y=DX/2.
      YMAX=DIM1
      Z=DIM1/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
      AREA(1)=DIM1*DIM2
      DO 100 I=2,N
      AREA(I)=AREA(1)
  100 CONTINUE
```

```
C
C     FOR THIS ANALYSIS THE AREA IS CONSTANT FOR THE REMAINING
C     PENETRATION, THEREFORE SET THE SUCCEEDING AREAS AS FOLLOWS
      DO 200 I=N,100
      AREA(I)=AREA(N)
C     PRINT,AREA(I)
  200 CONTINUE
C
C
C
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,100
      VOL(I)=AREA(I)*DX
  300 CONTINUE
C     CHECK VOLUME CALCULATIONS
      HAFVOL=DIM1**2*DIM2
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
C     PRINT,CVOL,HAFVOL,ERROR
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE THE RECTANGLE BY USING ONE HALF OF AN ELLIPTICAL PLATE
C     WITH THE SAME AREA AND RATIO OF MAXIMUM AND MINIMUM DIMENSIONS
C     AS THE RECTANGLE.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION
C     SINCE SEPARATION OCCURS AT IMPACT AMASS REMAINS CONSTANT AND THERE
C     IS NO CONTRIBUTION FROM THE DISPLACED MASS.
C
      K=N+1
      DO 400 I=2,K
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
      EK=.51
C     THE ELLIPSE DIMENSIONS ARE
      A=SQRT(DIM2**2/PI)
      B=A/1.5
```

```
      REA=PI*A*B
C     PRINT,A,B,REA
C
      AMASS(I-1)=EK*(2./3.)*BWD*PI*A**2*B
  400 CONTINUE
C
C     AMASS REMAINS THE SAME AFTER THE MAX AREA
C
      DO 450 I=N,100
      AMASS(I)=AMASS(N)
C     PRINT,AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
C     PRINT,DMASS(N)
  500 CONTINUE
C
C
C
C
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT FOR PROGRAM CHECK
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,100
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=RWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
```

```
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT
C
      DO 760 I=N,100
      WB(I)=SUMSUS(N)+(I-(N-1))*WBSUB(N)
C     PRINT,WB(I)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C     ACTUAL WORK BY INTEGRATION IS
C
      X=N*DX
      AWB=(GAMMA)*DIM1*DIM2*X**2/2.
      PRINT,AWB,X
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) DIM1,DIM2,WT,BWD,CD
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      F(1)=BMASS*VO**2/2.
```

```
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
C
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,100
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE RECTANGLE TAKE THE DEPTH FOR THE SHEAR STRENGTH TO BE
C     PENETRATION DEPTH
      DEPTH=I*DX-Y
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
C
```

```
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GU TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.4.0) GO TO 9
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
C
    9 SSS=(SS30+SS305+SS40)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X S*S X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
```

```
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(VP+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORK DONE BY  SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,8F5.2)
 2200 FORMAT('1',60X,'RECTANGLE'//9X,'WIDTH = ',F7.2,'FEET'/9X,'LENGTH
     2= ',F7.2,'FEET'/9X,'WEIGHT = ',F7.2,' LBS'/9X,'BULK WET DENSITY =
     3',F5.2,' SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,8F5.2//)
 2500 FORMAT('0',29X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///16X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'FORM DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

RECTANGLE

IMPACT VELOCITY EQUALS 0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.50 0.71 1.04 1.34 1.74 2.12 2.78 2.87

WIDTH = 2.00FEET
LENGTH = 3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.00

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	1.421	3.600	32.272	8.003	9.598	0.656	0.210
2	0.10	1.700	10.800	50.536	24.008	5.432	1.967	1.066
3	0.15	1.871	18.000	55.213	40.014	1.391	3.278	1.379
4	0.20	1.719	25.200	46.[illegible]2	56.020	-2.567	4.589	1.327
5	0.25	1.257	32.400	24.923	72.025	-6.441	5.900	0.913

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.35 1.02 1.37 2.68 2.99 3.02 2.95 2.77

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	4.581	2.520	330.886	5.602	98.405	0.656	9.449
2	0.10	4.702	7.560	348.690	16.806	5.295	1.967	8.865
3	0.15	4.755	12.600	356.583	28.010	2.349	3.278	9.203
4	0.20	4.743	17.640	354.778	39.214	-0.539	4.589	9.283
5	0.25	4.667	22.680	343.453	50.418	-3.368	5.900	9.112
6	0.30	4.524	27.720	322.804	61.622	-6.141	7.211	8.694
7	0.35	4.310	32.760	293.019	72.825	-8.858	8.522	8.033
8	0.40	4.015	37.800	254.278	84.029	-11.521	9.833	7.136
9	0.45	3.621	42.840	206.765	95.233	-14.130	11.144	6.004
10	0.50	3.091	47.880	150.657	106.437	-16.696	12.455	4.639
11	0.55	2.234	55.224	82.237	122.763	-20.348	13.766	2.977

RECTANGLE

WIDTH = 2.00FEET
LENGTH = 3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.00

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.51 0.68 0.71 1.17 1.74 2.07 1.95 3.13

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	8.795	3.672	1219.220	8.163	362.771	0.656	36.373
2	0.10	8.774	11.016	1214.055	24.489	-1.714	1.967	31.761
3	0.15	8.705	18.360	1194.946	40.814	-5.593	3.278	31.437
4	0.20	8.587	25.704	1162.759	57.140	-9.572	4.589	30.767
5	0.25	8.419	33.048	1117.755	73.466	-13.384	5.900	29.759
6	0.30	8.199	40.392	1060.190	89.791	-17.120	7.211	28.420
7	0.35	7.924	47.736	990.314	106.117	-20.761	8.522	26.755
8	0.40	7.589	55.080	908.373	122.443	-24.369	9.833	24.771
9	0.45	7.197	62.424	814.609	138.768	-27.695	11.144	22.473
10	0.50	6.706	69.768	709.259	155.094	-31.331	12.455	19.869
11	0.55	6.151	74.664	596.106	165.978	-33.473	13.766	17.018
12	0.60	5.524	77.112	491.248	171.420	-34.337	15.077	14.034
13	0.65	4.797	79.560	362.948	176.862	-35.182	16.388	10.970
14	0.70	3.916	82.008	241.869	182.304	-36.009	17.699	7.821
15	0.75	2.737	84.456	118.096	187.746	-36.810	19.010	4.564

RECTANGLE

WIDTH = 2.00FEET
LENGTH = 3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.00

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.38 0.69 0.69 1.56 2.00 2.75 2.86 2.96

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	13.100	2.736	2766.221	6.092	804.823	0.656	81.305
2	0.10	13.025	8.208	2675.613	18.246	-9.102	1.967	70.231
3	0.15	12.927	13.680	2635.334	30.411	-11.979	3.278	69.306
4	0.20	12.804	19.152	2595.572	42.575	-14.739	4.589	68.131
5	0.25	12.657	24.624	2526.570	54.739	-17.562	5.900	66.711
6	0.30	12.445	30.096	2455.351	66.903	-20.270	7.211	65.051
7	0.35	12.253	35.568	2391.277	79.068	-22.975	8.522	63.155
8	0.40	12.065	41.040	2298.445	91.232	-25.526	9.833	61.029
9	0.45	11.814	46.512	2201.039	103.396	-28.076	11.144	58.676
10	0.50	11.535	51.984	2098.230	115.560	-30.575	12.455	56.101
11	0.55	11.229	56.952	19[illegible].045	126.604	-32.769	13.766	53.321
12	0.60	10.[illegible]4	61.416	1971.482	136.529	-34.666	15.077	50.360
13	0.65	10.[illegible]0	65.880	1749.669	145.451	-36.124	16.388	47.235
14	0.70	10.174	70.344	1610.729	155.375	-38.345	17.699	43.948
15	0.75	9.703	74.808	1464.787	166.299	-40.131	19.010	40.507
16	0.80	9.231	79.272	1323.962	175.222	-41.091	20.321	36.900
17	0.85	8.713	83.736	1108.372	185.145	-44.595	21.632	33.145
18	0.90	8.141	88.200	1045.133	195.069	-45.276	22.943	29.240
19	0.95	7.501	92.664	857.359	205.092	-46.922	24.254	25.186
20	1.00	6.776	97.129	724.163	215.915	-48.534	25.565	20.986
21	1.05	5.955	99.360	559.441	220.877	-49.988	26.876	16.692
22	1.10	5.017	99.360	337.616	220.877	-48.305	28.187	12.402
23	1.15	3.[illegible]5	99.360	23[illegible].859	220.877	-47.630	29.498	8.149
24	1.20	2.236	99.360	79.998	220.877	-45.948	30.809	3.860

RECTANGLE

WIDTH = 2.00FEET
LENGTH = 3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.00

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.40 0.33 0.35 0.60 1.74 2.70 2.7[illegible] 2.[illegible]

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	13.099	2.[illegible]	27[illegible].577	[illegible]	804.751	0.436	81.302
2	0.10	[illegible]	[illegible]	[illegible]	[illegible].207	-[illegible]	1.967	76.[illegible]
3	0.15	[illegible]	[illegible]	[illegible]	32.[illegible]	[illegible]	3.278	[illegible]
4	0.20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	0.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	0.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	0.70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	0.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	0.90	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	[illegible]	[illegible]	49.104	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	1.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	1.50	4.079	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	1.55	3.337	52.648	178.617	[illegible]	[illegible]	[illegible]	[illegible]
32	1.60	2.273	57.744	81.452	[illegible].304	-2[illegible].005	41.297	3.[illegible]

RECTANGLE

WIDTH = 2.00FEET
LENGTH = 3.00FEET
WEIGHT = 1014.75 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 1.00

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.26 0.35 0.95 1.10 1.56 2.45 2.53 2.44

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	17.421	1.872	4786.410	4.161	1423.468	0.656	144.199
2	0.10	17.298	5.616	4718.759	12.484	-20.120	1.967	124.039
3	0.15	17.162	9.360	4645.102	20.807	-21.905	3.278	122.195
4	0.20	17.015	13.104	4565.555	29.130	-23.657	4.589	120.196
5	0.25	16.855	16.848	4480.246	37.453	-25.371	5.900	118.045
6	0.30	16.683	20.592	4389.281	45.776	-27.053	7.211	115.745
7	0.35	16.49[illegible]	24.336	4292.773	54.099	-28.702	8.522	113.298
8	0.40	16.302	28.080	4190.644	62.472	-30.314	9.833	110.708
9	0.45	16.097	31.824	40[illegible]3.597	70.745	-31.[illegible]	11.144	107.977
10	0.50	15.868	35.568	3971.171	79.068	-33.[illegible]	12.455	105.111
11	0.55	15.636	38.0[illegible]	3855.6[illegible]	84.670	-34.247	13.766	102.136
12	0.60	15.398	39.3[illegible]	3739.244	87.551	-34.615	15.077	99.110
13	0.65	15.155	40.5[illegible]	3621.971	90.432	-34.877	16.388	96.061
14	0.70	14.906	41.97[illegible]	3503.834	93.313	-35.133	17.699	92.999
15	0.75	14.650	43.27[illegible]	3384.852	96.194	-35.385	19.010	89.894
16	0.80	14.389	44.[illegible]	3265.039	99.075	-35.632	20.321	86.778
17	0.85	14.120	45.[illegible]	3144.416	101.956	-35.873	21.632	83.640
18	0.90	13.845	47.160	3022.995	104.837	-36.109	22.943	80.481
19	0.95	13.562	48.45[illegible]	2[illegible]0.7[illegible]	107.718	-36.341	24.254	77.302
20	1.00	13.272	49.752	2777.839	110.599	-36.569	25.565	74.102
21	1.05	12.958	54.720	2647.[illegible]	121.642	-38.644	26.876	70.801
22	1.10	12.603	63.360	25[illegible]4.[illegible]9	140.849	-42.531	28.187	67.237
23	1.15	12.205	72.000	2349.672	160.056	-46.339	29.498	63.335
24	1.20	11.759	80.640	2180.705	179.262	-50.072	30.809	59.101
25	1.25	11.262	89.280	2003.039	198.469	-53.730	32.120	54.543
26	1.30	10.705	97.920	1807.318	217.675	-57.315	33.431	49.664
27	1.35	10.081	106.560	1602.784	236.882	-60.828	34.742	44.473
28	1.40	9.377	115.200	1386.675	256.089	-64.270	36.053	38.974
29	1.45	8.574	123.840	1159.224	275.296	-67.643	37.364	33.171
30	1.50	7.641	132.480	920.662	294.502	-70.948	38.675	27.068
31	1.55	6.551	137.880	675.715	306.507	-72.540	39.986	20.740
32	1.60	5.240	140.040	433.003	311.309	-72.479	41.297	14.322
33	1.65	3.467	142.200	189.591	316.110	-72.390	42.608	7.821

APPENDIX B: COMPUTATION OF THE PENETRATION OF A CONE

```
C DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
C PROGRAM TO CALCULATE SECTION PROPERTIES OF A CONE
C
C UNITS FEET/POUNDS/SLUGS/SECONDS/
C
C DX       INCREMENT SIZE
C
C BWD      BULK WET DENSITY OF SEDIMENT
C
C BMASS    OBJECT MASS
C
C AMASS()  ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
C
C DMASS( )CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
C
C AREA( ) PROJECTED AREA FOR SECTION ( )
C
C CNC      BEARING CAPACITY COEFFICIENT
C
C VOL( )   VOLUME OF SECTION ( )
C
C CFOOT    BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
C
C XXX      DEPTH OF PENETRATION
C
C SVOL( ) SUM OF VOLUMES TO SECTION INDICATED
C
C V( )     VELOCITY OF OBJECT AT SECTION ( )
C
C WS( )    WORK DONE BY SEDIMENT IN SECTION ( )
C
C WT       WEIGHT OF OBJECT
C
C G        ACCELERATION OF GRAVITY
C
C SPS      SHEAR STRENGTH OF SEDIMENT
C
C RAD      RADIUS
C
C DIM      LENGTH OF CONE
C
C WDRAG    WORK DONE BY DRAG FORCES
C
C WB( )    WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
C
```

```
C WBSUB( )WORK DONE BY SUBMERGED SECTION ( )
C
C US( )    WORK TO SUBMERGE SECTION ( )
C
C SUMSUB()WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
C
C E( )     KINETIC ENERGY OF BODY AT SECTION( )
C
C
      DIMENSION AREA(500),VOL(500),AMASS(500),DMASS(500),SVOL(500),WS(50
     20),WB(500),WBSUB(500),US(500),SUMSUB(500),E(500),V(500)
      DATA PI/3.141593/,G/32.1725/,AREA/500*0.0/,VOL/500*0.0/,AMASS/500*
     20.0/,DMASS/500*0.0/,SVOL/500*0.0/,WS/500*0.0/,WB/500*0.0/,WBSUB/50
     30*0.0/,US/500*0.0/,SUMSUB/500*0.0/,E/500*0.0/,V/500*0.0/
C
C
C
C     INPUT DATA ON OBJECT
C     OBJECT CONE
      RAD=35.375/24.
      DIM=5.50
      WT=1127.
      BWD=37.402/G
      CFOOT=1.
C     THE CONE'S ANGLE AT THE TIP IS 30 DEGREES
      CNC=4.7
C     COHESION OR SHEAR STRENGTH IN PSI EQUALS .3
      COH=43.2
C
C     FOR A CONE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
      CD=0.3
C
C
C     SET INCREMENT
      DX=.05
C
C
C
C
C     CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C     FIND AREA AT MIDPOINT OF EACH SECTION
C     Y=DISTANCE ABOVE POINT OF A CONE
      Y=DX/2.
      YMAX=DIM
      Z=DIM/DX
      N=Z+1.
C     THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
C     FIND HALF THE ANGLE AT THE TIP OF THE CONE
      ALFA=ATAN(RAD/DIM)
```

```
      RAA=TAN(ALFA)*(DX-Y)
      AREA(1)=PI*RAA**2
      DO 100 I=2,N
      RAA=TAN(ALFA)*(I*DX-Y)
      AREA(I)=PI*RAA**2
  100 CONTINUE
C
C     FOR THIS ANALYSIS AFTER THE AREA HAS BECOME A MAXIMUM IT WILL BE
C     CONSTANT FOR THE REMAINING PENETRATION THEREFORE SET SUCCEEDING
C     AREAS AS FOLLOWS
      DO 200 I=N,500
      AREA(I)=AREA(N)
  200 CONTINUE
C
C     COMPUTE THE VOLUME OF EACH SECTION
C     VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C
      DO 300 I=1,500
      VOL(I)=AREA(I)*DY
  300 CONTINUE
C
C     CHECK VOLUME CALCULATIONS
      HAFVOL=PI*RAD**2*DIM/3.
      CVOL=VOL(1)
      DO 350 I=2,N
      CVOL=CVOL+VOL(I)
  350 CONTINUE
C
      ERROR=CVOL-HAFVOL
      PRINT,CVOL,HAFVOL,ERROR
C
C
C
C
C     CALCULATE ADDED MASS, DISPLACED MASS AND CHANGE IN ADDED MASS PLUS
C     DISPLACED MASS FROM SECTION TO SECTION.
C     APPROXIMATE ADDED MASS BY USING ONE HALF OF A PROLATE ELLIPSOID.
C     AMASS BECOMES CONSTANT WHEN THE MAXIMUM AREA HAS BEEN REACHED.
C
      SUMVOL=0.0
      K=N+1
C     INTEGERS TRUNCATE SO THERE IS AN APPROXIMATION HERE IN THE NUMBER
C     OF ITERATIONS TAKEN
      DO 400 I=2,K
C     SEE PAGE 421 OF SAUNDERS FOR FORMULAS BELOW
C     NOW ADDED MASS,DESIGNATE SOME NEW VARIABLES
      EK=0.005
      A=(I-1)*DX-Y
      B=TAN(ALFA)*A
```

```
      AMASS(I-1)=BWD*EK*(2./3.)*PI*A*B**2
C     ADD DISPLACED VOL AT THE SAME TIME
C
C     SUM THE VOLUMES BEFORE ADDING
C
      SUMVOL=SUMVOL+VOL(I-1)
C     SUMVOL AT END OF DO LOOP SHOULD EQUAL HAFVOL
C
      AMASS(I-1)=AMASS(I-1)+BWD*SUMVOL
  400 CONTINUE
C
C     CHECK ADDED MASS BY COMPARING LAST INCREMENT TO ONE HALF ELLIPSOID
C
      HAMAS=BWD*(PI*RAD**2*[illegible]M*EK*(2./3.)+PI*RAD**2*DIM/3.)
      ERROR=HAMAS-AMASS(N)
      PRINT,HAMAS,AMASS(N),ERROR
C
      DO 450 I=N,500
      AMASS(I)=AMASS(N)
  450 CONTINUE
C
C     COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
      DMASS(1)=0.0
      DO 500 I=2,N
      DMASS(I)=AMASS(I)-AMASS(I-1)
  500 CONTINUE
C
C     SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C
      CDMASS=DMASS(1)
      DO 550 I=2,N
      CDMASS=CDMASS+DMASS(I)
  550 CONTINUE
      PRINT,CDMASS,AMASS(N)
C
C
C
C     FOR THE ORIGINAL PROGRAM CHECKOUT
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     PER SECTION IF THE SHEAR STRENGTH IS CONSTANT OVER THE DEPTH
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X COHESIONX DX
      CT=CFOOT*CNC
      DO 600 I=1,500
      WS(I)=CT*COH*AREA(I)*DX
  600 CONTINUE
C
C
C
```

```
C     CALCULATE WORK DONE BY BUOYANCY
C
      GAMMA=BWD*G
      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
      SUMSUB(1)=2.0*WB(1)
      DO 700 I=2,N
C
C     WORK TO SUBMERGE SECTION
      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C     WORK TO CONTINUE SECTION AFTER SUBMERGING
      WBSUB(I)=2.0*US(I)
C
C     TOTAL WORK OF THE SUBMERGED SECTIONS
      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)
C
C     TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
      WB(I)=US(I)+SUMSUB(I-1)
  700 CONTINUE
C
C     AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C     SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHUR INCREMENT.
C     THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C     ITS MAXIMUM DIMENSION.
C
      DO 760 I=N,500
      WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
  760 CONTINUE
C
C     CHECK WORK TO SUBMERGE
C
      CWB=WB(1)
      DO 800 I=2,N
      CWB=CWB+WB(I)
  800 CONTINUE
      PRINT,CWB
C
C
C
C
C
C     PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
C
C     BE ABLE TO DO NNN DIFFERENT VELOCITIES AND SHEAR STRENGTHS
      READ(5,2050) NNN
      WRITE(6,2060)NNN
C
      DO 1000 J=1,NNN
      WRITE(6,2200) RAD,DIM,WT,BWD,CD
```

```
C
C     READ IN THE VELOCITIES AND SHEAR STRENGTHS
      READ(5,2100) VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40,SS405,
     2SS500,SS505,SS600
      WRITE(6,2300)VO,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40,SS405,
     2SS500,SS505,SS600
      WRITE(6,2500)
C
C
C     CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
      BMASS=WT/G
      E(1)=BMASS*VO**2/2.
C
C     CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
      EP=WT*DX
C
C
C
C     COMPUTE SLOPE OF SHEAR STRENGTH VARIATIONS
      SLOPE1=SS05/.5
      BINT1=0.0
C
      SLOPE2=(SS10-SS05)/.5
      BINT2=-SLOPE2*.5+SS05
C
      SLOPE3=(SS105-SS10)/.5
      BINT3=-SLOPE3*1.+SS10
C
      SLOPE4=(SS20-SS105)/.5
      BINT4=-SLOPE4*1.5+SS105
C
      SLOPE5=(SS205-SS20)/.5
      BINT5=-SLOPE5*2.0+SS20
C
      SLOPE6=(SS30-SS205)/.5
      BINT6=-SLOPE6*2.5+SS205
C
      SLOPE7=(SS305-SS30)/.5
      BINT7=-SLOPE7*3.+SS30
C
      SLOPE8=(SS40-SS305)/.5
      BINT8=-SLOPE8*3.5+SS305
C
      SLOPE9=(SS405-SS40)/.5
      BINT9=-SLOPE9*4.0+SS40
C
      SLOPEA=(SS500-SS405)/.5
      BINTA=-SLOPEA*4.5+SS405
```

```
C
      SLOPEB=(SS505-SS500)/.5
      BINTB=-SLOPEB*5.0+SS500
C
      SLOPEC=(SS600-SS505)/.5
      BINTC=-SLOPEC*5.5+SS505
C
C     VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS O AT INSTANT OF IMPACT
      V(1)=0.0
      DO 2000 I=1,500
C     SECTION TO COMPUTE SHEAR STRENGTH
C     NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
C     TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
C
C     FOR THE CONE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
C     PENETRATION DEPTH MINUS ONE HALF THE PENETRATION DEPTH
      DEPTH=I*DX-Y-(I*DX-Y)/2.
C     WHEN THE DEPTH OF PENETRATION EQUALS ONE HALF THE LENGTH OF THE
C     CONE THE DEPTH FOR SHEAR STRENGTHS EQUALS THE PENETRATION DEPTH
C     MINUS ONE HALF THE LENGTH
      IF((I*DX-Y).GT.DIM) DEPTH=I*DX-Y-DIM/2.
C
C     CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH  DATA
      DEPTHI=DEPTH*12.
C
C     SELECT PROPER DEPTH
      IF(DEPTH.LE..5) GO TO 1
C
      IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
      IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
      IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
      IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
      IF((DEPTH.LT.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
      IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
      IF((DEPTH.LE.4.0).AND.(DEPTH.GT.3.5)) GO TO 8
      IF((DEPTH.LE.4.5).AND.(DEPTH.GT.4.0)) GO TO 9
      IF((DEPTH.LE.5.0).AND.(DEPTH.GT.4.5)) GO TO 11
      IF((DEPTH.LE.5.5).AND.(DEPTH.GT.5.0)) GO TO 12
      IF((DEPTH.LE.6.0).AND.(DEPTH.GT.5.5)) GO TO 13
C
C     FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
C     AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
C
      IF(DEPTH.GT.6.0) GO TO 14
C
C     FORMULAS FOR SHEAR STRENGTH FOLLOW
C     LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED
C
```

```
    1 SSS=SLOPE1*DEPTH
      GO TO 10
    2 SSS=SLOPE2*DEPTH+BINT2
      GO TO 10
    3 SSS=SLOPE3*DEPTH+BINT3
      GO TO 10
    4 SSS=SLOPE4*DEPTH+BINT4
      GO TO 10
    5 SSS=SLOPE5*DEPTH+BINT5
      GO TO 10
    6 SSS=SLOPE6*DEPTH+BINT6
      GO TO 10
    7 SSS=SLOPE7*DEPTH+BINT7
      GO TO 10
    8 SSS=SLOPE8*DEPTH+BINT8
      GO TO 10
    9 SSS=SLOPE9*DEPTH+BINT9
      GO TO 10
   11 SSS=SLOPEA*DEPTH+BINTA
      GO TO 10
   12 SSS=SLOPEB*DEPTH+BINTB
      GO TO 10
   13 SSS=SLOPEC*DEPTH+BINTC
      GO TO 10
   14 SSS=(SS500+SS505+SS600)/3.
C
C     SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
   10 SPS=SSS*144.
C     CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C     ULT. BEARING CAPACITY EQUALS CFOOT X CNC X AVG AREA X SPS X DX
      CT=CFOOT*CNC
      WS(I)=CT*SPS*AREAA(I)*DX
      AMASS1=(AMASS(I)*V(I)**2/2.)
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I))/(BMASS+DMASS(I)+AMASS(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
      V(I+1)=SQRT(VELOSQ)
C
C
C     SECTION TO COMPUTE THE WORK DONE BY DRAG
C     APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
C     FIRST TIME OVER THE SECTION, AS DONE ABOVE
      VAVG=(V(I)+V(I+1))/2.
      IF(I.EQ.1) VAVG=(VO+V(I+1))/2.
      WDRAG=.5*BWD*CD*AREA(I)*DX*VAVG**2
C
      VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
     2S(I))
      IF (VELOSQ.LE.0.0)GO TO 1000
```

```
      V(I+1)=SQRT(VELOSQ)
C
C     CALCULATE E AT NEXT SECTION
      E(I+1)=BMASS*V(I+1)**2/2.
C
C     CALCULATE ENERGY DISSIPATED BY ADDED MASS EFFECTS, EAM
      EAM=.5*(AMASS(I)*V(I+1)**2-2.0*AMASS1+DMASS(I)*V(I+1)**2)
C
C     COMPUTE PENETRATION DEPTH
      XXX=I*DX
C
C     PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
C     SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
C     WORKDONE BY   SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
C     AND DRAG
C
      WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
 2000 CONTINUE
 1000 CONTINUE
 2050 FORMAT(I5)
 2060 FORMAT(' ',I3)
 2100 FORMAT(F5.1,12F5.2)
 2200 FORMAT('1',60X,'CONE '//9X,'RADIUS = ',F7.3,' FEET'/9X,'LENGTH = '
     2,F7.3,' FEET'/9X,'WEIGHT = ',F7.1,' LBS'/9X,'BULK WET DENSITY =  '
     3,F5.2,' SLUGS PER CUBIC FOOT'/9X,'DRAG COEFFICIENT = ',F5.2///)
 2300 FORMAT(' ',10X,'IMPACT VELOCITY EQUALS',F5.1///10X,'SEDIMENT SHEAR
     2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE'//15X,12F6.2//)
 2500 FORMAT('0',28X,'CONDITIONS AT THE END OF SECTION',19X,'WORK DONE I
     2N SECTION - FOOT POUNDS'///15X,'ITERATION',1X,'PENETRATION',4X,'VE
     3LOCITY',3X,'SHEAR',5X,'BODY ENERGY',6X,'STATIC',4X,'SEDIMENT',5X,'
     4BUOYANT',3X,'DEPTH DRAG'/17X,'SECTION',6X,'FEET',8X,'FT/SEC',2X,'ST
     5RENGTH PSF',4X,'FT-LBS',7X,'FORCES',4X,'INERTIA',6X,'FORCES',4X,'F
     6ORCES'//)
 2600 FORMAT(' ',16X,I3,3X,F12.2,7F12.3)
      STOP
      END
```

CONE

RADIUS = 1.474 FEET
LENGTH = 5.500 FEET
WEIGHT = 1127.0 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.48 0.69 1.10 1.38 1.86 2.50 2.31 2.52 2.81 2.65 2.50 2.80

CONDITIONS AT THE END OF SECTION					WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	1.794	1.728	56.350	0.000	0.000	0.000	0.000
2	0.10	2.537	5.184	112.697	0.002	0.001	0.000	0.000
3	0.15	3.107	8.640	169.035	0.007	0.004	0.001	0.001
4	0.20	3.557	12.096	225.352	0.020	0.010	0.002	0.002
5	0.25	4.010	15.552	281.632	0.042	0.020	0.004	0.003
6	0.30	4.392	19.008	337.955	0.076	0.036	0.007	0.005
7	0.35	4.743	22.464	393.998	0.126	0.058	0.011	0.010
8	0.40	5.067	25.920	450.032	0.193	0.089	0.017	0.016
9	0.45	5.375	29.376	505.925	0.281	0.128	0.025	0.023
10	0.50	5.653	32.832	561.637	0.393	0.177	0.035	0.032
11	0.55	5.936	36.288	617.128	0.530	0.237	0.048	0.043
12	0.60	6.196	39.744	672.353	0.697	0.309	0.063	0.056
13	0.65	6.444	43.200	727.260	0.895	0.395	0.080	0.072
14	0.70	6.681	46.656	781.797	1.127	0.494	0.101	0.090
15	0.75	6.905	50.112	835.904	1.397	0.608	0.125	0.112
16	0.80	7.126	53.568	889.520	1.706	0.738	0.153	0.136
17	0.85	7.336	57.024	942.578	2.059	0.885	0.185	0.164
18	0.90	7.537	60.480	995.009	2.455	1.049	0.221	0.195
19	0.95	7.731	63.936	1046.740	2.901	1.228	0.261	0.229
20	1.00	7.917	67.392	1097.693	3.397	1.427	0.305	0.268
21	1.05	8.095	69.876	1147.842	3.893	1.644	0.354	0.310
22	1.10	8.267	71.388	1197.172	4.374	1.881	0.409	0.356
23	1.15	8.433	72.900	1245.620	4.892	2.136	0.468	0.406
24	1.20	8.592	74.412	1293.119	5.447	2.410	0.534	0.460
25	1.25	8.745	75.924	1339.600	6.041	2.703	0.605	0.519
26	1.30	8.892	77.436	1384.996	6.675	3.015	0.682	0.581
27	1.35	9.033	78.948	1429.237	7.349	3.346	0.765	0.649
28	1.40	9.168	80.460	1472.253	8.066	3.694	0.855	0.720
29	1.45	9.297	81.972	1513.970	8.826	4.058	0.952	0.796
30	1.50	9.420	83.484	1554.318	9.630	4.439	1.055	0.876
31	1.55	9.537	84.996	1593.225	10.481	4.835	1.166	0.961
32	1.60	9.649	86.508	1630.616	11.378	5.245	1.285	1.050
33	1.65	9.754	88.020	1665.421	12.324	5.667	1.411	1.143

34	1.70	9.854	89.532	1700.565	13.319	6.100	1.545	1.240
35	1.75	9.947	91.044	1732.980	14.365	6.542	1.688	1.341
36	1.80	10.034	92.556	1763.593	15.462	6.990	1.839	1.446
37	1.85	10.116	94.068	1792.334	16.612	7.443	1.999	1.555
38	1.90	10.191	95.580	1819.134	17.817	7.898	2.167	1.667
39	1.95	10.260	97.092	1843.927	19.077	8.353	2.345	1.782
40	2.00	10.323	98.604	1866.646	20.393	8.804	2.533	1.900
41	2.05	10.380	100.335	1887.080	21.924	9.240	2.730	2.021
42	2.10	10.429	103.788	1905.002	23.694	9.652	2.937	2.144
43	2.15	10.471	106.740	1920.325	25.557	10.046	3.155	2.268
44	2.20	10.505	109.692	1932.971	27.514	10.415	3.383	2.394
45	2.25	10.532	112.644	1942.855	29.569	10.756	3.621	2.520
46	2.30	10.551	115.596	1949.902	31.722	11.063	3.871	2.646
47	2.35	10.562	118.548	1954.0[illegible]	33.978	11.331	4.132	2.771
48	2.40	10.565	121.500	1955.195	36.338	11.554	4.404	2.896
49	2.45	10.560	124.452	1953.304	38.805	11.729	4.688	3.018
50	2.50	10.547	127.404	1948.305	41.380	11.846	4.984	3.139
51	2.55	10.525	130.356	1940.135	44.067	11.902	5.292	3.256
52	2.60	10.494	133.308	1928.744	46.867	11.891	5.613	3.369
53	2.65	10.454	136.260	1914.081	49.794	11.805	5.946	3.478
54	2.70	10.405	139.212	1896.099	52.819	11.638	6.292	3.581
55	2.75	10.345	142.164	1874.759	55.974	11.385	6.652	3.678
56	2.80	10.277	145.116	1850.025	59.252	11.038	7.025	3.768
57	2.85	10.199	148.068	1821.868	62.656	10.590	7.411	3.849
58	2.90	10.110	151.020	1790.261	66.187	10.036	7.812	3.922
59	2.95	10.011	153.972	1755.185	69.848	9.367	8.226	3.985
60	3.00	9.900	156.924	1716.621	73.642	8.578	8.655	4.036
61	3.05	9.778	159.408	1674.[illegible]	77.343	7.701	9.099	4.077
62	3.10	9.646	161.424	1629.768	80.932	6.739	9.558	4.105
63	3.15	9.503	163.440	1581.687	84.629	5.650	10.032	4.120
64	3.20	9.349	165.456	1530.527	88.476	4.431	10.521	4.121
65	3.25	9.181	167.472	1476.310	92.356	3.077	11.026	4.108
66	3.30	9.001	169.488	1419.064	96.388	1.581	11.546	4.080
67	3.35	8.809	171.504	1358.821	100.535	-0.060	12.083	4.035
68	3.40	8.601	173.520	1295.615	104.799	-1.853	12.637	3.972
69	3.45	8.378	175.536	1229.486	109.182	-3.801	13.207	3.891
70	3.50	8.140	177.552	1160.477	113.663	-5.909	13.793	3.791
71	3.55	7.884	179.568	1088.[illegible]	118.307	-8.182	14.397	3.671
72	3.60	7.609	181.584	1014.005	123.053	-10.624	15.019	3.530
73	3.65	7.313	183.600	936.643	127.924	-13.239	15.658	3.367
74	3.70	6.993	185.616	856.005	132.920	-16.029	16.315	3.181
75	3.75	6.647	187.632	773.949	138.045	-19.000	16.990	2.971
76	3.80	6.271	189.648	688.734	143.299	-22.155	17.683	2.737
77	3.85	5.859	191.664	601.024	148.684	-25.497	18.395	2.477
78	3.90	5.401	193.680	510.984	154.202	-29.028	19.126	2.191
79	3.95	4.887	195.696	418.379	159.854	-32.753	19.875	1.877
80	4.00	4.298	197.712	323.590	165.641	-36.672	20.645	1.535
81	4.05	3.593	200.448	226.139	172.195	-40.989	21.434	1.161
82	4.10	2.679	203.904	125.700	179.532	-45.737	22.242	0.752
83	4.15	1.1[illegible]	207.360	22.342	187.093	-50.731	23.071	0.284

CONE

RADIUS = 1.474 FEET
LENGTH = 5.500 FEET
WEIGHT = 1127.0 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.65 0.63 0.68 1.80 2.32 2.56 2.51 2.26 1.89 1.64 1.60 1.79

CONDITIONS AT THE END OF SECTION / WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	5.312	2.340	494.222	0.000	0.000	0.000	0.000
2	0.10	5.607	7.020	550.565	0.002	0.003	0.000	0.001
3	0.15	5.926	11.700	605.891	0.010	0.011	0.001	0.002
4	0.20	6.153	16.380	663.183	0.027	0.023	0.002	0.005
5	0.25	6.409	21.060	719.470	0.057	0.042	0.004	0.009
6	0.30	6.654	25.740	775.575	0.103	0.069	0.007	0.015
7	0.35	6.931	30.420	831.615	0.170	0.105	0.011	0.022
8	0.40	7.118	35.100	887.503	0.262	0.151	0.017	0.032
9	0.45	7.338	39.780	943.154	0.381	0.209	0.025	0.043
10	0.50	7.551	44.460	998.841	0.532	0.278	0.035	0.057
11	0.55	7.757	49.140	1053.790	0.719	0.360	0.043	0.074
12	0.60	7.956	53.820	1110.592	0.943	0.457	0.063	0.094
13	0.65	8.148	58.500	1162.955	1.212	0.559	0.080	0.116
14	0.70	8.335	63.180	1216.837	1.525	0.697	0.101	0.142
15	0.75	8.516	67.860	1270.157	1.891	0.841	0.126	0.172
16	0.80	8.691	72.540	1322.935	2.310	1.003	0.153	0.204
17	0.85	8.860	77.220	1374.789	2.737	1.183	0.185	0.241
18	0.90	9.023	81.900	1425.930	3.425	1.382	0.221	0.281
19	0.95	9.180	86.580	1476.167	3.928	1.590	0.261	0.326
20	1.00	9.333	91.260	1525.402	4.600	1.835	0.305	0.374
21	1.05	9.477	93.528	1573.669	5.210	2.091	0.354	0.427
22	1.10	9.620	93.324	1621.036	5.722	2.369	0.409	0.485
23	1.15	9.757	93.240	1667.466	6.257	2.667	0.468	0.546
24	1.20	9.883	93.096	1712.950	6.915	2.985	0.534	0.613
25	1.25	10.015	92.952	1757.193	7.396	3.323	0.605	0.683
26	1.30	10.139	92.808	1800.471	8.000	3.691	0.682	0.759
27	1.35	10.256	92.664	1842.490	8.626	4.060	0.765	0.839
28	1.40	10.369	92.520	1883.320	9.275	4.457	0.855	0.925
29	1.45	10.478	92.376	1922.854	9.945	4.873	0.952	1.015
30	1.50	10.592	92.232	1961.123	10.540	5.307	1.055	1.109
31	1.55	10.690	92.088	1997.983	11.355	5.758	1.166	1.209
32	1.60	10.775	91.944	2033.417	12.093	6.225	1.285	1.313
33	1.65	10.864	91.800	2067.373	12.453	6.707	1.411	1.422

CONE

RADIUS = 1.474 FEET
LENGTH = 5.500 FEET
WEIGHT = 1127.0 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.30 0.23 0.47 2.05 2.53 3.31 3.81 3.95 3.73 3.35 3.22 3.12

	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	10.160	1.080	1807.943	0.000	0.001	0.000	0.000
2	0.10	10.317	3.240	1864.178	0.001	0.010	0.000	0.003
3	0.15	10.471	5.400	1920.484	0.004	0.031	0.001	0.008
4	0.20	10.624	7.560	1976.740	0.012	0.063	0.002	0.016
5	0.25	10.773	9.720	2032.[illegible]27	0.026	0.109	0.004	0.027
6	0.30	10.921	11.880	2089.[illegible]	0.048	0.170	0.007	0.041
7	0.35	11.0[illegible]	14.040	2144.959	0.079	0.246	0.011	0.059
8	0.40	11.209	16.200	2200.748	0.121	0.340	0.017	0.080
9	0.45	11.[illegible]	18.360	2255.338	0.176	0.451	0.025	0.106
10	0.50	11.[illegible]	20.520	2311.6[illegible]	0.245	0.581	0.035	0.135
11	0.55	11.624	22.680	2366.75[illegible]	0.331	0.731	0.049	0.169
12	0.60	11.758	24.840	2421.499	0.435	0.903	0.063	0.208
13	0.65	11.[illegible]59	27.000	24[illegible]	0.559	1.096	0.080	0.251
14	0.70	12.018	29.160	25[illegible]9.791	0.704	1.312	0.101	0.299
15	0.75	12.144	31.320	2583.234	0.873	1.552	0.126	0.353
16	0.80	12.268	33.480	2636.135	1.066	1.817	0.153	0.411
17	0.85	12.389	35.640	26[illegible].430	1.296	2.107	0.185	0.476
18	0.90	12.509	37.800	2740.055	1.535	2.422	0.221	0.545
19	0.95	12.623	39.960	[illegible]	1.813	2.764	0.261	0.621
20	1.00	12.736	42.120	2[illegible]1.029	2.123	3.133	0.305	0.703
21	1.05	12.846	42.948	2890.313	2.392	3.529	0.354	0.790
22	1.10	12.953	42.444	2938.816	2.631	3.953	0.409	0.884
23	1.15	13.058	41.940	2986.402	2.814	4.406	0.468	0.994
24	1.20	13.160	41.436	3033.295	3.033	4.887	0.534	1.091
25	1.25	13.259	40.932	3079.182	3.257	5.396	0.605	1.204
26	1.30	13.355	40.428	3124.107	3.495	5.934	0.682	1.324
27	1.35	13.449	39.924	3168.025	3.716	6.499	0.765	1.450
28	1.40	13.540	39.420	3210.893	3.952	7.093	0.855	1.583
29	1.45	13.627	38.916	3252.[illegible]	4.190	7.715	0.952	1.723
30	1.50	13.712	38.412	3293.291	4.431	8.364	1.055	1.870
31	1.55	13.794	37.908	3332.738	4.674	9.039	1.166	2.023
32	1.60	13.873	37.404	3370.957	4.920	9.741	1.285	2.193
33	1.65	13.949	36.900	3407.912	5.166	10.467	1.411	2.350
34	1.70	14.022	36.396	3443.559	5.414	11.219	1.545	2.524

35	1.75	14.091	35.892	3477.859	5.663	11.992	1.688	2.704
36	1.80	14.158	35.398	3510.777	5.912	12.789	1.839	2.891
37	1.85	14.221	34.884	3542.277	6.160	13.605	1.999	3.084
38	1.90	14.281	34.380	3572.324	6.409	14.442	2.167	3.284
39	1.95	14.338	33.876	3600.887	6.656	15.296	2.345	3.490
40	2.00	14.392	33.372	3627.934	6.902	16.167	2.533	3.702
41	2.05	14.442	33.984	3653.205	7.359	17.038	2.730	3.920
42	2.10	14.488	35.712	3676.418	8.153	17.901	2.937	4.144
43	2.15	14.529	37.440	3697.510	8.964	18.765	3.155	4.372
44	2.20	14.567	39.168	3716.420	9.825	19.627	3.383	4.605
45	2.25	14.599	40.896	3733.098	10.735	20.484	3.621	4.843
46	2.30	14.627	42.624	3747.451	11.697	21.330	3.871	5.084
47	2.35	14.651	44.352	3759.457	12.712	22.162	4.132	5.329
48	2.40	14.669	46.080	3769.059	13.782	22.977	4.404	5.577
49	2.45	14.693	47.808	3776.207	14.907	23.771	4.688	5.827
50	2.50	21.515	128.628	8107.480	41.778	46.177	4.984	13.085
51	2.55	21.443	132.012	8053.281	44.627	47.081	5.292	13.532
52	2.60	21.364	135.396	7994.571	47.602	47.895	5.613	13.975
53	2.65	21.280	138.780	7931.211	50.705	48.596	5.946	14.413
54	2.70	21.189	142.164	7863.293	53.938	49.170	6.292	14.844
55	2.75	21.090	145.548	7790.762	57.306	49.631	6.652	15.268
56	2.80	20.986	148.932	7713.613	60.810	49.962	7.025	15.682
57	2.85	20.874	152.316	7631.840	64.453	50.151	7.411	16.086
58	2.90	20.756	155.700	7545.449	68.238	50.191	7.812	16.479
59	2.95	20.630	159.084	7454.461	72.167	50.074	8.226	16.858
60	3.00	20.498	162.468	7358.879	76.244	49.788	8.655	17.223
61	3.05	20.357	167.724	7257.984	81.378	49.175	9.097	17.571
62	3.10	20.206	174.852	7151.016	87.664	48.185	9.558	17.898
63	3.15	20.046	181.980	7037.934	94.229	46.937	10.032	18.203
64	3.20	19.875	189.108	6919.750	101.078	45.429	10.521	18.483
65	3.25	19.694	196.236	6793.465	108.218	43.641	11.026	18.736
66	3.30	19.503	203.364	6662.072	115.653	41.561	11.546	18.961
67	3.35	19.301	210.492	6524.509	123.390	39.179	12.083	19.154
68	3.40	19.087	217.620	6381.078	131.434	36.479	12.637	19.314
69	3.45	18.862	224.748	6231.520	139.791	33.452	13.207	19.439
70	3.50	18.625	231.876	6075.977	148.466	30.086	13.793	19.527
71	3.55	18.376	239.004	5914.492	157.465	26.367	14.397	19.576
72	3.60	18.114	246.132	5747.137	166.794	22.289	15.019	19.584
73	3.65	17.839	253.260	5573.961	176.459	17.835	15.658	19.548
74	3.70	17.551	260.388	5395.055	186.465	13.001	16.315	19.466
75	3.75	17.249	267.516	5210.459	196.818	7.767	16.990	19.337
76	3.80	16.930	274.644	5020.205	207.522	2.130	17.683	19.158
77	3.85	16.597	281.772	4824.645	218.585	-3.918	18.395	18.927
78	3.90	16.247	288.900	4623.596	230.013	-10.391	19.126	18.642
79	3.95	15.881	296.028	4417.230	241.810	-17.297	19.875	18.302
80	4.00	15.496	303.156	4205.684	253.981	-24.643	20.645	17.904
81	4.05	15.095	307.476	3990.694	264.121	-31.662	21.434	17.449
82	4.10	14.679	308.988	3774.010	272.056	-39.226	22.242	16.943
83	4.15	14.249	310.500	3555.809	280.137	-45.061	23.071	16.389
84	4.20	13.801	312.012	3336.236	288.367	-52.160	23.920	15.786
85	4.25	13.337	313.524	3115.432	296.747	-59.525	24.790	15.133
86	4.30	12.853	315.036	2893.543	305.276	-67.154	25.680	14.430
87	4.35	12.348	316.548	2670.703	313.959	-75.043	26.592	13.675
88	4.40	11.820	318.060	2447.055	322.795	-83.196	27.525	12.870

89	4.45	11.265	319.572	2222.729	331.785	-91.605	28.479	12.012
90	4.50	10.680	321.084	1997.857	340.930	-100.269	29.456	11.102
91	4.55	10.057	322.596	1772.565	350.233	-109.186	30.454	10.139
92	4.60	9.378	324.108	1546.972	359.694	-118.356	31.475	9.123
93	4.65	8.625	325.620	1321.215	369.314	-127.772	32.518	[illegible].053
94	4.70	7.905	327.132	1095.391	379.094	-137.434	33.594	6.928
95	4.75	7.046	328.644	8[illegible]9.621	389.037	-147.339	34.673	5.748
96	4.80	6.064	330.156	644.013	399.142	-157.482	35.795	4.512
97	4.85	4.839	331.668	419.674	409.411	-167.860	36.921	3.216
98	4.90	3.326	333.180	193.714	419.845	-178.464	38.081	1.847

CCMS

RADIUS = 1.474 FEET
LENGTH = 5.500 FEET
WEIGHT = 1127.0 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.30

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.30 0.23 0.2[illegible] 0.76 1.77 1.67 2.[illegible] 2.9[illegible] [illegible].40 3.89 3.84 3.89

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
	CONDITIONS AT THE END OF SECTION				WORK DONE IN SECTION - FOOT POUNDS			
1	0.05	[illegible]	[illegible]	[illegible]	0.002	0.002	0.000	0.001
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.022	0.000	0.006
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.017
4	[illegible]	[illegible]	[illegible]	[illegible]	0.012	[illegible]	[illegible]	0.033
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.271	0.004	0.056
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.007	0.084
7	[illegible]	[illegible]	[illegible]	[illegible]	0.079	0.451	[illegible]	0.119
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.017	0.161
9	[illegible]	[illegible]	[illegible]	[illegible]	0.176	[illegible]	0.025	0.209
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.265
11	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.349	0.048	0.327
12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.643	[illegible]	0.397
13	[illegible]	[illegible]	[illegible]	[illegible]	0.559	1.971	0.077	0.475
14	0.73	[illegible]	[illegible]	[illegible]	0.704	2.333	0.101	0.560
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.729	0.125	0.654
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.160	[illegible]	0.755
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.627	0.195	0.865
18	[illegible]	[illegible]	[illegible]	[illegible]	1.535	4.130	0.221	0.983
19	[illegible]	[illegible]	[illegible]	[illegible]	1.813	4.668	0.261	1.109
20	[illegible]	[illegible]	[illegible]	[illegible]	2.173	5.245	0.304	1.245
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.354	1.389
22	1.10	[illegible]	[illegible]	[illegible]	[illegible]	6.509	0.409	1.541
23	[illegible]	[illegible]	[illegible]	[illegible]	2.514	7.106	0.468	1.703
24	1.20	[illegible]	[illegible]	[illegible]	3.033	7.921	0.534	1.873
25	1.25	[illegible]	[illegible]	[illegible]	3.257	8.682	0.505	2.053
26	[illegible]	[illegible]	[illegible]	[illegible]	3.495	9.479	0.692	2.241
27	1.35	[illegible]	[illegible]	[illegible]	3.716	10.312	0.765	2.439
28	1.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.855	2.646
29	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.093	0.952	2.861
30	1.50	[illegible]	[illegible]	[illegible]	4.431	13.019	1.055	3.086
31	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.997	1.166	3.320
32	1.60	[illegible]	[illegible]	[illegible]	4.920	[illegible]	1.285	3.562
33	[illegible]	17.74[illegible]	[illegible]	[illegible]	5.166	[illegible].014	1.411	3.813
34	1.70	[illegible]	[illegible]	554[illegible]	5.414	17.071	1.545	4.073

35	1.75	17.832	35.892	5569.978	5.663	18.194	1.688	4.341
36	1.80	17.872	35.398	5594.273	5.912	19.262	1.839	4.619
37	1.85	17.908	34.886	5617.152	6.160	20.393	[illegible]	4.903
38	1.90	17.942	34.330	5639.165	6.409	21.544	2.167	5.195
39	1.95	17.972	33.876	[illegible]	6.656	22.715	2.345	5.496
40	2.00	17.999	33.372	5674.484	6.902	[illegible]	2.533	5.804
41	2.05	18.023	[illegible]	5689.629	7.240	[illegible]	2.730	6.119
42	2.10	18.044	33.610	5702.605	7.684	26.295	2.937	6.441
43	2.15	[illegible]	34.070	5713.371	8.145	27.499	3.155	6.769
44	2.20	18.074	[illegible]	[illegible]	8.624	28.705	3.383	7.103
45	2.25	18.084	[illegible]	[illegible]	9.119	29.910	3.621	7.444
46	2.30	[illegible]	35.100	[illegible]	9.632	31.110	3.871	7.789
47	2.35	[illegible]	35.460	[illegible]	10.164	32.302	4.132	8.139
48	2.40	18.092	[illegible]	[illegible]	10.713	33.482	4.404	8.494
49	2.45	18.087	[illegible]	[illegible]	[illegible]	34.747	4.688	8.852
50	2.50	14.652	47.536	[illegible]	[illegible]	[illegible]	4.984	[illegible]
51	2.55	[illegible]	[illegible]	[illegible]	[illegible]	25.274	5.292	6.333
52	2.60	[illegible]	[illegible]	[illegible]	[illegible]	25.975	5.613	6.588
53	2.65	[illegible]	54.720	[illegible]	[illegible]	26.637	5.946	6.844
54	2.70	14.679	56.448	3773.718	[illegible]	27.253	6.292	7.099
55	2.75	14.652	58.176	[illegible]	22.905	27.820	6.652	7.353
56	2.80	14.641	59.904	[illegible]	[illegible]	28.332	7.025	7.606
57	2.85	14.615	61.632	3743.451	26.080	28.785	7.411	7.857
58	2.90	14.581	[illegible]	3723.936	[illegible]	29.174	7.812	8.104
59	2.95	14.544	[illegible]	3704.684	[illegible]	[illegible]	8.226	8.349
60	3.00	14.500	[illegible]	[illegible]	[illegible]	29.739	8.655	[illegible]
61	3.05	[illegible]	[illegible]	3655.009	35.597	[illegible]	9.099	8.822
62	3.10	14.392	[illegible]	[illegible]	[illegible]	[illegible]	9.558	9.041
63	3.15	14.301	[illegible]	[illegible]	49.771	27.615	10.032	9.243
64	3.20	14.204	[illegible]	[illegible]	57.457	[illegible]	[illegible]	9.426
65	3.25	14.097	[illegible]	[illegible]	[illegible]	[illegible]	11.026	[illegible]
66	3.30	13.971	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
67	3.35	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.083	9.831
68	3.40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.637	9.911
69	3.45	[illegible]	[illegible]	[illegible]	102.240	[illegible]	13.207	9.960
70	3.50	[illegible]	175.752	3007.400	[illegible]	[illegible]	13.793	9.974
71	3.55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.397	9.952
72	3.60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.019	[illegible]
73	3.65	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.658	[illegible]
74	3.70	12.310	221.256	2654.131	158.442	-5.651	16.315	9.637
75	3.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	16.990	9.440
76	3.80	11.672	[illegible]	[illegible]	[illegible]	[illegible]	17.683	9.194
77	3.85	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18.395	[illegible]
78	3.90	10.915	[illegible]	[illegible]	[illegible]	-30.372	19.126	8.537
79	3.95	[illegible]	[illegible]	[illegible]	[illegible]	-37.833	19.875	8.122
80	4.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20.645	7.646
81	4.05	[illegible]	[illegible]	[illegible]	255.061	-53.309	21.434	7.109
82	4.10	8.967	[illegible]	1405.732	[illegible]	[illegible]	[illegible]	6.521
83	4.15	8.370	[illegible]	[illegible]	[illegible]	-67.139	23.071	[illegible]
84	4.20	7.724	[illegible]	[illegible]	284.003	-74.526	[illegible]	5.197
85	4.25	7.008	310.752	860.092	294.123	-82.229	24.790	4.459
86	4.30	[illegible]	314.209	[illegible]	304.474	-90.251	25.680	3.669
87	4.35	5.253	317.664	483.329	[illegible]	[illegible]	[illegible]	[illegible]
88	4.40	[illegible]	321.120	[illegible]	[illegible]	-107.257	27.525	1.920
89	4.45	2.363	[illegible]	[illegible]	[illegible]	-116.233	28.479	0.936

IMPACT VELOCITY EQUALS 20.0

CONE

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.54 0.67 1.14 2.13 2.34 2.45 2.47 2.34 2.69 2.86 2.92 3.19

RADIUS = 1.474 FEET
LENGTH = 5.500 FEET
WEIGHT = 1127.0 LBS
BULK WET DENSITY = 2.72
DRAG COEFFICIENT = 0.30

CONDITIONS AT THE END OF SECTION — WORK DONE IN SECTION - FOOT POUNDS

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	[illegible]	[illegible]	[illegible]	0.000	0.004	0.000	0.001
2	0.10	[illegible]	[illegible]	[illegible]	0.002	0.030	0.000	0.019
3	0.15	[illegible]	[illegible]	[illegible]	0.008	0.111	0.001	0.029
4	0.20	[illegible]	[illegible]	[illegible]	0.022	0.224	0.002	0.058
5	0.25	[illegible]	[illegible]	[illegible]	0.047	0.377	0.004	0.096
6	0.30	[illegible]	[illegible]	[illegible]	[illegible]	0.572	0.007	0.145
7	0.35	[illegible]	[illegible]	[illegible]	[illegible]	0.810	0.011	0.204
8	0.40	[illegible]	[illegible]	[illegible]	0.217	1.092	0.017	0.274
9	0.45	[illegible]	[illegible]	[illegible]	0.317	1.410	0.025	0.355
10	0.50	[illegible]	[illegible]	[illegible]	[illegible]	1.792	0.035	0.446
11	0.55	[illegible]	[illegible]	[illegible]	[illegible]	2.212	0.049	0.549
12	0.60	[illegible]	[illegible]	[illegible]	[illegible]	2.670	0.063	0.663
13	0.65	[illegible]	[illegible]	[illegible]	1.007	[illegible]	0.080	0.789
14	0.70	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.101	0.926
15	0.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.126	1.075
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.155	1.236
17	[illegible]	[illegible]	[illegible]	[illegible]	2.415	5.748	0.185	1.409
18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.511	0.221	1.594
19	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.322	0.261	1.792
20	1.00	[illegible]	[illegible]	[illegible]	[illegible]	8.183	0.305	2.001
21	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9.092	0.354	2.223
22	1.10	[illegible]	[illegible]	[illegible]	[illegible]	10.051	0.409	2.458
23	1.15	[illegible]	[illegible]	[illegible]	5.375	11.057	0.468	2.704
24	1.20	[illegible]	[illegible]	[illegible]	[illegible]	12.109	0.534	2.963
25	1.25	[illegible]	[illegible]	[illegible]	[illegible]	13.207	0.605	3.234
26	1.30	[illegible]	[illegible]	[illegible]	7.145	14.349	0.682	3.516
27	1.35	21.747	[illegible]	[illegible]	[illegible]	15.532	0.765	3.811
28	1.40	[illegible]	[illegible]	[illegible]	[illegible]	16.756	0.855	4.118
29	1.45	[illegible]	[illegible]	[illegible]	9.229	18.018	0.952	4.436
30	1.50	[illegible]	[illegible]	[illegible]	[illegible]	19.315	1.055	4.766
31	1.55	[illegible]	[illegible]	[illegible]	[illegible]	20.646	1.166	5.107
32	1.60	[illegible]	[illegible]	8389.070	[illegible]	22.007	1.285	5.459
33	1.65	[illegible]	[illegible]	8402.246	12.526	[illegible]	1.411	5.821
34	1.70	21.916	[illegible]	8412.556	13.447	24.908	1.545	6.193
35	1.75	21.925	91.332	8420.004	14.410	26.240	1.688	6.576
36	1.80	[illegible]	[illegible]	[illegible]	15.414	27.689	1.839	6.968
37	1.85	21.933	[illegible]	8425.781	16.450	29.150	1.909	7.368
38	1.90	21.931	[illegible]	8424.034	17.548	30.620	2.167	7.777
39	1.95	21.924	95.076	8419.020	18.681	32.093	2.345	8.195
40	2.00	21.914	96.012	8410.773	19.857	33.565	2.533	8.619
41	2.05	21.898	98.172	8398.949	21.345	35.016	2.730	9.051
42	2.10	21.873	101.555	[illegible]	[illegible]	36.432	2.937	9.488
43	2.15	21.852	104.940	8363.551	25.124	37.822	3.155	9.930
44	2.20	21.821	[illegible]	8339.777	27.171	39.178	3.383	10.376
45	2.25	21.784	[illegible]	8311.852	29.323	40.493	3.621	10.825

46	2.30	21.742	115.092	8279.688	31.584	41.758	3.871	11.276
47	2.35	21.694	118.476	8243.227	33.958	42.967	4.132	11.729
48	2.40	21.640	121.850	8202.414	36.446	44.113	4.404	12.182
49	2.45	21.581	125.244	8157.176	39.052	45.184	4.688	12.634
50	2.50	18.079	36.540	5724.238	11.866	35.794	4.984	9.215
51	2.55	18.066	36.900	5716.309	12.474	36.917	5.292	9.580
52	2.60	18.049	37.260	5705.969	13.100	38.014	5.613	9.947
53	2.65	18.029	37.620	5693.215	13.745	39.080	5.946	10.316
54	2.70	18.005	37.980	5678.047	14.410	40.113	6.292	10.687
55	2.75	17.977	38.340	5660.465	15.095	41.107	6.652	11.059
56	2.80	17.945	38.700	5640.477	15.802	42.060	7.025	11.431
57	2.85	17.910	39.060	5618.094	16.528	42.968	7.411	11.802
58	2.90	17.870	39.420	5593.326	17.276	43.827	7.812	12.173
59	2.95	17.827	39.780	5566.223	18.046	44.635	8.226	12.542
60	3.00	17.780	40.140	5536.755	18.837	45.384	8.655	12.909
61	3.05	17.729	42.048	5504.371	20.401	45.950	9.099	13.272
62	3.10	17.670	45.504	5468.414	22.914	46.289	9.558	13.630
63	3.15	17.604	48.960	5428.863	25.352	46.509	10.032	13.981
64	3.20	17.535	52.416	5385.723	28.016	46.608	10.521	14.322
65	3.25	17.459	55.872	5338.984	30.312	46.576	11.026	14.655
66	3.30	17.377	59.328	5288.645	33.740	46.404	11.546	14.976
67	3.35	17.288	62.784	5234.707	36.904	46.085	12.093	15.286
68	3.40	17.193	66.240	5177.185	40.097	45.617	12.637	15.582
69	3.45	17.091	69.696	5116.109	43.350	44.991	13.207	15.865
70	3.50	16.983	73.152	5051.480	46.839	44.197	13.793	16.133
71	3.55	16.863	76.608	4983.324	50.472	43.230	14.397	16.384
72	3.60	16.746	80.064	4911.680	54.256	42.099	15.019	16.617
73	3.65	16.617	83.520	4836.506	58.193	40.755	15.659	16.832
74	3.70	16.482	86.976	4758.0[illegible]1	62.294	39.238	16.315	17.028
75	3.75	16.339	90.4[illegible]	4676.113	66.533	37.521	16.990	17.202
76	3.80	16.190	9[illegible].[illegible]88	4590.863	70.942	35.603	17.683	17.354
77	3.85	16.033	97.344	4502.324	75.515	33.479	18.395	17.483
78	3.90	15.869	100.[illegible]	4410.555	80.254	31.143	19.126	17.588
79	3.95	15.697	104.256	4315.602	85.161	28.587	19.875	17.667
80	4.00	15.518	107.712	4217.531	90.240	25.807	20.645	17.719
81	4.05	15.328	113.076	4115.293	97.132	22.274	21.434	17.741
82	4.10	15.127	120.348	4007.809	105.963	17.989	22.242	17.728
83	4.15	14.91[illegible]	127.620	3[illegible].129	115.140	13.135	23.071	17.673
84	4.20	14.6[illegible]5	134.892	3777.303	124.663	8.001	23.920	17.576
85	4.25	14.444	142.164	3654.391	134.557	2.478	24.790	17.435
86	4.30	14.189	149.436	3526.426	144.907	-3.441	25.680	17.246
87	4.35	13.919	156.708	3393.500	155.426	-9.766	26.592	17.012
88	4.40	13.6[illegible]4	163.980	325[illegible].[illegible]74	166.421	-16.507	27.525	16.727
89	4.45	13.332	171.252	3113.020	177.797	-23.669	28.479	16.390
90	4.50	13.012	178.524	2965.609	189.559	-31.264	29.456	15.999
91	4.55	12.674	185.796	2813.525	201.714	-39.297	30.454	15.552
92	4.60	12.315	193.068	2656.592	214.266	-47.776	31.475	15.048
93	4.65	11.937	200.340	2495.672	227.223	-56.709	32.518	14.485
94	4.70	11.534	207.612	2330.078	240.589	-66.095	33.584	13.861
95	4.75	11.106	214.884	2160.156	254.372	-75.953	34.673	13.174
96	4.80	10.649	222.156	1986.002	268.575	-86.282	35.785	12.422
97	4.85	10.159	229.428	1807.707	283.205	-97.089	36.921	11.604
98	4.90	9.633	236.700	1625.267	298.270	-108.380	38.081	10.719
99	4.95	9.064	243.972	1439.078	313.772	-120.162	39.265	9.763
100	5.00	8.444	251.244	1248.939	329.718	-132.439	40.473	8.736
101	5.05	7.771	254.520	1057.931	340.766	-142.659	41.705	7.645
102	5.10	7.042	253.800	869.638	346.507	-150.526	42.963	6.508
103	5.15	6.237	253.080	691.423	352.458	-158.472	44.245	5.333
104	5.20	5.323	252.3[illegible]	49[illegible].244	358.346	-166.492	45.553	4.121
105	5.25	4.278	251.[illegible]	313.157	364.262	-174.570	46.886	2.868
106	5.30	2.748	250.920	132.219	370.294	-192.721	48.245	1.560

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