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PENETRATION OF FREE-FALLING
OBJECTS INTO DEEP-SEA SEDIMENTS

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PENETRATION OF FREE-FALLING OBJECTS
INTO DEEP-SEA SEDIMENTS

by

Jon William Carlmark

Thesis Advisor:

R. J. Smith

December 1971

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Penetration of Free-Falling Objects
Into Deep-sea Sediments

by

Jon William Carlmark
Lieutenant Commander, United States Navy
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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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ABSTRACT

A rational method is presented to predict the penetration of free-falling objects into deep-sea sediments by combining proven empirical theories from the field of soil mechanics with known hydrodynamic phenomena. The impact velocity of the object and the shear strength profile and density of the sediment are assumed to be known. The penetration problem was solved through the use of a computer by equating the work done during penetration to the energy of the object falling through air and impacting onto a modeled deep-sea sediment. The objects were simple geometric shapes ranging in weight from 500 to more than 1,000 pounds. The impact velocities ranged from zero to twenty feet-per-second. The results are compared with full scale tests and recommendations are made to extend the method to a water-sediment interface. The method successfully predicts the penetration of objects into weak, saturated, sediments within the accuracy of the state-of-the-art techniques for measuring the sediment mechanical properties. The impact duration time was observed to be relatively constant and independent of object velocity, shape, and weight implying that it may be a unique property of the dynamic behavior of a sediment type.

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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 interstitial 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, diagenesis 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 nonexistent. 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. The Variables Involved

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

$$f(V_o, M, A, z, e, r, S, E, \nu, \rho_s, T, \phi, w, s, \xi, \mu_w, \mu_s, c, k, \gamma, \delta, \rho_w, a_s, h) = 0 \quad (1)$$

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 phenomenological 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,

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

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 ;

$$-M\ddot{x} = c_1 + f_1(V) + f_2(V^2) + \dots + f_n(V^n) \quad (3)$$

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, $f_1, f_2, \dots, f_n$, are taken to be constants and the highest power of n assumed to be 2, then equation (3) simplifies to;

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

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,

$V = V_0$ at $t = 0$, and final conditions, $V = 0$ at $t = T$.

$$\text{Robins-Euler} \quad z = \frac{M V_0^2}{2 \alpha} \quad (\text{constant resisting force}) \quad (5)$$

$$\text{Poncelet} \quad z = \frac{M}{2 \gamma} \ln \left(1 + \frac{\gamma V_0^2}{\alpha} \right) \quad (\text{resisting forces constant and similar to fluid drag}) \quad (6)$$

$$\text{Resal} \quad z = \frac{M}{\gamma} \ln \left(1 + \frac{\gamma V_0^2}{\alpha} \right) \quad (\text{resisting forces similar to fluid viscosity and fluid drag}) \quad (7)$$

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.

$$z = \frac{P}{2 \text{ gib}} \ln \left(1 + \frac{b}{a} V_0^2 \right) \quad (8)$$

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:

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

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:

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

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];

$$M\ddot{x} = A V(t) \quad (11)$$

which has as its solution

$$x = \frac{V_0}{\alpha} (1 - e^{-\alpha t}) \quad (12)$$

where

$$\alpha = \frac{A\mu}{M} \quad (13)$$

When t goes to infinity, the maximum penetration becomes:

$$z = \frac{V_0}{\alpha} \quad (14)$$

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 1. 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 explicitly solved an equation of motion for a sphere and cylinder penetrating at high velocities into a Leda clay

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

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. Known Variables for Which Data Exists

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 standardized 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 for non plastic sediments.

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cludes 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 uncertainties 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,

$$q_d = \gamma D_t + 5.14c \quad (16)$$

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.

$$q = 1.3c N_c + \gamma D_f N_q + .6 \gamma N_\gamma \quad (17)$$

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:

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

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.

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

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;

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

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 approximately 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:

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

If the viscosity of clay is taken to be on the order of 3×10^{-3} , lbs - sec/in² [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 oversimplification, 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.

$$\sum F_x = M \frac{d^2 x}{dt^2} \quad (21)$$

Multiplication by dx gives

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

The first integral with respect to displacement is:

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

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:

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

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

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

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)

$$U = \int_{v_1}^{v_2} m' v \, dv \quad (26)$$

$$U = 1/2 m' v_2^2 - 1/2 m' v_1^2 \quad (27)$$

it follows that

$$\Delta U = 1/2 m'_1 v_2^2 - 1/2 m'_1 v_1^2 + 1/2 m' v_2^2 + U_b + U_s + U_d \quad (28)$$

- 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

$$E_2 = E_1 + PE - \Delta U = 1/2 M v_2^2 \quad (29)$$

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

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

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 straightforward 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;

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

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

The work done against drag forces was taken to be:

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

where γ = bulk wet density of the sediment

$C_{d\infty}$ = 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.

$$U_s = C_f N_c A c x \quad (32)$$

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 1. CONSTANTS AND SHAPES USED FOR COMPUTATIONS

(see next page for footnotes)

Table II. FORMULAS FOR CALCULATING ADDED MASS 4

- ¹Hoerner, S. F., Fluid Dynamic Drag, Practical Information on Aerodynamic Drag and Hydrodynamic Resistance, Chap. II, Published by the author, Midland Park, New Jersey, 1958.
- ²Terzaghi, Karl and Peck, Ralph B., Soil Mechanics in Engineering Practice, p. 172, John Wiley and Sons, 1948.
- ³Meyerhof, 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.
- ⁴Saunders, 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 threshold 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 presclected 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 PIT⁵

Depth (in)	0-3	4-7
Color (GSA No.)	5GY 6/1	5GY 6/1
Odor	H ₂ S	H ₂ S
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 SEDIMENT⁶

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

Note: The mixed loyer 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.

⁶Whelan, 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 SEDIMENT⁷

<u>OXIDE</u>	<u>PERCENTAGE</u>
Si O ₂	48.34
Al ₂ O ₃	18.26
Fe ₂ O ₃	7.88
MgO	2.98
CaO	1.92
K ₂ O	2.74
Na ₂ O	3.02
H ₂ O	2.78
L.O.I.	<u>9.67</u>
Total	97.59
Surface H ₂ O	73.01

⁷Whelan, op. cit., p. 8a.

TABLE VI. RANGE OF VARIATION OF TEST PIT SEDIMENT⁸

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

RANGE OF VARIATION (42 TESTS)

	<u>MINIMUM</u>	<u>MAXIMUM</u>	<u>AVERAGE</u>
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)."

⁸Muga, 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

----- mean
[shaded area] one standard deviation from mean
—— average shear strength from
114 cores from water depths
greater than 6,000
[Hoag, 1970]

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	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	1.56	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	2.38	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	3.86	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"
5.0	b	<u>1.18</u>	.54	.49	<u>3.11</u>	2.49	1.79	1.72	2.08	1.44	1.31	1.28	1.28
"	c	<u>.95</u>	.67	.82	<u>1.88</u>	3.03	3.15	2.96	1.80	2.57	2.12	1.62	2.10
10.0	30	.22	.15	.31	<u>3.25</u>	<u>7.50</u>	<u>6.30</u>	<u>6.90</u>	<u>4.92</u>	<u>8.70</u>	<u>3.65</u>	<u>3.01</u>	<u>2.49</u>
"	a	<u>.17</u>	.35	.66	<u>2.28</u>	<u>4.78</u>	<u>5.00</u>	<u>8.46</u>	<u>5.80</u>	<u>6.11</u>	<u>5.45</u>	<u>3.27</u>	<u>3.29</u>
"	b	.45	.19	.22	<u>.34</u>	<u>.75</u>	<u>3.45</u>	<u>8.32</u>	<u>9.46</u>	<u>7.64</u>	<u>4.63</u>	<u>2.92</u>	<u>4.93</u>
"	c	.33	.24	.69	<u>2.33</u>	<u>2.19</u>	<u>2.49</u>	<u>4.38</u>	<u>3.81</u>	<u>2.92</u>	<u>3.15</u>	<u>3.67</u>	<u>3.59</u>
15.0	31	<u>.15</u>	.15	.20	.55	1.14	1.68	2.45	1.79	7.26	3.76	5.79	5.35
"	a	<u>.10</u>	.15	.41	1.20	2.26	1.60	1.74	5.43	8.93	9.90	4.47	4.85
"	b	<u>.28</u>	.15	.17	.24	.80	1.32	1.11	2.71	2.40	3.80	3.38	4.01
"	c	.70	.43	.33	<u>1.04</u>	2.89	2.07	4.12	5.91	6.66	5.46	5.02	3.57
20.0	32	.36	.38	.76	1.32	1.60	6.32	<u>5.70</u>	<u>2.60</u>	2.23	2.36	2.54	5.80
"	a	.43	.73	1.03	2.16	2.30	<u>5.35</u>	<u>2.34</u>	3.01	2.64	2.85	3.72	3.80
"	b	.66	1.01	.87	<u>7.20</u>	<u>4.94</u>	<u>2.82</u>	2.17	1.97	2.54	2.80	2.74	4.13
"	c	<u>1.39</u>	.54	1.91	2.86	2.97	<u>3.59</u>	1.60	1.76	3.34	3.45	2.66	3.16

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OTHER MEASUREMENTS													
39		<u>1.57</u>	1.22	1.13	.87	<u>.70</u>	<u>.68</u>	.68	1.57	2.61	2.18	3.27	1.94
41		<u>.69</u>	.73	.73	1.57	<u>1.58</u>	<u>1.57</u>	5.90	7.65	2.36	2.70	2.65	2.78
-		<u>.67</u>	.60	.45	.90	<u>1.40</u>	<u>1.56</u>	<u>1.75</u>	<u>1.50</u>	1.25	1.90	1.75	1.60
18		<u>.20</u>	.45	.85	1.05	<u>1.05</u>	<u>1.45</u>	<u>1.65</u>	<u>1.40</u>	1.25	1.20	1.15	1.30
a		<u>.40</u>	.65	.65	.75	<u>.85</u>	<u>.85</u>	<u>.75</u>	<u>.90</u>	.90	.20	.35	.60
b		<u>.60</u>	1.20	.85	.85	<u>1.00</u>	<u>1.00</u>	<u>1.10</u>	<u>1.20</u>	.90	.70	.70	1.00
c		<u>.80</u>	1.20	1.85	1.70	<u>1.15</u>	<u>1.10</u>	<u>1.15</u>	<u>1.30</u>	1.15	<u>1.00</u>	<u>3.20</u>	1.70
21		<u>.10</u>	.15	.35	.60	<u>1.00</u>	<u>1.05</u>	<u>1.00</u>	<u>.80</u>	.60	.40	.90	2.50
a		<u>.30</u>	.70	1.10	1.20	<u>1.00</u>	<u>1.05</u>	<u>1.15</u>	<u>.85</u>	.95	1.30	1.90	2.90
b		<u>.40</u>	.85	1.20	1.60	<u>2.05</u>	<u>1.50</u>	<u>1.10</u>	.95	1.10	1.30	2.15	2.90
c		<u>.60</u>	1.05	1.25	1.65	<u>2.25</u>	<u>1.65</u>	<u>1.25</u>	1.20	1.45	1.75	2.60	3.25
24		<u>.40</u>	1.05	.80	.90	<u>1.05</u>	<u>.80</u>	<u>.80</u>	<u>1.35</u>	1.40	.90	.75	.90
a		<u>.60</u>	1.40	1.20	1.15	<u>1.20</u>	<u>1.20</u>	<u>1.20</u>	<u>1.50</u>	1.60	<u>1.80</u>	<u>1.35</u>	1.50
b		<u>1.10</u>	1.75	2.15	2.05	<u>1.35</u>	<u>1.75</u>	<u>1.60</u>	<u>1.60</u>	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		DIFFERENCE (in)
	OBSERVED (in)	PREDICTED (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		DIFFERENCE (in)
	OBSERVED (in)	PREDICTED (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 consistently 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

SPHERE
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	
0.0	10.7	+1.2	15	.25	$\frac{1}{2}$	.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	$\frac{1}{2}$	.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	$\frac{1}{2}$	.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	$2\frac{1}{2}$	.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	
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	
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	$\frac{1}{2}$	.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)

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	TIME TO PENETRATE (sec)	REBOUND DISTANCE (in)	TIME FOR REBOUND (sec)	PERCENT ULTIMATE BEARING CAPACITY	SHEAR STRENGTH ADJUSTED	
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	----

TABLE X. (CONTINUED)

CUBE
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	
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	$\frac{1}{2}$	.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)

RECTANGLE
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	RECTANGLE
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	$\frac{1}{2}$	.12	366	no	----
10.0	9.4	+0.2	14	.22	$\frac{1}{2}$	.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	$1\frac{1}{2}$	.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 abscissa 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.

HORIZONTAL CYLINDER $V_o = 0.0$ fps

HORIZONTAL CYLINDER $V_o = 20.0$ fps

CYLINDER ON END $V_o = 20.0$ fps

CUBE $V_o = 10.0$ 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

o observed
x adjusted

SPHERE
Velocity 5.0 fps
Station 7

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

SPHERE
Velocity 10.0 fps
Station 9

SPHERE
Velocity 15.0 fps
Station 20

○ observed
× adjusted
--- mean
--- shear strength used
shaded area one standard deviation from mean

o observed
 x adjusted
 ----- mean
 shaded area one standard deviation from mean

SPHERE
Velocity 10.0 fps
Station -

o observed
x adjusted

----- mean
----- one standard deviation from mean

SPHERE
Velocity 15.0 fps
Station -

o observed
x adjusted

----- mean
----- one standard deviation from mean

SPHERE
Velocity 20.0 fps
Station -

o observed
x adjusted

--- mean
shaded area one standard deviation from mean

HORIZONTAL CYLINDER
Velocity 0.0 fps
Station 23

7.31
10.11
5.57

HORIZONTAL CYLINDER
Velocity 5.0 fps
Station 15

HORIZONTAL CYLINDER
Velocity 10.0 fps
Station 21

o observed
 x adjusted
 ----- mean
 shaded area one standard deviation from mean

HORIZONTAL CYLINDER
Velocity 15.0 fps
Station 16

HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 22

o observed
 x adjusted
 ----- mean
 shaded area one standard deviation from mean

HORIZONTAL CYLINDER
Velocity 20.0 fps
Station 12

○ observed
× adjusted

CYLINDER ON END
Velocity 5.0 fps
Station -

--- mean
shaded region one standard deviation from mean

CYLINDER ON END
Velocity 15.0 fps
Station -

CYLINDER ON END
Velocity 10.0 fps
Station -

o observed
 x adjusted
 --- mean
 shaded area one standard deviation from mean

CYLINDER ON END
Velocity 0.0 fps
Station 22

CYLINDER ON END
Velocity 20.0 fps
Station -

○ observed
x adjusted
----- mean
----- shear strength used
shaded region one standard deviation from mean

CYLINDER ON END
Velocity 5.0 fps
Station 14

CYLINDER ON END
Velocity 10.0 fps
Station 16

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

CYLINDER ON END
Velocity 15.0 fps
Station 21

CYLINDER ON END
Velocity 15.0 fps
Station 12

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

CYLINDER ON END
Velocity 5.0 fps
Station 20

CYLINDER ON END
Velocity 20.0 fps
Station 11

o observed
 x adjusted
 ----- mean
 shaded area one standard deviation from mean

5.54 →

SHEAR STRENGTH (psi)

SHEAR STRENGTH (psi)

CYLINDER ON END
Velocity 10.0 fps
Station 25

CYLINDER ON END
Velocity 15.0 fps
Station 19

○ observed
× adjusted
----- mean
shaded area one standard deviation from mean

○ observed
 × adjusted
 ----- mean
 shaded area one standard deviation from mean

CUBE
Velocity 15.0 fps
Station -

CUBE
Velocity 10.0 fps
Station -

○ observed
× adjusted
----- mean
shaded area one standard deviation from mean

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

RECTANGLE
Velocity 10.0 fps
Station 11

RECTANGLE
Velocity 5.0 fps
Station 13

o observed
 x adjusted
 ----- mean
 [shaded area] one standard deviation from mean

○ observed
x adjusted
--- mean
shaded area one standard deviation from mean
— shear strength used

RECTANGLE
 Velocity 20.0 fps
 Station 18

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

○ observed
× adjusted

----- mean
shaded area one standard deviation from mean

----- mean
shaded area 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 SUMSUB( )WORK DONE BY SUBMERGED SECTIONS TO SECTION( )
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
C 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 INPUT DATA ON OBJECT
C OBJECT SPHERE
C RAD=1.192
C WT=561.402/G
C BWD=87.402/G
C CFOOT=1.3
C CNC=5.7
C COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
C COH=43.2
C FOR A SPHERE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
C CD=0.3
C
C SET INCREMENT
C DX=.05
C
C CALCULATE THE SECTION PROPERTIES,AVERAGE PROJECTED AREA,VOLUME
C FIND AREA AT MIDPOINT OF EACH SECTION
C Y=0,STANCE ABOVE BOTTOM OF SPHERE
C Y=DX/2,
C YMAX=2*RAD
C Z=RAD/DX
C N=Z+1.
C THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
C AREA(1)=PI*(RAD**2-(RAD-Y)**2)
C DO 100 I=2,N
C AREA(I)=PI*(RAD**2--(RAD-(I-1)*DX-Y)**2)
C 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

```



```

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

```



```

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

CC
CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
BMASS=WT/G
E(1)=BMASS*VO**2/2.

CC
CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
EP=WT*DX

CCCC
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

CC
VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
V(1)=0.0
DO 2000 I=1,100
SECTION TO COMPUTE SHEAR STRENGTH
NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
FOR THE SPHERE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
TION DEPTH MINUS ONE HALF THE PENETRATION DEPTH UP TO THE MAX RAD
DEPTH=I*DX-Y-(I*DX-Y)/2
WHEN THE MAX PAD IS REACHED THE DEPTH EQUALS PENETRATION DEPTH
MINUS ONE HALF THE RADIUS
IF((I*DX-Y).GT.(RAD) DEPTH=I*DX-Y-RAD/2.
CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH DATA
DEPTHI=DEPTH*12.

CC
SELECT PROPER DEPTH

```


C

```

IF(DEPTH.LE.0.5) 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 C C

FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
AVERAGE OF THE LAST THREE AND CALL IT CONSTANT

```
IF(DEPTH.GT.4.0) GO TO 9
```

C C C C C

FORMULAS FOR SHEAR STRENGTH FOLLOW
LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED

```

1 SSS=SLOPE1*DEPTH
2 GO TO 10
3 SSS=SLOPE2*DEPTH+BINT2
4 GO TO 10
5 SSS=SLOPE3*DEPTH+BINT3
6 GO TO 10
7 SSS=SLOPE4*DEPTH+BINT4
8 GO TO 10
9 SSS=SLOPE5*DEPTH+BINT5
10 GO TO 10
11 SSS=SLOPE6*DEPTH+BINT6
12 GO TO 10
13 SSS=SLOPE7*DEPTH+BINT7
14 GO TO 10
15 SSS=SLOPE8*DEPTH+BINT8
16 GO TO 10
17 SSS=(SS30+SS305+SS40)/3.

```

C C

SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT

C C C

SPS=SSS*144.
CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
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*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
CALCULATE E AT NEXT SECTION
E(I+1)=BMASS*V(I+1)**2/2.
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
COMPUTE PENETRATION DEPTH
XXX=I*DX
C
PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
WORKDONE BY SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
AND DRAG
WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
CONTINUE
CONTINUE
1000 FORMAT(I5)
2050 FORMAT(F5.1,I3)
2060 FORMAT(F5.1,I3)
2100 FORMAT(F5.1,I3)
2100 FORMAT(F5.1,I3)
2200 FORMAT(F5.1,I3)
2200 FORMAT(F5.1,I3)
2300 2LBS/9X,BULK WET DENSITY = ,F5.2,SLUGS PER CUBIC FOOT',F7.1,
3 COEFFICIENT = ,F5.2,IMPACT VELOCITY EQUALS',F5.1//10X,SEDIMENT SHEAR
2300 2 STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE//15X,8F6.2//)
2500 2N SECTION - FOOT CONDITIONS AT THE END OF SECTION,19X,WORK DONE I
3 LOCITY',3X,SHEAR,5X,POUNDS//16X,ITERATION,1X,PENETRATION,4X,VE
4 BUOYANT,3X,FORM DRAG,17X,ENERGY,6X,STATIC,4X,SEDIMENT,5X,ST
5 FORCES PSF,4X,FT-LBS,7X,FORCES,4X,INERTIA,6X,FORCES,4X,
6 FORCES//)
2600 2600 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

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	WORK DONE IN SECTION - FOOT POUNDS			
					STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	1.787	1.080	27.832	0.074	0.121	0.020	0.003
2	0.10	2.482	1.240	53.126	0.553	1.352	0.100	0.051
3	0.15	3.971	1.400	76.958	1.775	2.628	0.156	0.135
4	0.20	5.335	1.560	96.945	3.402	3.928	0.246	0.246
5	0.25	6.605	1.720	113.323	5.496	5.017	0.375	0.375
6	0.30	7.800	1.880	125.579	8.020	5.801	0.510	0.510
7	0.35	8.929	1.940	139.415	10.936	6.205	0.641	0.641
8	0.40	9.978	1.960	140.492	14.792	6.711	0.758	0.758
9	0.45	10.978	1.960	140.492	17.658	7.263	0.856	0.856
10	0.50	11.900	1.960	137.956	21.574	7.753	0.959	0.959
11	0.55	12.751	2.040	122.700	25.074	8.110	1.075	1.075
12	0.60	13.558	2.120	110.373	30.550	8.439	1.205	1.205
13	0.65	14.304	2.200	95.171	34.154	8.710	1.348	1.348
14	0.70	14.977	2.290	77.286	39.187	8.939	1.505	1.505
15	0.75	15.551	2.380	56.908	43.847	9.129	1.674	1.674
16	0.80	16.031	2.470	34.206	48.594	9.289	1.854	1.854
17	0.85	16.437	2.560	9.370	53.355	9.430	2.045	2.045
18	0.90	16.767	2.650	37.800	58.093	9.567	2.249	2.249

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 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
0.36 1.04 1.03 1.56 2.41 2.68 2.61 2.16

WORK DONE IN SECTION - FOOT POUNDS									
CONDITIONS AT THE END OF SECTION									
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	1.295	244.746	0.089	1.060	0.020	0.100	0.100
2	0.10	5.534	3.088	266.986	0.784	4.600	0.100	0.325	0.325
3	0.15	5.716	6.480	285.987	2.130	8.989	0.256	0.573	0.573
4	0.20	5.855	9.072	298.890	4.082	8.849	0.486	0.830	0.830
5	0.25	5.946	11.656	306.250	5.595	10.192	0.785	1.084	1.084
6	0.30	5.994	14.254	313.858	9.624	10.983	1.151	1.326	1.326
7	0.35	6.005	16.848	320.573	13.123	11.323	1.580	1.544	1.544
8	0.40	6.091	19.440	327.570	17.051	11.376	2.068	1.730	1.730
9	0.45	6.178	22.032	330.240	21.351	9.878	2.612	1.881	1.881
10	0.50	6.263	24.624	332.573	25.917	8.378	3.209	1.981	1.981
11	0.55	6.329	27.216	335.353	30.989	6.902	3.856	2.041	2.041
12	0.60	6.390	29.808	337.573	36.460	5.577	4.548	2.095	2.095
13	0.65	6.439	32.400	339.064	41.494	4.321	5.282	2.141	2.141
14	0.70	6.480	35.000	340.832	46.917	3.217	6.064	2.185	2.185
15	0.75	6.519	37.600	342.832	51.836	2.265	6.875	2.229	2.229
16	0.80	6.558	40.176	345.036	56.247	1.535	7.704	2.274	2.274
17	0.85	6.598	42.768	347.356	60.125	1.059	8.549	2.318	2.318
18	0.90	6.636	45.360	349.781	63.481	0.769	9.409	2.363	2.363
19	0.95	6.675	47.952	352.316	66.321	0.559	10.280	2.407	2.407
20	1.00	6.715	50.544	354.936	68.641	0.409	11.160	2.451	2.451

SPHERE

RAQIUS = 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	509	0.121	3.878	0.020	0.383
2	0.105	10.199	5.292	509	1.067	14.349	0.100	1.146
3	0.15	10.216	8.220	509	1.899	20.019	0.256	1.985
4	0.205	10.192	12.548	509	5.556	23.645	0.485	3.216
5	0.305	10.131	15.976	488	8.977	23.845	0.785	3.282
6	0.35	10.008	16.404	488	13.099	25.762	1.151	3.268
7	0.40	9.749	22.932	488	17.203	26.553	1.580	4.669
8	0.45	9.560	26.460	488	23.061	25.330	2.068	4.980
9	0.50	9.342	33.516	477	35.374	23.195	2.612	5.198
10	0.55	9.094	37.044	477	42.082	20.250	3.209	5.355
11	0.60	8.817	40.572	463	49.121	16.311	3.856	5.297
12	0.65	8.510	44.100	452	56.431	12.506	4.582	5.151
13	0.70	8.170	47.628	441	63.951	7.263	5.055	4.921
14	0.75	7.797	51.154	414	71.617	2.332	6.064	4.613
15	0.80	7.385	54.684	389	79.370	-9.197	7.704	4.283
16	0.85	6.931	58.210	328	87.186	-15.253	9.469	3.782
17	0.90	6.428	61.740	227	95.506	-21.424	11.320	3.279
18	0.95	5.863	65.268	111	102.038	-27.826	13.270	2.702
19	1.00	5.250	68.798	22	110.523	-33.389	15.231	2.146
20	1.05	4.575	72.358	1	116.523	-39.696	17.231	1.603
21	1.10	3.864	75.960	1	124.634	-48.700	19.200	1.080

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.30 0.37 0.45 2.44 2.73 2.78 2.86 3.14

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
DRAG COEFFICIENT = 0.36

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	1.020	1980.215	0.074	8.576	0.020	0.854
2	0.15	12.948	3.200	11974.411	0.675	30.629	0.100	2.516
3	0.25	11.456	7.560	11954.218	1.402	41.899	0.256	4.076
4	0.35	11.4709	9.820	11886.266	5.496	48.844	0.486	5.511
5	0.45	11.4342	11.620	11842.166	8.020	52.972	0.785	6.952
6	0.55	11.4137	11.620	11774.179	10.936	54.280	1.151	7.897
7	0.65	11.3907	11.620	11686.292	14.202	55.230	1.580	8.797
8	0.75	11.3670	11.620	11629.354	17.758	55.230	2.068	9.500
9	0.85	11.3423	11.620	11570.589	21.654	52.080	2.612	10.064
10	0.95	11.3167	11.620	11511.595	25.764	49.309	3.209	10.495
11	1.05	11.2903	11.620	11451.536	30.074	45.012	3.856	11.002
12	1.15	11.2633	11.620	11391.046	34.550	41.284	4.548	11.491
13	1.25	11.2369	11.620	11330.416	39.157	36.237	5.285	11.971
14	1.35	11.2106	11.620	11269.723	43.894	31.947	6.055	12.430
15	1.45	11.1843	11.620	11209.075	48.594	25.908	6.864	12.877
16	1.55	11.1578	11.620	11148.877	53.355	20.984	7.704	13.306
17	1.65	11.1314	11.620	11088.855	58.093	14.984	8.574	13.715
18	1.75	11.1051	11.620	11028.875	62.771	9.916	9.469	14.107
19	1.85	11.0788	11.620	10968.875	67.455	3.526	10.337	14.479
20	1.95	11.0525	11.620	10908.875	71.997	-1.809	11.170	14.835
21	2.05	11.0262	11.620	10848.875	76.398	-6.180	11.953	15.177
22	2.15	10.9999	11.620	10788.875	80.731	-10.809	12.686	15.506
23	2.25	10.9736	11.620	10728.875	84.985	-13.454	13.371	15.829
24	2.35	10.9473	11.620	10668.875	89.184	-16.113	14.006	16.146
25	2.45	10.9210	11.620	10608.875	93.331	-18.809	14.591	16.456
26	2.55	10.8947	11.620	10548.875	97.427	-21.454	15.127	16.756
27	2.65	10.8684	11.620	10488.875	101.464	-24.065	15.612	17.046
28	2.75	10.8421	11.620	10428.875	105.451	-26.622	16.047	17.327
29	2.85	10.8158	11.620	10368.875	109.388	-29.134	16.432	17.599
30	2.95	10.7895	11.620	10308.875	113.275	-31.591	16.767	17.864
31	3.05	10.7632	11.620	10248.875	117.121	-34.004	17.052	18.121
32	3.15	10.7369	11.620	10188.875	120.927	-36.375	17.287	18.371
33	3.25	10.7106	11.620	10128.875	124.694	-38.704	17.472	18.614
34	3.35	10.6843	11.620	10068.875	128.421	-40.991	17.617	18.851
35	3.45	10.6580	11.620	10008.875	132.108	-43.236	17.712	19.084
36	3.55	10.6317	11.620	9948.875	135.755	-45.444	17.757	19.314
37	3.65	10.6054	11.620	9888.875	139.364	-47.614	17.752	19.544
38	3.75	10.5791	11.620	9828.875	142.933	-49.745	17.697	19.769
39	3.85	10.5528	11.620	9768.875	146.462	-51.836	17.592	19.989
40	3.95	10.5265	11.620	9708.875	150.051	-53.887	17.437	20.204
41	4.05	10.5002	11.620	9648.875	153.590	-55.898	17.232	20.414
42	4.15	10.4739	11.620	9588.875	157.189	-57.869	16.977	20.619
43	4.25	10.4476	11.620	9528.875	160.748	-59.800	16.672	20.819
44	4.35	10.4213	11.620	9468.875	164.267	-61.691	16.317	21.014
45	4.45	10.3950	11.620	9408.875	167.746	-63.542	15.912	21.204
46	4.55	10.3687	11.620	9348.875	171.185	-65.353	15.457	21.389
47	4.65	10.3424	11.620	9288.875	174.584	-67.124	14.952	21.569
48	4.75	10.3161	11.620	9228.875	177.943	-68.855	14.397	21.744
49	4.85	10.2898	11.620	9168.875	181.262	-70.546	13.792	21.914
50	4.95	10.2635	11.620	9108.875	184.541	-72.197	13.137	22.079
51	5.05	10.2372	11.620	9048.875	187.780	-73.808	12.432	22.239
52	5.15	10.2109	11.620	8988.875	190.981	-75.379	11.677	22.394
53	5.25	10.1846	11.620	8928.875	194.142	-76.910	10.872	22.544
54	5.35	10.1583	11.620	8868.875	197.263	-78.401	10.017	22.689
55	5.45	10.1320	11.620	8808.875	200.344	-79.852	9.112	22.829
56	5.55	10.1057	11.620	8748.875	203.385	-81.263	8.157	22.964
57	5.65	10.0794	11.620	8688.875	206.386	-82.634	7.152	23.094
58	5.75	10.0531	11.620	8628.875	209.347	-83.965	6.097	23.219
59	5.85	10.0268	11.620	8568.875	212.268	-85.256	5.092	23.339
60	5.95	10.0005	11.620	8508.875	215.149	-86.507	4.037	23.454
61	6.05	9.9742	11.620	8448.875	217.990	-87.718	2.932	23.564
62	6.15	9.9479	11.620	8388.875	220.791	-88.889	1.777	23.669
63	6.25	9.9216	11.620	8328.875	223.552	-89.920	0.572	23.769
64	6.35	9.8953	11.620	8268.875	226.273	-90.911	-0.683	23.864
65	6.45	9.8690	11.620	8208.875	228.954	-91.862	-1.428	23.954
66	6.55	9.8427	11.620	8148.875	231.595	-92.773	-2.173	24.039
67	6.65	9.8164	11.620	8088.875	234.196	-93.644	-2.918	24.119
68	6.75	9.7901	11.620	8028.875	236.757	-94.475	-3.663	24.194
69	6.85	9.7638	11.620	7968.875	239.278	-95.266	-4.408	24.264
70	6.95	9.7375	11.620	7908.875	241.759	-96.017	-5.153	24.329
71	7.05	9.7112	11.620	7848.875	244.190	-96.728	-5.898	24.389
72	7.15	9.6849	11.620	7788.875	246.581	-97.399	-6.643	24.444
73	7.25	9.6586	11.620	7728.875	248.932	-98.030	-7.388	24.494
74	7.35	9.6323	11.620	7668.875	251.243	-98.621	-8.133	24.539
75	7.45	9.6060	11.620	7608.875	253.514	-99.172	-8.878	24.579
76	7.55	9.5797	11.620	7548.875	255.745	-99.683	-9.623	24.614
77	7.65	9.5534	11.620	7488.875	257.936	-100.154	-10.368	24.644
78	7.75	9.5271	11.620	7428.875	260.087	-100.585	-11.113	24.669
79	7.85	9.5008	11.620	7368.875	262.198	-100.976	-11.858	24.689
80	7.95	9.4745	11.620	7308.875	264.269	-101.327	-12.603	24.704
81	8.05	9.4482	11.620	7248.875	266.300	-101.638	-13.348	24.719
82	8.15	9.4219	11.620	7188.875	268.291	-101.909	-14.093	24.729
83	8.25	9.3956	11.620	7128.875	270.242	-102.140	-14.838	24.734
84	8.35	9.3693	11.620	7068.875	272.153	-102.331	-15.583	24.739
85	8.45	9.3430	11.620	7008.875	274.024	-102.482	-16.328	24.739
86	8.55	9.3167	11.620	6948.875	275.855	-102.593	-17.073	24.734
87	8.65	9.2904	11.620	6888.875	277.646	-102.664	-17.818	24.719
88	8.75	9.2641	11.620	6828.875	279.397	-102.695	-18.563	24.689
89	8.85	9.2378	11.620	6768.875	281.108	-102.686	-19.308	24.644
90	8.95	9.2115	11.620	6708.875	282.779	-102.637	-20.053	24.579
91	9.05	9.1852	11.620	6648.875	284.410	-102.548	-20.798	24.494
92	9.15	9.1589	11.620	6588.875	285.991	-102.419	-21.543	24.389
93	9.25	9.1326	11.620	6528.875	287.532	-102.250	-22.288	24.264
94	9.35	9.1063	11.620	6468.875	289.033	-102.041	-23.033	24.119
95	9.45	9.0800	11.620	6408.875	290.494	-101.792	-23.778	23.954
96	9.55	9.0537	11.620	6348.875	291.915	-101.503	-24.523	23.769
97	9.65	9.0274	11.620	6288.875	293.296	-101.174	-25.268	23.564
98	9.75	9.0011	11.620	6228.875	294.637	-100.805	-26.013	23.339
99	9.85	8.9748	11.620	6168.875	295.938	-100.396	-26.758	23.094
100	9.95	8.9485	11.620	6108.875	297.199	-100.947	-27.503	22.829
101	10.05	8.9222	11.620	6048.875	298.420	-101.458	-28.248	22.544
102	10.15	8.8959	11.620	5988.875	299.601	-101.929	-28.993	22.239

SPHERE

RADIUS = 1.192
 WEIGHT = 561.0 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
 0.40 0.52 1.08 1.51 1.74 1.95 2.11 2.44

CONDITIONS AT THE END OF SECTION

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	WORK DONE IN SECTION - FOOT POUNDS			
					STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	5.298	1.440	246.736	0.099	1.060	0.020	0.100
2	0.15	5.533	4.320	266.832	0.871	4.597	0.100	0.325
3	0.25	5.715	7.200	284.773	2.366	6.973	0.256	0.572
4	0.35	5.849	10.080	298.171	4.328	8.802	0.486	0.828
5	0.45	5.933	12.960	306.930	7.293	10.600	0.785	1.081
6	0.55	5.968	15.840	311.050	10.263	10.795	1.151	1.338
7	0.65	5.919	18.720	310.547	14.581	10.887	1.580	1.607
8	0.75	5.828	21.600	305.476	18.941	10.358	2.068	1.891
9	0.85	5.694	24.480	296.164	23.727	9.695	2.609	2.180
10	0.95	5.515	27.360	282.664	28.873	7.227	3.209	2.507
11	1.05	5.292	30.240	265.310	34.093	5.243	3.856	2.848
12	1.15	5.022	33.120	244.864	40.097	2.743	4.548	3.198
13	1.25	4.696	35.980	219.239	46.063	-0.743	5.285	3.550
14	1.35	4.306	38.820	192.641	52.205	-4.334	6.053	3.907
15	1.45	3.835	41.640	161.285	58.463	-8.244	6.864	4.178
16	1.55	3.291	44.440	128.373	64.792	-12.417	7.705	4.327
17	1.65	2.692	47.220	92.370	71.140	-16.791	8.574	4.364
18	1.75	2.052	50.000	54.100	77.458	-21.303	9.469	4.200
19	1.85	1.252	52.800	13.656	83.695	-25.890	10.385	3.904

SPHERE

RADIUS = 1.192
 WEIGHT = 561.0 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

0.69 0.66 0.77 1.39 1.56 2.05 2.44 3.01

CONDITIONS AT THE END OF SECTION

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	2.484	895.460	0.171	3.878	0.020	0.383
2	0.10	10.196	7.452	906.428	1.502	19.933	0.100	1.145
3	0.15	10.207	17.420	908.317	4.082	19.933	0.256	1.885
4	0.20	10.272	17.358	908.049	7.084	25.435	0.486	2.572
5	0.25	10.093	22.324	888.129	12.645	25.435	0.785	3.197
6	0.30	9.912	27.292	867.134	18.445	25.435	1.151	3.744
7	0.35	9.816	33.260	839.179	25.152	25.435	1.580	4.199
8	0.40	9.665	37.228	804.841	32.922	23.907	2.068	4.556
9	0.45	9.508	42.196	764.941	40.818	15.837	2.612	4.800
10	0.50	9.354	47.164	718.055	49.813	10.837	3.209	4.981
11	0.55	9.201	52.132	612.405	59.846	5.035	3.825	4.901
12	0.60	9.059	57.100	558.167	69.905	1.339	4.471	4.711
13	0.70	7.983	62.068	428.924	90.846	-1.339	5.064	4.417
14	0.80	6.943	72.036	320.574	100.715	-15.837	5.645	4.023
15	0.85	6.325	77.004	274.140	112.615	-31.528	6.205	3.520
16	0.90	5.748	86.972	196.521	123.615	-31.528	6.704	3.273
17	0.95	5.250	96.876	116.333	134.615	-37.047	7.174	2.948
18	1.00	4.856	96.876	33.333	145.615	-37.047	7.574	2.528
19		4.516					7.949	
20		4.250					8.290	
							8.645	
							9.010	
							9.385	
							9.760	
							10.135	
							10.510	
							10.885	
							11.260	

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	14.973	1.040	1954.567	0.610	30.907	0.020	0.516
3	0.15	14.857	1.056	1928.576	1.175	48.867	0.020	0.247
4	0.20	14.711	1.078	1884.881	1.300	55.065	0.020	0.512
5	0.25	14.549	1.088	1843.875	2.485	55.434	0.020	0.679
6	0.30	14.342	1.104	1774.148	10.207	55.434	1.150	0.956
7	0.40	14.128	1.122	1693.506	10.259	52.409	1.068	0.807
8	0.50	13.968	1.152	1606.226	16.217	45.464	2.209	0.517
9	0.55	13.846	1.164	1555.457	22.047	45.464	2.209	0.517
10	0.60	13.733	1.180	1519.457	22.047	45.464	2.209	0.517
11	0.65	13.624	1.200	1457.397	32.243	32.243	3.345	0.849
12	0.70	13.528	1.228	1397.397	32.243	32.243	3.345	0.849
13	0.75	13.443	1.264	1338.086	40.254	22.160	5.667	1.121
14	0.80	13.370	1.300	1282.086	40.254	22.160	5.667	1.121
15	0.85	13.308	1.336	1230.086	40.254	22.160	5.667	1.121
16	0.90	13.256	1.372	1182.086	58.861	16.243	7.704	1.121
17	0.95	13.213	1.408	1138.086	58.861	16.243	7.704	1.121
18	1.00	13.179	1.444	1098.086	66.745	0.690	9.485	1.121
19	1.05	13.153	1.480	1062.086	66.745	0.690	9.485	1.121
20	1.10	13.134	1.516	1030.086	66.745	0.690	9.485	1.121
21	1.15	13.121	1.552	1002.086	66.745	0.690	9.485	1.121
22	1.20	13.113	1.588	978.086	66.745	0.690	9.485	1.121
23	1.25	13.110	1.624	958.086	66.745	0.690	9.485	1.121
24	1.30	13.110	1.660	942.086	66.745	0.690	9.485	1.121
25	1.35	13.110	1.696	930.086	66.745	0.690	9.485	1.121
26	1.40	13.110	1.732	922.086	66.745	0.690	9.485	1.121
27	1.45	13.110	1.768	918.086	66.745	0.690	9.485	1.121
28	1.50	13.110	1.804	918.086	66.745	0.690	9.485	1.121
29	1.55	13.110	1.840	918.086	66.745	0.690	9.485	1.121
30	1.60	13.110	1.876	918.086	66.745	0.690	9.485	1.121
31	1.65	13.110	1.912	918.086	66.745	0.690	9.485	1.121
32	1.70	13.110	1.948	918.086	66.745	0.690	9.485	1.121
33	1.75	13.110	1.984	918.086	66.745	0.690	9.485	1.121
34	1.80	13.110	2.020	918.086	66.745	0.690	9.485	1.121
35	1.85	13.110	2.056	918.086	66.745	0.690	9.485	1.121
36	1.90	13.110	2.092	918.086	66.745	0.690	9.485	1.121
37	1.95	13.110	2.128	918.086	66.745	0.690	9.485	1.121
38	2.00	13.110	2.164	918.086	66.745	0.690	9.485	1.121

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72 SLUGS 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	349.87	0.129	15.153	0.020	15.13
2	0.15	19.943	1.536	346.71	0.137	15.336	0.100	14.431
3	0.25	19.785	1.360	344.12	0.136	15.336	0.100	14.431
4	0.35	19.630	1.248	342.57	0.136	15.336	0.100	14.431
5	0.45	19.475	1.160	341.04	0.136	15.336	0.100	14.431
6	0.55	19.320	1.098	339.52	0.136	15.336	0.100	14.431
7	0.65	19.165	1.048	338.02	0.136	15.336	0.100	14.431
8	0.75	19.010	1.008	336.53	0.136	15.336	0.100	14.431
9	0.85	18.855	0.978	335.05	0.136	15.336	0.100	14.431
10	0.95	18.700	0.958	333.58	0.136	15.336	0.100	14.431
11	1.05	18.545	0.948	332.12	0.136	15.336	0.100	14.431
12	1.15	18.390	0.948	330.67	0.136	15.336	0.100	14.431
13	1.25	18.235	0.948	329.22	0.136	15.336	0.100	14.431
14	1.35	18.080	0.948	327.77	0.136	15.336	0.100	14.431
15	1.45	17.925	0.948	326.32	0.136	15.336	0.100	14.431
16	1.55	17.770	0.948	324.87	0.136	15.336	0.100	14.431
17	1.65	17.615	0.948	323.42	0.136	15.336	0.100	14.431
18	1.75	17.460	0.948	321.97	0.136	15.336	0.100	14.431
19	1.85	17.305	0.948	320.52	0.136	15.336	0.100	14.431
20	1.95	17.150	0.948	319.07	0.136	15.336	0.100	14.431
21	2.05	17.000	0.948	317.62	0.136	15.336	0.100	14.431
22	2.15	16.845	0.948	316.17	0.136	15.336	0.100	14.431
23	2.25	16.690	0.948	314.72	0.136	15.336	0.100	14.431
24	2.35	16.535	0.948	313.27	0.136	15.336	0.100	14.431
25	2.45	16.380	0.948	311.82	0.136	15.336	0.100	14.431
26	2.55	16.225	0.948	310.37	0.136	15.336	0.100	14.431
27	2.65	16.070	0.948	308.92	0.136	15.336	0.100	14.431
28	2.75	15.915	0.948	307.47	0.136	15.336	0.100	14.431
29	2.85	15.760	0.948	306.02	0.136	15.336	0.100	14.431
30	2.95	15.605	0.948	304.57	0.136	15.336	0.100	14.431
31	3.05	15.450	0.948	303.12	0.136	15.336	0.100	14.431
32	3.15	15.295	0.948	301.67	0.136	15.336	0.100	14.431
33	3.25	15.140	0.948	300.22	0.136	15.336	0.100	14.431
34	3.35	15.000	0.948	298.77	0.136	15.336	0.100	14.431

SPHERE

RADIUS = 1.192
WEIGHT = 561.0 LBS
BULK WET DENSITY = 2.72 SLUGS 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

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	3498.631	0.175	15.152	0.020	1.513
2	0.15	19.542	2.668	3467.424	0.1546	53.357	0.100	4.431
3	0.25	19.756	17.992	3435.043	1.4209	83.229	0.1256	7.139
4	0.35	19.021	23.468	3325.142	13.081	89.224	0.4785	9.762
5	0.45	18.539	33.352	3104.221	18.522	90.233	1.151	13.269
6	0.55	17.907	43.544	2870.317	25.105	86.431	1.580	16.547
7	0.65	17.207	53.690	2653.149	32.716	81.371	2.061	19.438
8	0.75	16.635	63.602	2457.613	41.176	74.068	2.548	21.811
9	0.85	16.096	73.012	2283.571	50.633	66.761	3.025	23.834
10	0.95	15.467	81.968	2130.830	60.725	56.046	3.508	25.454
11	1.05	14.963	90.473	2000.520	71.004	46.001	4.065	27.078
12	1.15	14.433	99.524	1891.423	82.374	36.709	4.679	28.518
13	1.25	13.873	109.140	1801.119	94.888	28.019	5.335	29.733
14	1.35	13.380	119.340	1726.561	107.559	20.101	6.050	30.751
15	1.45	12.851	129.124	1666.920	121.485	13.486	6.820	31.581
16	1.55	12.291	139.490	1620.800	136.699	9.473	7.641	32.141
17	1.65	11.703	149.340	1586.696	153.333	6.661	8.506	32.538
18	1.75	11.094	159.680	1563.927	171.699	4.738	9.427	32.786
19	1.85	10.559	169.500	1551.102	191.699	3.529	10.406	32.845
20	1.95	10.000	178.800	1547.615	213.333	2.655	11.467	32.855
21	2.05	9.519	187.560	1552.577	236.699	2.069	12.617	32.799
22	2.15	9.014	195.800	1565.963	261.699	1.681	13.846	32.694
23	2.25	8.583	203.520	1587.141	288.333	1.372	15.167	32.532
24	2.35	8.219	210.720	1615.674	316.699	1.119	16.632	32.311
25	2.45	7.919	217.400	1651.963	346.699	0.912	18.246	32.032
26	2.55	7.673	223.600	1696.748	378.333	0.749	19.996	31.691
27	2.65	7.481	229.200	1750.518	411.699	0.621	21.881	31.288
28	2.75	7.339	234.400	1813.577	446.699	0.529	23.896	30.825
29	2.85	7.244	239.200	1886.257	483.333	0.469	26.032	30.311
30	2.95	7.194	243.600	1968.963	521.699	0.431	28.286	29.742
31	3.05	7.188	247.600	2061.141	561.699	0.411	30.661	29.122
32	3.15	7.219	251.200	2163.674	603.333	0.402	33.167	28.451
33	3.25	7.281	254.400	2276.963	646.699	0.402	35.812	27.732
34	3.35	7.372	257.200	2399.674	691.699	0.402	38.596	26.961


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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

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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
C DIMENSION AREA(100),VOL(100),AMASS(100),DMASS(100),SVOL(100),WS(10
20),WBSUB(100),US(100),SUMSUB(100),E(100),V(100)
C DATA PI/3,141593/16/32,1725/100*0.0/,VOL/100*0.0/,AMASS/100*
20.0/,DMASS/100*0.0/,SVOL/100*0.0/,WS/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 INPUT DATA ON OBJECT
C OBJECT HORIZONTAL CYLINDER
C RAD=.94791
C WT=540.75
C DIM=33.834/12.
C BWD=37.402/C
C CFEET=1.3
C CNCE=5.7
C COHESION OR SHEAR STRENGTH IN PSI EQUALS .3 FOR PROGRAM CHECKOUT
C COH=43.2
C
C FOR A CYLINDER USE A COEFFICIENT OF DRAG EQUAL TO 0.68
C CD=0.68
C
C SET INCREMENT
C DX=.05
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
C Y=DX/2.*RAD
C YMAX=2.*RAD
C Z=RAD/DX
C N=Z+1.
C THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
C DIM2=2.*(RAD**2-(RAD-Y)**2)
C AREA(1)=DIM*DIM2
C DO 100 I=2,N
C AREA(I)=DIM**2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)

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C 100 PRINT,AREA(I)
C      CONTINUE
C
C 200 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
C      DO 200 I=N,100
C      AREA(I)=AREA(N)
C      PRINT,AREA(I)
C      CONTINUE
C
C 300 COMPUTE THE VOLUME OF EACH SECTION
C      VOLUME EQUALS AVERAGE AREA TIMES SECTION HEIGHT
C      DO 300 I=1,100
C      VOL(I)=AREA(I)*DX
C      CONTINUE
C
C 350 CHECK VOLUME CALCULATIONS
C      HAFVOL=PI*RAD**2*DIM/2.
C      CVOL=VOL(1)
C      DO 350 I=2,N
C      CVOL=CVOL+VOL(I)
C      CONTINUE
C
C      ERROR=CVOL-HAFVOL
C      PRINT, CVOL, HAFVOL, ERROR
C
C 400 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
C      SUMVOL=0.0
C      K=N+1
C      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
C      AA=DIM
C      BB=2.*SQRT(RAD**2-(RAD-(I-1)*DX-Y)**2)
C      THE ELLIPSE DIMENSIONS ARE
C      A=SQRT(DIM**2/PI)
C      R=AA/BB
C      B=A/R

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

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C CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
BMASS=WT/G
E(1)=BMASS*VO**2/2.
C CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
EP=WT*DX
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
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
C 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
C IF((I*DX-Y).GT.RAD) DEPTH=I*DX-Y-RAD/2.

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C CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH DATA
C DEPTHI=DEPTH*12.
C
C SELECT PROPER DEPTH
C IF((DEPTH.LE.5) GO TO 1
C IF((DEPTH.LE.1.0).AND.(DEPTH.GT.0.5)) GO TO 2
C IF((DEPTH.LE.1.5).AND.(DEPTH.GT.1.0)) GO TO 3
C IF((DEPTH.LE.2.0).AND.(DEPTH.GT.1.5)) GO TO 4
C IF((DEPTH.LE.2.5).AND.(DEPTH.GT.2.0)) GO TO 5
C IF((DEPTH.LE.3.0).AND.(DEPTH.GT.2.5)) GO TO 6
C IF((DEPTH.LE.3.5).AND.(DEPTH.GT.3.0)) GO TO 7
C 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
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=SS*144.
C CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
C ULT*CFEET*CNCG
C WT(I)=CT*SPS*AREA(I)*DX
C AMASSI=(AMASS(I)*V(I)**2/2.)
C VFLOSQ=2.0*(F(I)+EP+AMASSI-WI(WI(I)-WB(I)))/(BMASS+DMASS(I)+AMASS(I))
C IF (VELOSO.LE.0.0) GO TO 1000

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V(I+1)=SQRT(VELOSQ)

SECTION TO COMPUTE THE WORK DONE BY DRAG
APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
FIRST TIME OVER THE SECTION, AS DONE ABOVE
VAVG=(V(I)+V(I+1))/2.
IF(I.EQ.1) VAVG=(VD+V(I+1))/2.
WDRAG=.5*BWDCD*AREA(J)*DX*VAVG**2

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)

CALCULATE E AT NEXT SECTION
E(I+1)=BMASS*V(I+1)**2/2.

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)

COMPUTE PENETRATION DEPTH
XXX=1*DX

PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
WORKDONE BY SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
AND DRAG

WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
CONTINUE
2000 CONTINUE
1000 FORMAT(I5)
2050 FORMAT(F5.1,I3)
2100 FORMAT(F5.1,I3)
2200 FORMAT(F5.1,I3)
2300 FORMAT(F5.1,I3)
2400 FORMAT(F5.1,I3)
2500 FORMAT(F5.1,I3)
2600 FORMAT(F5.1,I3)
2700 FORMAT(F5.1,I3)
2800 FORMAT(F5.1,I3)
2900 FORMAT(F5.1,I3)
3000 FORMAT(F5.1,I3)
3100 FORMAT(F5.1,I3)
3200 FORMAT(F5.1,I3)
3300 FORMAT(F5.1,I3)
3400 FORMAT(F5.1,I3)
3500 FORMAT(F5.1,I3)
3600 FORMAT(F5.1,I3)
3700 FORMAT(F5.1,I3)
3800 FORMAT(F5.1,I3)
3900 FORMAT(F5.1,I3)
4000 FORMAT(F5.1,I3)
4100 FORMAT(F5.1,I3)
4200 FORMAT(F5.1,I3)
4300 FORMAT(F5.1,I3)
4400 FORMAT(F5.1,I3)
4500 FORMAT(F5.1,I3)
4600 FORMAT(F5.1,I3)
4700 FORMAT(F5.1,I3)
4800 FORMAT(F5.1,I3)
4900 FORMAT(F5.1,I3)
5000 FORMAT(F5.1,I3)
5100 FORMAT(F5.1,I3)
5200 FORMAT(F5.1,I3)
5300 FORMAT(F5.1,I3)
5400 FORMAT(F5.1,I3)
5500 FORMAT(F5.1,I3)
5600 FORMAT(F5.1,I3)
5700 FORMAT(F5.1,I3)
5800 FORMAT(F5.1,I3)
5900 FORMAT(F5.1,I3)
6000 FORMAT(F5.1,I3)
6100 FORMAT(F5.1,I3)
6200 FORMAT(F5.1,I3)
6300 FORMAT(F5.1,I3)
6400 FORMAT(F5.1,I3)
6500 FORMAT(F5.1,I3)
6600 FORMAT(F5.1,I3)
6700 FORMAT(F5.1,I3)
6800 FORMAT(F5.1,I3)
6900 FORMAT(F5.1,I3)
7000 FORMAT(F5.1,I3)
7100 FORMAT(F5.1,I3)
7200 FORMAT(F5.1,I3)
7300 FORMAT(F5.1,I3)
7400 FORMAT(F5.1,I3)
7500 FORMAT(F5.1,I3)
7600 FORMAT(F5.1,I3)
7700 FORMAT(F5.1,I3)
7800 FORMAT(F5.1,I3)
7900 FORMAT(F5.1,I3)
8000 FORMAT(F5.1,I3)
8100 FORMAT(F5.1,I3)
8200 FORMAT(F5.1,I3)
8300 FORMAT(F5.1,I3)
8400 FORMAT(F5.1,I3)
8500 FORMAT(F5.1,I3)
8600 FORMAT(F5.1,I3)
8700 FORMAT(F5.1,I3)
8800 FORMAT(F5.1,I3)
8900 FORMAT(F5.1,I3)
9000 FORMAT(F5.1,I3)

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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 2.60 2.93

CONDITIONS AT THE END OF SECTION

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	0.148	2.029	0.029	0.009
2	0.10	2.253	4.536	42.655	3.502	5.037	0.285	0.381
3	0.15	2.558	7.360	54.977	7.431	5.769	0.803	0.713
4	0.20	2.720	10.584	62.196	12.135	5.251	1.431	1.002
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	2.538	19.656	54.132	29.342	-0.120	3.787	1.288
8	0.40	2.254	22.680	42.694	35.784	-3.139	4.693	1.138
9	0.45	1.806	25.704	27.406	42.459	-6.634	5.645	0.856
10	0.50	1.011	28.728	8.591	49.307	-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 1.08 1.88 2.04 1.96 2.38 2.70

CONDITIONS AT THE END OF SECTION

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	0.285	2.550
3	0.15	5.174	9.180	224.929	9.023	11.355	0.803	3.386
4	0.20	5.127	12.852	220.922	14.735	11.073	1.431	3.816
5	0.25	5.017	16.524	217.516	21.167	8.892	2.147	4.137
6	0.30	4.846	20.196	197.349	28.170	5.839	2.936	4.260
7	0.35	4.613	23.868	178.853	35.630	1.922	3.787	4.195
8	0.40	4.311	27.540	156.157	43.452	-2.358	4.693	3.645
9	0.45	3.927	31.212	129.592	51.557	-7.120	5.645	3.521
10	0.50	3.440	34.854	99.472	59.873	-12.291	6.638	2.927
11	0.55	2.804	38.556	66.092	68.336	-17.759	7.667	2.173
12	0.60	1.881	42.228	29.734	76.886	-23.474	8.726	1.258

CYLINDER

RADIUS = 0.948 FEET
 LENGTH = 2.819 FEET
 WEIGHT = 540.8 LBS
 BULK NET 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	9.761	0.936	800.685	0.091	65.433	0.029	1.190
2	0.15	9.598	2.808	774.137	2.168	42.072	0.285	1.060
3	0.25	9.420	4.680	775.666	4.600	38.963	0.803	1.433
4	0.35	9.248	6.552	771.744	7.512	32.786	1.431	1.532
5	0.45	9.058	8.424	685.585	10.791	29.786	2.137	1.247
6	0.55	8.850	10.296	628.845	14.361	25.835	2.787	1.056
7	0.65	8.631	12.168	597.275	18.162	21.306	3.463	1.436
8	0.75	8.404	14.040	564.257	22.152	17.180	4.158	1.443
9	0.85	8.167	15.912	531.909	26.152	13.069	4.867	1.356
10	0.95	7.927	17.784	499.555	30.152	9.086	5.587	1.268
11	1.05	7.684	19.656	468.210	34.157	4.886	6.321	1.184
12	1.15	7.442	21.528	437.735	38.160	0.915	7.062	1.101
13	1.25	7.202	23.400	408.182	42.160	-8.188	7.812	1.019
14	1.35	6.958	25.272	379.580	46.160	-16.053	8.563	0.938
15	1.45	6.715	27.144	351.958	50.160	-24.026	9.314	0.859
16	1.55	6.472	29.016	325.350	54.160	-32.000	10.065	0.787
17	1.65	6.229	30.888	300.760	58.160	-40.075	10.816	0.713
18	1.75	5.986	32.760	277.186	62.160	-48.150	11.567	0.640
19	1.85	5.743	34.632	254.639	66.160	-56.225	12.318	0.566
20	1.95	5.497	36.504	233.113	70.160	-64.300	13.069	0.493
21	2.05	5.251	38.376	212.578	74.160	-72.375	13.820	0.420
22	2.15	5.005	40.248	193.013	78.160	-80.450	14.571	0.346
23	2.25	4.761	42.120	174.436	82.160	-88.525	15.322	0.273
24	2.35	4.514	44.000	156.856	86.160	-96.600	16.073	0.200
25	2.45	4.268	45.872	140.276	90.160	-104.675	16.824	0.126

CYLINDER

RADIUS = 0.948
 LENGTH = 2.819 FEET
 WEIGHT = 530.8 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 APE

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	51.69	1.1320	170.449	0.102	144.684	0.029	2.654
2	0.10	44.817	1.1320	160.277	2.1411	188.046	0.285	19.889
3	0.15	40.160	1.1320	150.204	5.1379	79.546	0.603	24.821
4	0.20	36.642	1.1320	140.135	8.0336	68.781	1.437	28.557
5	0.25	33.642	1.1320	130.066	10.9109	58.816	2.693	29.018
6	0.30	30.642	1.1320	120.000	13.7971	48.839	3.793	30.180
7	0.35	27.642	1.1320	110.033	16.6819	38.831	5.645	30.947
8	0.40	24.642	1.1320	100.066	19.5690	28.817	7.726	32.703
9	0.45	21.642	1.1320	90.100	22.4597	18.797	9.812	34.705
10	0.50	18.642	1.1320	80.133	25.3530	8.788	11.921	36.484
11	0.55	15.642	1.1320	70.166	28.2497	-3.206	14.047	38.181
12	0.60	12.642	1.1320	60.200	31.1490	-14.210	16.189	39.784
13	0.65	9.642	1.1320	50.233	34.0507	-25.350	18.350	41.404
14	0.70	6.642	1.1320	40.266	36.9530	-36.586	20.521	43.015
15	0.75	3.642	1.1320	30.300	39.8567	-47.837	22.697	44.618
16	0.80	0.642	1.1320	20.333	42.7619	-59.094	24.874	46.215
17	0.85	0.000	1.1320	10.366	45.6690	-70.350	26.997	47.808
18	0.90	0.000	1.1320	0.400	48.5771	-81.611	29.071	49.396
19	0.95	0.000	1.1320	0.000	51.4852	-92.866	31.149	50.984
20	1.00	0.000	1.1320	0.000	54.3933	-104.111	33.221	52.572
21	1.05	0.000	1.1320	0.000	57.3014	-115.366	35.297	54.160
22	1.10	0.000	1.1320	0.000	60.2095	-126.611	37.371	55.748
23	1.15	0.000	1.1320	0.000	63.1176	-137.866	39.445	57.336
24	1.20	0.000	1.1320	0.000	66.0257	-149.111	41.519	58.924
25	1.25	0.000	1.1320	0.000	68.9338	-160.366	43.593	60.512
26	1.30	0.000	1.1320	0.000	71.8419	-171.611	45.667	62.100
27	1.35	0.000	1.1320	0.000	74.7500	-182.866	47.741	63.688
28	1.40	0.000	1.1320	0.000	77.6581	-194.111	49.815	65.276

CYLINDER

RADIUS = 0.948
 LENGTH = 2.819 FEET
 WEIGHT = 540.8 LBS
 BULK WEIGHT 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

0.68 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	19.2774	2.448	3127.0	0.239	255.626	0.029	4.705
2	0.10	18.2774	7.344	2969.0	5.670	151.621	0.085	35.034
3	0.15	17.2759	17.240	2751.0	18.631	134.355	0.180	32.237
4	0.20	16.2757	22.020	2503.0	37.506	110.357	0.317	46.639
5	0.30	15.2758	36.720	2286.0	57.932	79.358	0.567	49.304
6	0.40	14.2754	46.616	2055.0	79.931	62.667	0.835	50.100
7	0.50	13.2754	55.509	1829.0	91.542	48.681	1.198	50.887
8	0.60	12.2754	64.404	1603.0	115.425	31.547	1.667	46.543
9	0.70	11.2754	73.300	1378.0	139.551	18.488	2.221	44.509
10	0.80	10.2754	82.205	1153.0	163.659	9.483	2.949	42.422
11	0.90	9.2754	91.109	928.0	187.766	4.326	3.841	39.363
12	1.00	8.2754	100.014	703.0	211.873	0.006	4.934	36.307
13	1.10	7.2754	108.919	478.0	235.980	0.000	6.241	33.252
14	1.20	6.2754	117.824	253.0	260.086	0.000	7.794	30.207
15	1.30	5.2754	126.729	22.0	284.193	0.000	9.589	27.157
16	1.40	4.2754	135.634	1.0	308.300	0.000	11.691	24.103
17	1.50	3.2754	144.539	0.0	332.406	0.000	14.143	21.049
18	1.60	2.2754	153.444	0.0	356.511	0.000	16.957	18.000
19	1.70	1.2754	162.349	0.0	380.616	0.000	19.143	15.000
20	1.80	0.2754	171.254	0.0	404.721	0.000	21.713	12.000
21	1.90	0.0754	180.159	0.0	428.826	0.000	24.681	9.000
22	2.00	0.0254	189.064	0.0	452.931	0.000	27.055	6.000
23	2.10	0.0054	197.969	0.0	477.036	0.000	29.825	3.000
24	2.20	0.0004	206.874	0.0	501.141	0.000	32.595	0.000
25	2.30	0.0000	215.779	0.0	525.246	0.000	35.365	0.000
26	2.40	0.0000	224.684	0.0	549.351	0.000	38.135	0.000

CYLINDER

RADIUS = 0.948
 LENGTH = 2.819 FEET
 WEIGHT = 580.8 LBS
 BULK WEIGHT 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	19.273	2.662	3127.979	0.260	255.624	0.029	4.705
2	0.15	18.274	2.520	3297.852	0.103	151.837	0.028	35.031
3	0.25	17.245	2.320	2794.566	131.371	134.746	0.003	42.207
4	0.35	16.245	2.064	2645.318	131.371	94.339	1.147	46.604
5	0.45	15.225	1.820	2322.159	40.569	78.239	2.937	50.561
6	0.55	14.225	1.586	2073.136	53.898	61.469	4.635	50.559
7	0.65	13.225	1.364	1805.663	74.875	46.470	6.667	48.052
8	0.75	12.225	1.164	1674.205	89.155	32.541	8.921	46.184
9	0.85	11.225	0.972	1472.123	114.507	18.914	7.726	43.849
10	0.95	10.225	0.834	1327.777	114.419	-8.320	8.121	41.481
11	0.05	11.140	0.737	1193.205	114.419	-23.370	10.047	38.350
12	0.05	10.306	0.672	1050.270	113.680	-36.687	12.343	35.481
13	0.05	9.837	0.612	923.225	113.680	-50.049	14.502	32.950
14	0.05	9.374	0.555	805.453	111.855	-60.601	15.429	29.944
15	0.05	8.917	0.503	699.475	111.855	-70.527	16.597	26.944
16	0.05	8.465	0.455	605.411	111.855	-80.323	17.921	23.944
17	0.05	8.017	0.412	523.357	111.855	-90.049	19.429	20.944
18	0.05	7.574	0.374	453.311	111.855	-100.049	21.009	17.944
19	0.05	7.135	0.340	395.265	111.855	-110.049	22.659	14.944
20	0.05	6.700	0.309	349.219	111.855	-120.049	24.389	11.944
21	0.05	6.269	0.281	315.173	111.855	-130.049	26.199	8.944
22	0.05	5.842	0.256	283.127	111.855	-140.049	28.089	5.944
23	0.05	5.419	0.233	253.081	111.855	-150.049	30.059	2.944
24	0.05	5.000	0.212	225.035	111.855	-160.049	32.109	0.000


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DYNAMIC PENETRATION OF AN OBJECT INTO THE OCEAN BOTTOM
PROGRAM TO CALCULATE SECTION PROPERTIES OF A FLAT ENDED CYLINDER

UNITS FEET/POUNDS/SLUGS/SECONDS/

DX      INCREMENT SIZE
BWD     BULK WET DENSITY OF SEDIMENT
BMASS   OBJECT MASS
AMASS( ) ADDED MASS PLUS MASS OF DISPLACED SEDIMENT AT SECTION ( )
DMASS( ) CHANGE IN AMASS OVER SECTION INDICATED BY SUBSCRIPT
AREA( ) PROJECTED AREA FOR SECTION ( )
CNC     BEARING CAPACITY COEFFICIENT
VOL( )  VOLUME OF SECTION ( )
CFOOT   BEARING CAPACITY CONSTANT DEPENDS ON SHAPE OF AREA
XXX     DEPTH OF PENETRATION
V( )    VELOCITY OF OBJECT AT SECTION ( )
WS( )   WORK DONE BY SEDIMENT IN SECTION ( )
WT       WEIGHT OF OBJECT
G        ACCELERATION OF GRAVITY
SPS     SHEAR STRENGTH OF SEDIMENT
RAD      RADIUS
WDRAW   WORK DONE BY DRAG FORCES
WB( )   WORK DONE BY BUOYANCY WHEN SUBMERGING TO SECTION ( )
WBSUB( ) WORK DONE BY SUBMERGED SECTION ( )
US( )   WORK TO SUBMERGE SECTION ( )

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C PRINT, AREA(I)
C 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
CONTINUE
300
C
C CHECK VOLUME CALCULATIONS
HAFVOL=PI*RAD**2*YMAX
CVOL=VOL(1)
DO 350 I=2,N
CVOL=CVOL+VOL(I)
CONTINUE
350
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 CIRCULAR DISK, AMASS BECOMES
C CONSTANT WHEN MAX AREA HAS BEEN REACHED.
C
SUMVOL=0.0
K=N+1
DO 400 I=2,K
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
C AMASS REMAINS THE SAME AFTER MAX AREA
C
DO 450 I=N,100
AMASS(I)=AMASS(N)
PRINT, AMASS(N)
CONTINUE
450
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)

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C 500 PRINT,DMASS(N)
C CONTINUE

CCCCC
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
C CT=CFOOT*CNC
C DO 600 I=1,100
C WS(I)=CT*COH*AREA(I)*DX
C CONTINUE

600

CCCCC
C CALCULATE WORK DONE BY BUOYANCY

GAMMA=BWD*G
WB(I)=(GAMMA*AREA(I)*DX**2)/2.
SUMSUB(I)=2.0*WB(I)
DO 700 I=2,N

C WORK TO SUBMERGE SECTION
C US(I)=(GAMMA*AREA(I)*DX**2)/2.

C WORK TO CONTINUE SECTION AFTER SUBMERGING
C WBSUB(I)=2.0*US(I)

C TOTAL WORK OF THE SUBMERGED SECTIONS
C SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)

C TOTAL WORK DONE SUBMERGING SECTION PLUS THOSE ALREADY SUBMERGED
C WB(I)=US(I)+SUMSUB(I-1)
C CONTINUE

700

CCCCC
C AFTER ALL SECTIONS ARE SUBMERGED WORK BECOMES CONSTANT EQUAL TO
C SUMSUB(N) PLUS WBSUB(N) FOR EACH FURTHER INCREMENT
C THIS ASSUMES A CAVITY IS FORMED AFTER THE OBJECT PENETRATES PAST
C ITS MAXIMUM DIMENSION

C DO 760 I=N,100
C WB(I)=SUMSUB(N)+(I-(N-1))*WBSUB(N)
C PRINT,WB(I)
C CONTINUE

760

CCCC
C CHECK WORK TO SUBMERGE

CWB=WB(I)

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DO 800 I=2,N
CWB=CWB+WB(I)
CONTINUE
PRINT,CWB
C C C C
ACTUAL WORK BY INTEGRATION IS
X=N*DX
AWB=(GAMMA*PI*RAD**2*X**2/2.)
PRINT,AWB,X
C C C C C C C C
PROGRAM TO COMPUTE PENETRATION DEPTH FOLLOWS
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) VQ,SS05,SS10,SS105,SS20,SS205,SS30,SS305,SS40
WRITE(6,2300) VQ,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*VQ**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

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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

VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
 V(1)=0.0
 DO 2000 I=1,100
 SECTION TO COMPUTE SHEAR STRENGTH
 NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
 TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
 FOR THE CYLINDER TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
 PENETRATION DEPTH
 DEPTH=I*DX-Y

CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH DATA
 DEPTH=DEPTH*12.

SELECT PROPER DEPTH
 IF((DEPTH.LE.5) GO TO 1
 IF((DEPTH.LE.1.5).AND.(DEPTH.GT.0.5)) GO TO 2
 IF((DEPTH.LE.2.5).AND.(DEPTH.GT.1.5)) GO TO 3
 IF((DEPTH.LE.3.5).AND.(DEPTH.GT.2.5)) GO TO 4
 IF((DEPTH.LE.4.5).AND.(DEPTH.GT.3.5)) GO TO 5
 IF((DEPTH.LE.5.5).AND.(DEPTH.GT.4.5)) GO TO 6
 IF((DEPTH.LE.6.5).AND.(DEPTH.GT.5.5)) GO TO 7
 IF((DEPTH.LE.7.5).AND.(DEPTH.GT.6.5)) GO TO 8

FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
 AVERAGE OF THE LAST THREE AND CALL IT CONSTANT

IF(DEPTH.GT.4.0) GO TO 9

FORMULAS FOR SHEAR STRENGTH FOLLOW
 LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED


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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.
10 SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
    SPS=SS*144.
    CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
    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)

SECTION TO COMPUTE THE WORK DONE BY DRAG
APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
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*BXD*CD*AREA(I)*DX*VAVG**2

VELOSQ=2.0*(E(I)+EP+AMASS1-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I))+AMASS
2 S(I)
IF (VELOSQ.LE.0.0) GO TO 1000
V(I+1)=SQRT(VELOSQ)

CALCULATE E AT NEXT SECTION
E(I+1)=BMASS*V(I+1)**2/2.

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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RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72 SLUGS 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
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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	0.5	4.829	2.160	203.599	2.259	35.974	0.308	4.203
2	0.105	4.994	5.800	2126.359	6.777	1.631	0.925	4.123
3	0.205	5.147	10.420	2231.555	15.631	0.835	1.562	4.561
4	0.305	5.150	15.760	2227.559	22.950	0.055	2.376	4.573
5	0.405	5.106	28.080	2217.289	34.950	-0.710	3.392	4.453
6	0.505	5.812	36.720	2160.226	33.866	-1.463	4.009	4.249
7	0.450	4.668	41.540	169.602	33.840	2.930	5.263	3.956
8	0.550	4.408	41.540	114.921	32.922	3.646	5.860	3.331
9	0.650	4.674	49.836	115.536	47.515	3.603	6.476	3.584
10	0.805	3.693	58.360	4.536	52.853	-5.077	7.093	2.596
11	0.905	2.939	58.360	183.562	61.521	-3.774	8.278	1.979
12	0.75	2.870	63.828	6.602	66.520	-7.131	8.944	0.445

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
 HEIGHT = 561.8 LBS
 DENSITY = 2.72 SLUGS PER CUBIC FOOT
 BULK WET 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 2.60 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	9.266	2.562	749.511	2.711	132.433	0.308	16.151
2	0.15	9.297	7.776	752.938	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	0.25	9.235	18.144	744.499	18.976	-1.194	2.159	14.906
5	0.30	9.067	23.328	737.764	24.398	-2.073	2.776	14.722
6	0.30	9.020	28.512	716.137	29.819	-2.938	3.392	14.439
7	0.40	8.751	33.696	694.102	35.241	-3.788	4.009	14.060
8	0.45	8.547	38.880	668.537	40.663	-4.623	4.626	13.585
9	0.50	8.305	44.064	637.724	46.085	-5.444	5.243	13.017
10	0.55	8.036	49.248	602.340	51.507	-6.252	5.860	12.457
11	0.60	7.743	54.432	563.716	55.929	-7.047	6.476	11.898
12	0.65	7.416	59.616	522.710	58.283	-7.825	7.093	11.341
13	0.70	7.056	64.800	479.623	60.705	-8.599	7.710	10.787
14	0.75	6.662	69.984	434.490	63.127	-9.368	8.327	10.183
15	0.80	6.235	75.168	387.346	66.416	-10.133	8.944	9.587
16	0.85	5.776	80.352	338.225	69.138	-10.893	9.560	8.944
17	0.90	5.283	85.536	284.160	71.838	-11.648	10.177	8.265
18	0.95	4.743	90.720	224.181	74.540	-12.403	10.794	7.541
19	1.00	4.153	95.904	179.340	77.240	-13.158	11.411	6.765
20	1.05	3.517	101.088	129.340	79.940	-13.913	12.028	5.941
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 = 2.72 SLUGS PER CUBIC FOOT
 DRAG COEFFICIENT = 0.80

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 2.61 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	1658.988	3.916	293.131	0.308	36.057
2	0.15	13.723	11.222	1644.113	11.747	-2.628	0.925	32.918
3	0.20	13.632	18.720	1622.369	19.578	-3.642	0.542	32.053
4	0.25	13.512	26.595	1593.871	27.410	-5.035	1.159	32.412
5	0.30	13.382	33.594	1557.064	35.241	-7.362	3.352	30.652
6	0.35	13.197	48.172	1468.978	43.073	-8.497	4.009	29.758
7	0.40	12.729	53.160	1413.579	50.904	-9.612	4.626	28.736
8	0.45	12.453	63.549	1353.271	66.598	-10.708	5.243	27.589
9	0.50	12.143	76.752	1287.218	74.272	-11.786	5.860	26.320
10	0.55	11.803	80.495	1216.540	80.187	-12.555	6.476	24.947
11	0.60	11.440	84.284	1136.289	88.103	-13.018	7.071	23.504
12	0.65	11.063	87.984	1036.481	92.019	-13.473	7.710	22.009
13	0.70	10.689	91.728	906.128	95.934	-13.864	8.327	20.466
14	0.75	10.189	95.472	822.284	99.850	-14.397	8.944	18.866
15	0.80	9.704	99.216	736.756	103.766	-14.923	9.560	17.525
16	0.85	9.114	102.960	647.756	107.681	-15.642	10.177	15.782
17	0.90	8.614	106.704	556.797	111.597	-16.054	10.794	13.792
18	0.95	7.988	110.448	463.748	115.513	-16.459	11.411	11.752
19	1.00	7.277	114.640	366.792	119.513	-17.237	12.028	10.154
20	1.05	6.480	118.520	266.153	123.025	-18.383	12.644	8.226
21	1.10	5.480	122.920	151.752	131.061	-19.507	13.261	6.055
22	1.15	4.169	127.560	35.177	140.097	-20.598	14.495	4.066
23	1.20	2.007	142.560	1.179	149.097		14.495	1.667

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72 SLUGS 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	BODY ENERGY	STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
1	0.05	328	4.968	232.4	5.196	518.167	0.08	63.928
2	0.10	320	14.870	289.4	15.979	518.981	0.08	58.957
3	0.15	322	24.776	284.1	15.971	518.509	0.08	57.184
4	0.20	322	44.712	284.3	15.971	518.509	0.08	56.542
5	0.30	324	44.686	284.3	15.971	518.509	0.08	54.229
6	0.35	324	54.686	284.3	15.971	518.509	0.08	54.229
7	0.40	324	64.686	284.3	15.971	518.509	0.08	54.229
8	0.45	324	74.686	284.3	15.971	518.509	0.08	54.229
9	0.50	324	84.686	284.3	15.971	518.509	0.08	54.229
10	0.55	324	94.686	284.3	15.971	518.509	0.08	54.229
11	0.60	324	104.686	284.3	15.971	518.509	0.08	54.229
12	0.65	324	114.686	284.3	15.971	518.509	0.08	54.229
13	0.70	324	124.686	284.3	15.971	518.509	0.08	54.229
14	0.75	324	134.686	284.3	15.971	518.509	0.08	54.229
15	0.80	324	144.686	284.3	15.971	518.509	0.08	54.229
16	0.85	324	154.686	284.3	15.971	518.509	0.08	54.229
17	0.90	324	164.686	284.3	15.971	518.509	0.08	54.229
18	0.95	324	174.686	284.3	15.971	518.509	0.08	54.229
19	1.00	324	184.686	284.3	15.971	518.509	0.08	54.229
20	1.05	324	194.686	284.3	15.971	518.509	0.08	54.229
21	1.10	324	204.686	284.3	15.971	518.509	0.08	54.229
22	1.15	324	214.686	284.3	15.971	518.509	0.08	54.229
23	1.20	324	224.686	284.3	15.971	518.509	0.08	54.229
24	1.25	324	234.686	284.3	15.971	518.509	0.08	54.229
25	1.30	324	244.686	284.3	15.971	518.509	0.08	54.229
26	1.35	324	254.686	284.3	15.971	518.509	0.08	54.229
27	1.40	324	264.686	284.3	15.971	518.509	0.08	54.229
28	1.45	324	274.686	284.3	15.971	518.509	0.08	54.229
29	1.50	324	284.686	284.3	15.971	518.509	0.08	54.229
30	1.55	324	294.686	284.3	15.971	518.509	0.08	54.229
31	1.60	324	304.686	284.3	15.971	518.509	0.08	54.229
32	1.65	324	314.686	284.3	15.971	518.509	0.08	54.229
33	1.70	324	324.686	284.3	15.971	518.509	0.08	54.229
34	1.75	324	334.686	284.3	15.971	518.509	0.08	54.229
35	1.80	324	344.686	284.3	15.971	518.509	0.08	54.229
36	1.85	324	354.686	284.3	15.971	518.509	0.08	54.229
37	1.90	324	364.686	284.3	15.971	518.509	0.08	54.229
38	1.95	324	374.686	284.3	15.971	518.509	0.08	54.229
39	2.00	324	384.686	284.3	15.971	518.509	0.08	54.229
40	2.05	324	394.686	284.3	15.971	518.509	0.08	54.229
41	2.10	324	404.686	284.3	15.971	518.509	0.08	54.229
42	2.15	324	414.686	284.3	15.971	518.509	0.08	54.229
43	2.20	324	424.686	284.3	15.971	518.509	0.08	54.229
44	2.25	324	434.686	284.3	15.971	518.509	0.08	54.229
45	2.30	324	444.686	284.3	15.971	518.509	0.08	54.229
46	2.35	324	454.686	284.3	15.971	518.509	0.08	54.229
47	2.40	324	464.686	284.3	15.971	518.509	0.08	54.229
48	2.45	324	474.686	284.3	15.971	518.509	0.08	54.229
49	2.50	324	484.686	284.3	15.971	518.509	0.08	54.229
50	2.55	324	494.686	284.3	15.971	518.509	0.08	54.229
51	2.60	324	504.686	284.3	15.971	518.509	0.08	54.229
52	2.65	324	514.686	284.3	15.971	518.509	0.08	54.229
53	2.70	324	524.686	284.3	15.971	518.509	0.08	54.229
54	2.75	324	534.686	284.3	15.971	518.509	0.08	54.229
55	2.80	324	544.686	284.3	15.971	518.509	0.08	54.229
56	2.85	324	554.686	284.3	15.971	518.509	0.08	54.229
57	2.90	324	564.686	284.3	15.971	518.509	0.08	54.229
58	2.95	324	574.686	284.3	15.971	518.509	0.08	54.229
59	3.00	324	584.686	284.3	15.971	518.509	0.08	54.229
60	3.05	324	594.686	284.3	15.971	518.509	0.08	54.229
61	3.10	324	604.686	284.3	15.971	518.509	0.08	54.229
62	3.15	324	614.686	284.3	15.971	518.509	0.08	54.229
63	3.20	324	624.686	284.3	15.971	518.509	0.08	54.229
64	3.25	324	634.686	284.3	15.971	518.509	0.08	54.229
65	3.30	324	644.686	284.3	15.971	518.509	0.08	54.229
66	3.35	324	654.686	284.3	15.971	518.509	0.08	54.229
67	3.40	324	664.686	284.3	15.971	518.509	0.08	54.229
68	3.45	324	674.686	284.3	15.971	518.509	0.08	54.229
69	3.50	324	684.686	284.3	15.971	518.509	0.08	54.229
70	3.55	324	694.686	284.3	15.971	518.509	0.08	54.229
71	3.60	324	704.686	284.3	15.971	518.509	0.08	54.229
72	3.65	324	714.686	284.3	15.971	518.509	0.08	54.229
73	3.70	324	724.686	284.3	15.971	518.509	0.08	54.229
74	3.75	324	734.686	284.3	15.971	518.509	0.08	54.229
75	3.80	324	744.686	284.3	15.971	518.509	0.08	54.229
76	3.85	324	754.686	284.3	15.971	518.509	0.08	54.229
77	3.90	324	764.686	284.3	15.971	518.509	0.08	54.229
78	3.95	324	774.686	284.3	15.971	518.509	0.08	54.229
79	4.00	324	784.686	284.3	15.971	518.509	0.08	54.229
80	4.05	324	794.686	284.3	15.971	518.509	0.08	54.229
81	4.10	324	804.686	284.3	15.971	518.509	0.08	54.229
82	4.15	324	814.686	284.3	15.971	518.509	0.08	54.229
83	4.20	324	824.686	284.3	15.971	518.509	0.08	54.229
84	4.25	324	834.686	284.3	15.971	518.509	0.08	54.229
85	4.30	324	844.686	284.3	15.971	518.509	0.08	54.229
86	4.35	324	854.686	284.3	15.971	518.509	0.08	54.229
87	4.40	324	864.686	284.3	15.971	518.509	0.08	54.229
88	4.45	324	874.686	284.3	15.971	518.509	0.08	54.229
89	4.50	324	884.686	284.3	15.971	518.509	0.08	54.229
90	4.55	324	894.686	284.3	15.971	518.509	0.08	54.229
91	4.60	324	904.686	284.3	15.971	518.509	0.08	54.229
92	4.65	324	914.686	284.3	15.971	518.509	0.08	54.229
93	4.70	324	924.686	284.3	15.971	518.509	0.08	54.229
94	4.75	324	934.686	284.3	15.971	518.509	0.08	54.229
95	4.80	324	944.686	284.3	15.971	518.509	0.08	54.229
96	4.85	324	954.686	284.3	15.971	518.509	0.08	54.229
97	4.90	324	964.686	284.3	15.971	518.509	0.08	54.229
98	4.95	324	974.686	284.3	15.971	518.509	0.08	54.229
99	5.00	324	984.686	284.3	15.971	518.509	0.08	54.229
100	5.05	324	994.686	284.3	15.971	518.509	0.08	54.229

IMPACT VELOCITY EQUALS 0.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE CYLINDER FLAT END IMPACTING

0.21 0.35 0.52 1.10 2.30 2.78 2.56 3.10

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

CONDITIONS AT THE END OF SECTION

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	1.594	1.512	22.170	1.581	3.917	0.308	0.110
2	0.15	2.159	4.360	40.731	4.744	3.274	0.925	0.655
3	0.25	2.777	7.384	59.320	7.907	2.655	1.552	0.955
4	0.35	3.055	10.632	75.527	11.069	2.048	2.176	1.222
5	0.45	3.055	13.632	82.428	14.235	1.450	2.392	1.455
6	0.55	3.055	16.650	89.672	17.557	0.863	2.609	1.619
7	0.65	3.055	19.672	96.820	20.720	0.286	2.826	1.755
8	0.75	3.055	22.672	103.820	23.683	-0.282	3.043	1.819
9	0.85	3.055	25.672	110.764	26.605	-0.840	3.260	1.955
10	0.95	3.055	28.672	117.564	29.045	-1.389	3.476	2.046
11	0.65	3.055	31.672	124.364	32.729	-1.849	3.693	2.140
12	0.55	3.055	34.672	131.164	34.806	-2.252	3.910	2.240
13	0.45	3.055	37.672	137.964	36.806	-2.595	4.127	2.340
14	0.35	3.055	40.672	144.764	38.806	-2.938	4.344	2.440

IMPACT VELOCITY EQUALS 5.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.87 1.04 1.04 1.41 1.13 1.48 1.87 1.76

CONDITIONS AT THE END OF SECTION

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	4.786	6.264	199.982	6.551	35.335	0.308	4.167
2	0.15	4.821	18.792	202.951	19.654	0.324	0.925	4.015
3	0.25	4.718	31.320	194.308	32.756	-1.524	1.542	3.959
4	0.35	4.469	43.848	174.250	45.859	-3.544	2.159	3.671
5	0.45	4.047	56.376	142.973	58.961	-5.527	2.776	3.155
6	0.55	3.396	68.904	100.667	72.064	-7.475	3.392	2.411
7	0.35	2.333	81.432	47.537	85.166	-9.388	4.009	1.431

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
 WEIGHT = 561.8 LBS
 DENSITY = 2.72 SLUGS PER CUBIC FOOT
 BULK WET 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 1.79 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	9.270	1.728	750.272	1.807	132.568	0.308	15.159
2	0.15	9.206	1.740	755.948	15.422	1.010	0.925	15.010
3	0.25	9.307	1.760	755.948	9.035	0.363	1.542	15.033
4	0.35	9.224	1.528	754.833	12.651	-0.273	2.392	15.029
5	0.45	9.153	1.464	750.823	16.665	-1.518	3.009	15.468
6	0.55	9.093	1.420	730.525	19.494	-2.711	4.626	15.474
7	0.65	8.793	1.376	674.955	27.123	-3.297	5.243	15.071
8	0.75	8.634	1.320	650.800	36.822	-3.271	5.860	15.071
9	0.85	8.464	1.281	625.383	47.173	-4.268	6.493	15.071
10	0.95	8.281	1.240	599.824	59.583	-4.708	7.110	15.121
11	1.05	8.076	1.181	570.824	74.19	-4.923	7.710	15.121
12	1.15	7.855	1.120	541.591	90.844	-4.923	8.327	15.121
13	1.25	7.617	1.059	518.295	109.555	-5.344	8.940	15.088
14	1.35	7.361	1.010	497.061	130.505	-5.546	9.560	15.088
15	1.45	7.088	0.961	479.061	153.955	-5.746	10.177	15.088
16	1.55	6.882	0.911	461.125	179.666	-5.943	10.794	15.088
17	1.65	6.655	0.862	441.331	206.021	-5.943	11.411	15.088
18	1.75	6.405	0.813	419.327	233.637	-6.653	12.028	15.088
19	1.85	6.125	0.764	394.341	262.583	-7.434	12.644	15.088
20	1.95	5.837	0.715	369.802	292.809	-8.302	13.261	15.088
21	2.05	5.540	0.666	346.477	324.005	-9.289	13.878	15.088
22	2.15	5.233	0.617	324.802	356.175	-10.386	14.495	15.088
23	2.25	4.919	0.568	304.749	389.452	-11.485	15.112	15.088
24	2.35	4.600	0.519	286.210	423.869	-12.585	15.729	15.088
25	2.45	4.275	0.470	269.279	459.435	-13.685	16.346	15.088
26	2.55	3.944	0.421	253.949	496.169	-14.785	16.963	15.088
27	2.65	3.608	0.372	239.210	534.069	-15.885	17.580	15.088
28	2.75	3.267	0.323	225.061	573.135	-16.985	18.197	15.088
29	2.85	2.921	0.274	211.495	613.366	-18.085	18.814	15.088
30	2.95	2.570	0.225	198.510	654.755	-19.185	19.431	15.088
31	3.05	2.214	0.176	186.115	697.295	-20.285	20.048	15.088
32	3.15	1.853	0.127	174.310	740.985	-21.385	20.665	15.088
33	3.25	1.487	0.078	163.095	785.825	-22.485	21.282	15.088
34	3.35	1.116	0.029	152.470	831.815	-23.585	21.899	15.088
35	3.45	0.740	0.000	142.435	878.955	-24.685	22.516	15.088
36	3.55	0.359	0.000	132.990	927.245	-25.785	23.133	15.088
37	3.65	0.000	0.000	124.135	976.685	-26.885	23.750	15.088
38	3.75	0.000	0.000	115.870	1027.275	-27.985	24.367	15.088
39	3.85	0.000	0.000	108.195	1079.015	-29.085	24.984	15.088
40	3.95	0.000	0.000	101.010	1131.905	-30.185	25.601	15.088
41	4.05	0.000	0.000	94.315	1185.945	-31.285	26.218	15.088
42	4.15	0.000	0.000	88.110	1241.135	-32.385	26.835	15.088
43	4.25	0.000	0.000	82.395	1297.475	-33.485	27.452	15.088
44	4.35	0.000	0.000	77.170	1354.965	-34.585	28.069	15.088
45	4.45	0.000	0.000	72.435	1413.605	-35.685	28.686	15.088
46	4.55	0.000	0.000	68.190	1473.395	-36.785	29.303	15.088
47	4.65	0.000	0.000	64.435	1534.335	-37.885	29.920	15.088
48	4.75	0.000	0.000	61.170	1596.425	-38.985	30.537	15.088
49	4.85	0.000	0.000	58.395	1659.665	-40.085	31.154	15.088
50	4.95	0.000	0.000	56.010	1724.055	-41.185	31.771	15.088
51	5.05	0.000	0.000	54.015	1789.595	-42.285	32.388	15.088
52	5.15	0.000	0.000	52.410	1856.285	-43.385	33.005	15.088
53	5.25	0.000	0.000	51.195	1924.125	-44.485	33.622	15.088
54	5.35	0.000	0.000	50.370	1993.115	-45.585	34.239	15.088
55	5.45	0.000	0.000	49.935	2063.255	-46.685	34.856	15.088
56	5.55	0.000	0.000	49.890	2134.545	-47.785	35.473	15.088
57	5.65	0.000	0.000	49.795	2206.985	-48.885	36.090	15.088
58	5.75	0.000	0.000	49.640	2280.575	-49.985	36.707	15.088
59	5.85	0.000	0.000	49.425	2355.315	-51.085	37.324	15.088
60	5.95	0.000	0.000	49.150	2431.205	-52.185	37.941	15.088
61	6.05	0.000	0.000	48.815	2508.245	-53.285	38.558	15.088
62	6.15	0.000	0.000	48.430	2586.435	-54.385	39.175	15.088
63	6.25	0.000	0.000	47.985	2665.775	-55.485	39.792	15.088
64	6.35	0.000	0.000	47.480	2746.265	-56.585	40.409	15.088
65	6.45	0.000	0.000	46.915	2827.905	-57.685	41.026	15.088
66	6.55	0.000	0.000	46.290	2910.695	-58.785	41.643	15.088
67	6.65	0.000	0.000	45.605	2994.635	-59.885	42.260	15.088
68	6.75	0.000	0.000	44.860	3079.725	-60.985	42.877	15.088
69	6.85	0.000	0.000	44.055	3165.965	-62.085	43.494	15.088
70	6.95	0.000	0.000	43.190	3253.355	-63.185	44.111	15.088
71	7.05	0.000	0.000	42.265	3341.895	-64.285	44.728	15.088
72	7.15	0.000	0.000	41.280	3431.585	-65.385	45.345	15.088
73	7.25	0.000	0.000	40.235	3522.425	-66.485	45.962	15.088
74	7.35	0.000	0.000	39.140	3614.415	-67.585	46.579	15.088
75	7.45	0.000	0.000	37.985	3707.555	-68.685	47.196	15.088
76	7.55	0.000	0.000	36.770	3801.845	-69.785	47.813	15.088
77	7.65	0.000	0.000	35.505	3897.285	-70.885	48.430	15.088
78	7.75	0.000	0.000	34.190	3993.875	-71.985	49.047	15.088
79	7.85	0.000	0.000	32.835	4091.615	-73.085	49.664	15.088
80	7.95	0.000	0.000	31.440	4190.505	-74.185	50.281	15.088
81	8.05	0.000	0.000	29.995	4290.545	-75.285	50.898	15.088
82	8.15	0.000	0.000	28.500	4391.735	-76.385	51.515	15.088
83	8.25	0.000	0.000	26.955	4494.075	-77.485	52.132	15.088
84	8.35	0.000	0.000	25.360	4597.565	-78.585	52.749	15.088
85	8.45	0.000	0.000	23.715	4702.205	-79.685	53.366	15.088
86	8.55	0.000	0.000	22.020	4808.095	-80.785	53.983	15.088
87	8.65	0.000	0.000	20.275	4915.235	-81.885	54.600	15.088
88	8.75	0.000	0.000	18.480	5023.625	-82.985	55.217	15.088
89	8.85	0.000	0.000	16.635	5133.265	-84.085	55.834	15.088
90	8.95	0.000	0.000	14.740	5244.155	-85.185	56.451	15.088
91	9.05	0.000	0.000	12.795	5356.295	-86.285	57.068	15.088
92	9.15	0.000	0.000	10.800	5469.685	-87.385	57.685	15.088
93	9.25	0.000	0.000	8.755	5584.325	-88.485	58.302	15.088
94	9.35	0.000	0.000	6.660	5700.215	-89.585	58.919	15.088
95	9.45	0.000	0.000	4.515	5817.355	-90.685	59.536	15.088
96	9.55	0.000	0.000	2.320	5935.745	-91.785	60.153	15.088
97	9.65	0.000	0.000	0.075	6055.385	-92.885	60.770	15.088
98	9.75	0.000	0.000	0.000	6176.275	-93.985	61.387	15.088
99	9.85	0.000	0.000	0.000	6298.415	-95.085	62.004	15.088
100	9.95	0.000	0.000	0.000	6421.805	-96.185	62.621	15.088
101	10.05	0.000	0.000	0.000	6546.445	-97.285	63.238	15.088
102	10.15	0.000	0.000	0.000	6672.335	-98.385	63.855	15.088
103	10.25	0.000	0.000	0.000	6800.475	-99.485	64.472	15.088
104	10.35	0.000	0.000	0.000	6930.865	-100.585	65.089	15.088
105	10.45	0.000	0.000	0.000	7063.505	-101.685	65.706	15.088
106	10.55	0.000	0.000	0.000	7198.395	-102.785	66.323	15.088
107	10.65	0.000	0.000	0.000	7335.535	-103.885	66.940	15.088
108	10.75	0.000	0.000	0.000	7474.925	-104.985	67.557	15.088
109	10.85	0.000	0.000	0.000	7616.565	-106.085	68.174	15.088
110	10.95	0.000	0.000	0.000	7759.455	-107.185	68.791	15.088
111	11.05	0.000	0.000	0.000	7903.595	-108.285	69.408	15.088
112	11.15	0.000	0.000	0.000	8049.985	-109.385	70.025	15.088
113	11.25	0.000	0.000	0.000	8197.625	-110.485	70.642	15.088
114	11.35	0.000	0.000	0.000	8346.515	-111.585	71.259	15.088
115	11.45	0.000	0.000	0.000	8496.655	-112.685	71.876	15.088
116	11.55	0.000	0.000	0.000	8648.045	-113.785	72.493	15.088
117	11.65	0.000	0.000	0.000	8800.685	-114.885	73.110	15.088
118	11.75	0.000	0.000					

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
 WEIGHT = 561.8 LBS
 BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
 DRAG COEFFICIENT = 0.80

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	1658.100	4.970	292.974	0.308	36.048
2	0.10	13.708	14.256	11640.575	14.910	-3.096	0.925	32.873
3	0.15	13.599	23.760	11614.448	24.850	-4.616	1.542	32.439
4	0.20	13.452	32.764	11579.864	34.789	-6.111	2.159	31.833
5	0.25	13.269	42.768	11536.965	44.729	-7.580	2.776	31.061
6	0.30	13.046	52.772	11485.891	54.669	-9.025	3.392	30.124
7	0.35	12.784	61.776	11425.779	64.609	-10.445	4.009	29.026
8	0.40	12.480	71.780	11359.979	74.549	-11.814	4.626	27.768
9	0.45	12.137	80.784	11284.554	84.488	-13.214	5.243	26.454
10	0.50	11.737	90.788	11194.552	94.428	-14.532	5.860	25.088
11	0.55	11.297	97.788	11094.551	101.979	-15.725	6.476	23.691
12	0.60	10.825	107.780	10985.829	107.079	-16.708	7.093	22.291
13	0.65	10.315	117.775	10861.022	111.320	-17.582	7.710	20.895
14	0.70	9.756	117.072	10721.025	117.441	-17.845	8.327	19.528
15	0.75	9.147	112.186	10568.879	122.561	-18.399	8.944	18.205
16	0.80	8.457	112.964	10408.679	127.561	-18.944	9.560	16.935
17	0.85	7.708	113.760	10238.436	132.561	-19.479	10.177	15.711
18	0.90	6.840	113.760	10058.223	137.561	-19.944	10.794	14.541
19	0.95	5.815	113.655	9868.097	142.043	-20.009	11.411	13.418
20	1.00	4.529	114.552	9611.867	148.043	-20.519	12.026	12.356
21	1.05	2.562	114.504	9141.867	151.130	-20.714	12.644	11.356

RADIUS = 0.948
 WEIGHT = 561.8 LBS
 BULK WET
 DRAG
 COEFFICIENT = 2.72 SLUGS PER CUBIC FOOT
 CYLINDER FLAT END IMPACTING

IMPACT VELOCITY EQUALS 15.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE APE
 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
1	0.05	13.786	3.600	1459.115	3.765	203.153	0.308
2	0.10	13.725	10.000	1644.601	11.825	-2.731	0.925
3	0.20	13.627	10.000	1629.612	11.835	-3.782	0.562
4	0.30	13.537	30.000	1556.151	33.846	-6.013	32.083
5	0.40	13.492	30.000	1527.550	41.846	-7.125	31.469
6	0.50	13.469	44.000	1472.410	48.476	-8.218	30.728
7	0.60	13.403	60.000	1393.374	56.006	-9.293	28.874
8	0.75	13.252	77.000	1293.535	64.537	-10.350	27.766
9	0.90	13.152	91.000	1153.831	71.949	-11.389	26.539
10	0.95	13.124	84.000	1109.133	80.719	-12.579	25.212
11	0.95	13.037	84.000	1099.134	88.745	-13.054	23.879
12	0.85	9.868	95.000	876.942	96.105	-13.830	22.037
13	0.85	9.373	95.000	763.397	96.775	-14.392	19.331
14	0.85	8.735	106.000	563.556	103.540	-14.717	17.469
15	0.85	8.246	106.000	500.217	107.305	-15.115	16.109
16	0.85	7.883	106.000	432.406	107.070	-15.506	14.244
17	0.85	7.609	117.680	392.120	116.090	-16.271	12.619
18	0.85	7.453	117.680	361.406	116.662	-17.034	10.086
19	0.85	7.409	117.680	340.114	126.142	-17.781	7.165
20	0.85	7.409	129.672	104.114	135.618	-18.495	3.048

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
 WEIGHT = 561.8 LBS
 DENSITY = 2.72 SLUGS 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		292.336	5.497	518.122	0.308	63.926
2	0.15	18.201	15.768		2892.072	16.491	-8.115	0.925	58.044
3	0.15	11.045	16.290		2842.699	27.485	-10.124	0.925	58.044
4	0.25	11.785	36.304		2784.359	38.479	-11.307	1.159	56.827
5	0.35	11.764	47.816		2717.445	49.473	-11.392	2.392	54.803
6	0.45	11.394	57.816		2647.145	60.467	-12.895	3.392	53.403
7	0.45	11.114	58.840		2557.477	71.461	-16.374	4.009	51.807
8	0.45	11.802	78.840		2463.582	82.455	-17.827	4.626	50.043
9	0.55	11.454	99.864		2364.598	93.449	-19.257	5.243	48.113
10	0.55	11.650	107.952		2254.582	104.443	-20.146	5.860	46.021
11	0.65	11.228	110.952		2140.536	111.040	-20.505	6.476	43.798
12	0.65	11.778	111.728		2024.493	116.040	-20.857	7.093	41.504
13	0.75	11.305	118.516		1906.486	124.172	-21.204	7.710	39.171
14	0.75	11.305	126.504		1784.550	129.239	-21.545	8.327	36.798
15	0.85	11.231	126.504		1664.717	132.305	-21.880	8.944	34.385
16	0.85	11.714	134.280		1540.018	136.371	-22.210	9.560	31.947
17	0.95	11.144	138.280		1415.485	140.439	-22.533	10.177	29.447
18	0.95	11.518	142.368		1287.141	144.504	-22.853	10.794	26.922
19	0.95	11.005	142.368		1162.041	148.570	-23.166	11.411	24.403
20	1.05	10.131	143.784		1027.969	150.528	-23.460	12.028	21.947
21	1.15	9.371	143.784		895.706	150.528	-23.748	12.644	19.450
22	1.15	8.569	143.640		766.226	150.528	-24.025	13.261	16.958
23	1.25	7.679	143.640		639.496	150.076	-24.291	13.878	14.459
24	1.25	6.679	143.352		513.406	149.976	-24.560	14.495	11.962
25	1.35	5.698	143.352		387.496	149.775	-24.821	15.112	9.463
26	1.35	4.698	143.064		261.584	149.624	-25.071	15.728	6.965
27	1.40	3.782	142.020		146.726	149.474	-25.300	16.345	4.468
28									1.962

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
 WEIGHT = 561.8 LBS
 BULK WET DENSITY = 2.72 SLUGS 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 2.55 2.44

CONDITIONS AT THE END OF SECTION

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	5.016	4.536	219.634	4.744	2.732	0.923	4.221
3	0.15	5.151	7.560	231.652	7.907	2.124	1.549	4.496
4	0.20	5.246	10.584	240.284	11.069	1.525	2.159	4.702
5	0.25	5.304	13.608	245.285	14.232	0.937	2.776	4.842
6	0.30	5.313	16.632	247.611	17.395	0.358	3.392	4.915
7	0.35	5.326	19.656	246.419	20.557	-0.211	4.009	4.923
8	0.40	5.336	22.680	242.061	23.720	-0.770	4.626	4.868
9	0.45	5.349	25.704	234.506	26.883	-1.320	5.280	4.750
10	0.50	5.366	28.728	221.823	30.045	-1.850	5.970	4.571
11	0.55	4.748	31.752	211.814	33.208	-2.369	6.670	4.337
12	0.60	4.551	34.776	196.856	36.370	-2.820	7.370	4.066
13	0.65	4.325	37.800	183.405	39.538	-3.238	8.064	3.763
14	0.70	4.067	40.824	164.478	42.704	-3.604	8.744	3.429
15	0.75	3.768	43.848	144.403	45.870	-3.952	9.424	3.065
16	0.80	3.419	46.872	123.976	49.036	-4.312	10.104	2.671
17	0.85	3.004	49.896	102.070	52.202	-4.677	10.784	2.248
18	0.90	2.489	52.920	78.070	55.368	-5.044	11.464	1.796
19	0.95	1.791	45.944	54.070	58.534	-4.418	12.144	1.313
20	1.00		43.968	28.003	61.700	-4.606	12.828	0.798

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
 WEIGHT = 561.8 LBS
 BULK WET DENSITY = 2.72 SLUGS 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

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	9.272	1.512	750.462	1.581	132.601	0.308	16.161
2	0.10	9.310	4.536	756.749	4.744	1.111	0.925	15.020
3	0.15	9.329	7.560	759.746	7.907	0.529	1.542	15.114
4	0.20	9.327	10.584	759.507	11.069	-0.042	2.159	15.140
5	0.25	9.306	13.608	756.097	14.232	-0.604	2.776	15.104
6	0.30	9.206	16.632	749.916	17.395	-1.170	3.392	15.005
7	0.35	9.127	19.656	739.270	20.557	-1.700	4.009	14.842
8	0.40	9.102	22.680	711.651	23.720	-2.234	4.626	14.622
9	0.45	9.010	25.704	683.109	26.883	-2.760	5.243	14.340
10	0.50	8.915	28.728	670.743	30.045	-3.286	5.860	14.099
11	0.55	8.765	31.752	643.663	33.208	-3.812	6.476	13.858
12	0.60	8.586	34.776	611.950	36.371	-4.338	7.093	13.617
13	0.65	8.372	37.800	575.682	39.534	-4.864	7.710	13.376
14	0.70	8.120	40.824	534.935	42.697	-5.390	8.327	13.135
15	0.75	7.828	43.848	489.784	45.860	-5.916	8.944	12.894
16	0.80	7.490	46.872	440.304	49.023	-6.442	9.560	12.653
17	0.85	7.102	49.896	386.568	52.186	-6.968	10.177	12.412
18	0.90	6.654	52.920	328.616	55.349	-7.494	10.794	12.171
19	0.95	6.156	55.944	266.648	58.512	-8.020	11.411	11.930
20	1.00	5.626	58.968	197.182	61.675	-8.546	12.028	11.689
21	1.05	5.073	61.992	117.121	64.838	-9.072	12.646	11.448
22	1.10	4.493	65.016	11.743	68.001	-9.598	13.264	11.207
23	1.15	3.888	68.040	2.679	71.164	-10.124	13.882	10.966

CYLINDER FLAT END IMPACTING

RADIUS = 0.948
WEIGHT = 561.8 LBS
BULK WET DENSITY = 2.72 SLUGS 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
1	0.05	13.789	2.592	16.60	711	293.310	0.308
2	0.15	13.740	7.776	64.63	134	2.095	0.925
3	0.25	13.679	12.760	163.09	155	2.957	1.542
4	0.35	13.568	18.212	168.22	398	3.807	2.159
5	0.45	13.433	23.260	155.51	819	4.642	2.762
6	0.55	13.288	28.304	144.43	243	5.463	3.370
7	0.65	13.131	33.348	133.80	665	6.270	3.979
8	0.75	12.962	38.392	123.60	1141	7.064	4.588
9	0.85	12.783	43.436	113.80	2065	7.844	5.197
10	0.95	12.595	48.480	104.39	3509	8.612	5.806
11	1.05	12.397	53.524	95.27	5501	9.365	6.415
12	1.15	12.190	58.568	86.34	8017	10.105	7.024
13	1.25	11.973	63.612	77.67	11127	10.827	7.633
14	1.35	11.747	68.656	69.24	15008	11.531	8.242
15	1.45	11.512	73.700	61.00	19544	12.218	8.851
16	1.55	11.268	78.744	52.93	24772	12.888	9.460
17	1.65	11.015	83.788	45.03	30738	13.541	10.069
18	1.75	10.753	88.832	37.28	37457	14.178	10.678
19	1.85	10.482	93.876	29.68	44945	14.800	11.287
20	1.95	10.202	98.920	22.23	53229	15.407	11.896
21	2.05	9.913	103.964	14.93	62362	16.000	12.505
22	2.15	9.615	108.999	7.78	72342	16.579	13.114
23	2.25	9.308	114.024	0.73	83169	17.144	13.723
24	2.35	8.992	119.039	-0.22	94852	17.695	14.332
25	2.45	8.667	124.044	-1.15	10829	18.232	14.941
26	2.55	8.333	129.039	-2.06	12350	18.755	15.550
27	2.65	7.990	134.024	-2.95	14067	19.265	16.159
28	2.75	7.637	139.009	-3.82	15980	19.762	16.768
29	2.85	7.274	143.984	-4.67	18091	20.246	17.377
30	2.95	6.901	148.949	-5.50	20412	20.717	17.986
31	3.05	6.518	153.904	-6.31	22955	21.175	18.595
32	3.15	6.125	158.849	-7.10	25720	21.620	19.204
33	3.25	5.722	163.784	-7.87	28707	22.052	19.813
34	3.35	5.309	168.709	-8.62	31916	22.472	20.422
35	3.45	4.886	173.624	-9.35	35347	22.880	21.031
36	3.55	4.453	178.529	-10.06	39000	23.276	21.640
37	3.65	4.010	183.424	-10.75	42875	23.660	22.249
38	3.75	3.557	188.309	-11.42	46982	24.032	22.858
39	3.85	3.094	193.184	-12.07	51321	24.392	23.467
40	3.95	2.621	198.049	-12.70	55892	24.740	24.076
41	4.05	2.138	202.904	-13.31	60695	25.076	24.685
42	4.15	1.645	207.749	-13.90	65730	25.400	25.294
43	4.25	1.142	212.584	-14.47	70997	25.712	25.903
44	4.35	0.629	217.409	-15.02	76496	26.012	26.512
45	4.45	0.106	222.224	-15.55	82227	26.300	27.121
46	4.55	-0.417	227.029	-16.06	88192	26.576	27.730
47	4.65	-0.930	231.824	-16.55	94391	26.840	28.339
48	4.75	-1.433	236.609	-17.03	100824	27.092	28.948
49	4.85	-1.926	241.384	-17.49	107491	27.332	29.557
50	4.95	-2.409	246.149	-17.93	114392	27.560	30.166
51	5.05	-2.882	250.904	-18.35	121527	27.776	30.775
52	5.15	-3.345	255.649	-18.75	128896	27.980	31.384
53	5.25	-3.798	260.384	-19.13	136499	28.172	31.993
54	5.35	-4.241	265.109	-19.49	144336	28.352	32.602
55	5.45	-4.674	269.824	-19.83	152407	28.520	33.211
56	5.55	-5.097	274.529	-20.15	160712	28.676	33.820
57	5.65	-5.510	279.224	-20.45	169251	28.820	34.429
58	5.75	-5.913	283.909	-20.73	178024	28.952	35.038
59	5.85	-6.306	288.584	-21.00	187031	29.072	35.647
60	5.95	-6.689	293.249	-21.25	196272	29.180	36.256
61	6.05	-7.062	297.904	-21.49	205747	29.276	36.865
62	6.15	-7.425	302.549	-21.71	215456	29.360	37.474
63	6.25	-7.778	307.184	-21.92	225399	29.432	38.083
64	6.35	-8.121	311.809	-22.12	235576	29.492	38.692
65	6.45	-8.454	316.424	-22.31	245987	29.540	39.301
66	6.55	-8.777	321.029	-22.49	256632	29.576	39.910
67	6.65	-9.090	325.624	-22.66	267511	29.600	40.519
68	6.75	-9.393	330.209	-22.82	278624	29.612	41.128
69	6.85	-9.686	334.784	-22.97	289971	29.612	41.737
70	6.95	-9.969	339.349	-23.11	301552	29.600	42.346
71	7.05	-10.242	343.904	-23.24	313367	29.576	42.955
72	7.15	-10.505	348.449	-23.36	325406	29.540	43.564
73	7.25	-10.758	352.984	-23.47	337669	29.492	44.173
74	7.35	-11.001	357.509	-23.57	350146	29.432	44.782
75	7.45	-11.234	362.024	-23.66	362837	29.360	45.391
76	7.55	-11.457	366.529	-23.74	375742	29.276	46.000
77	7.65	-11.670	371.024	-23.81	388861	29.180	46.609
78	7.75	-11.873	375.509	-23.88	402194	29.072	47.218
79	7.85	-12.066	380.000	-23.94	415741	28.952	47.827
80	7.95	-12.249	384.500	-24.00	429492	28.820	48.436
81	8.05	-12.422	389.000	-24.05	443447	28.676	49.045
82	8.15	-12.585	393.500	-24.09	457606	28.520	49.654
83	8.25	-12.738	398.000	-24.12	471969	28.352	50.263
84	8.35	-12.881	402.500	-24.15	486536	28.172	50.872
85	8.45	-13.014	407.000	-24.17	501307	27.980	51.481
86	8.55	-13.137	411.500	-24.19	516282	27.776	52.090
87	8.65	-13.250	416.000	-24.20	531461	27.560	52.699
88	8.75	-13.353	420.500	-24.21	546844	27.332	53.308
89	8.85	-13.446	425.000	-24.22	562431	27.092	53.917
90	8.95	-13.529	429.500	-24.23	578222	26.840	54.526
91	9.05	-13.602	434.000	-24.24	594217	26.576	55.135
92	9.15	-13.665	438.500	-24.24	610416	26.300	55.744
93	9.25	-13.718	443.000	-24.24	626819	26.012	56.353
94	9.35	-13.761	447.500	-24.24	643426	25.712	56.962
95	9.45	-13.794	452.000	-24.24	660237	25.400	57.571
96	9.55	-13.817	456.500	-24.24	677252	25.076	58.180
97	9.65	-13.830	461.000	-24.24	694471	24.740	58.789
98	9.75	-13.833	465.500	-24.24	711894	24.392	59.398
99	9.85	-13.826	470.000	-24.24	729521	24.032	60.007
100	9.95	-13.809	474.500	-24.24	747352	23.660	60.616

RADIUS = 0.948
 WEIGHT = 51.18 LBS
 BULK WET DENSITY = 2.72 SLUGS PER CUBIC FOOT
 DRAG COEFFICIENT = 0.90

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	2032	5.271	518.156	0.308	63.928
2	0.10	18.203	15.120	2294	15.816	7.014	0.925	58.054
3	0.15	17.859	35.280	2727	26.358	8.558	1.542	57.175
4	0.20	17.657	45.440	2724	26.898	11.076	2.176	56.124
5	0.25	17.415	55.600	2648	27.440	13.035	2.776	55.904
6	0.30	17.145	65.760	2566	27.982	14.478	3.392	55.516
7	0.35	16.850	75.920	2479	28.524	15.896	4.009	55.064
8	0.40	16.536	86.080	2372	29.067	17.291	4.626	54.580
9	0.45	16.212	96.240	2272	29.609	18.665	5.243	54.064
10	0.50	15.876	106.400	2167	30.151	19.605	5.860	46.349
11	0.55	15.536	116.560	2063	30.693	20.130	6.476	44.190
12	0.60	15.192	126.720	1953	31.234	20.646	7.093	41.948
13	0.65	14.845	136.880	1839	31.776	21.152	7.710	39.690
14	0.70	14.495	147.040	1723	32.318	21.646	8.327	37.423
15	0.75	14.143	157.200	1603	32.859	22.125	8.944	35.143
16	0.80	13.788	167.360	1480	33.399	22.595	9.560	32.857
17	0.85	13.430	177.520	1354	33.938	23.053	10.177	30.562
18	0.90	13.070	187.680	1226	34.477	23.503	10.791	28.265
19	0.95	12.708	197.840	1097	35.013	23.944	11.404	25.962
20	1.00	12.345	207.999	967	35.545	24.379	12.012	23.655
21	1.05	11.980	218.159	836	36.073	24.806	12.618	21.342
22	1.10	11.613	228.319	705	36.600	25.226	13.224	19.028
23	1.15	11.245	238.479	574	37.123	25.639	13.825	16.713
24	1.20	10.876	248.639	443	37.645	26.045	14.425	14.398
25	1.25	10.507	258.799	312	38.165	26.444	15.021	12.083
26	1.30	10.138	268.959	181	38.683	26.836	15.615	9.768
27	1.35	9.769	279.119	50	39.199	27.221	16.205	7.453

APPENDIX F: COMPUTATION OF THE PENETRATION OF A CUBE

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

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[illegible]


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C 450 PRINT,AMASS(I)
C      CONTINUE

C      COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
C      DMASS(I)=0.0
C      DO 500 I=2,N
C      DMASS(I)=AMASS(I)-AMASS(I-1)
C      PRINT,DMASS(I)
C      CONTINUE

C 500 SUM DMASS, IT SHOULD BE CLOSE TO AMASS(N)
C      CDMASS=DMASS(1)
C      DO 550 I=2,N
C      CDMASS=CDMASS+DMASS(I)
C      CONTINUE
C      PRINT,CDMASS,AMASS(N)

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
C      CT=CFOOT*CNC
C      DO 600 I=1,100
C      WS(I)=CT*COH*AREA(I)*DX
C      PRINT,WS(I)
C      CONTINUE

C 600 CALCULATE WORK DONE BY BUOYANCY
C      GAMMA=BWD*G
C      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
C      SUMSUB(1)=2.0*WB(1)
C      DO 700 I=2,N
C      WORK TO SUBMERGE SECTION
C      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C      WORK TO CONTINUE SECTION AFTER SUBMERGING
C      WBSUB(I)=2.0*US(I)
C      TOTAL WORK OF THE SUBMERGED SECTIONS
C      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)

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E(1)=BMASS*VO**2/2.
CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
EP=WT*DX

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

VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
V(1)=0.0
DO 2000 I=1,100
SECTION TO COMPUTE SHEAR STRENGTH
NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
TO POUNDS PER SQUARE FOOT FOR THE CALCULATION

FOR THE CUBE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE PENETRA
TION DEPTH
DEPTH=I*DX-Y

CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH DATA
DEPTHI=DEPTH*12.

SELECT PROPER DEPTH

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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

FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
AVERAGE OF THE LAST THREE AND CALL IT CONSTANT

IF(DEPTH.GT.4.0) GO TO 9

FORMULAS FOR SHEAR STRENGTH FOLLOW
LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED

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.

SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
SPS=SSS*144.
CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
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)

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SECTION TO COMPUTE THE WORK DONE BY DRAG
APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
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))+4MAS
2S(I)
IF (VELOSQ.LE.0.0)GO TO 1000
V(I+1)=SQRT(VELOSQ)
C
CALCULATE E AT NEXT SECTION
E(I+1)=BMASS*V(I+1)**2/2.
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
COMPUTE PENETRATION DEPTH
XXX=I*DX
C
PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
WORK DONE BY SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
AND DRAG
C
WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
CONTINUE
2000 CONTINUE
1000 CONTINUE
2050 FORMAT(15)
2060 FORMAT(F5.1,8F5.2)
2100 FORMAT(1,1,60X,1,60X,WET DENSITY =,F5.2,SLUGS PER CUBIC FOOT,9X,DRAG
2200 LBS./9X,BULK =,F5.2,IMPACT VELOCITY EQUALS,F5.1//10X,SEDIMENT SHEAR
2300 COEFFICIENT,10X,STRENGTHS IN HALF FOOT CONDITIONS,28X,FOOT POULVER,5X,80DY,ENERGATION,6X,STATION,4X,VE
2500 2N SECTION,3X,SHEAR,3X,FORM DRAG,17X,SECTION,6X,FEET,8X,FT/SEC,2X,ST
2600 3BUOYANT,3X,FORM DRAG,17X,SECTION,6X,FEET,8X,FT/SEC,2X,ST
6FORCES,16X,13,3X,F12.2,7F12.3)
END

```


CURE

SIDE WEIGHT = 2.000
702.8
BULK WEIGHT = 2.72 SLUGS 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

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS
1	0.05	1.475	3.456	23.756
2	0.10	1.865	10.288	37.995
3	0.15	1.884	17.280	43.012
4	0.20	1.891	24.192	39.047
5	0.25	1.552	31.104	28.297
6	0.30	0.676	38.016	4.997

WORK DONE IN SECTION - FOOT POUNDS			
STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
5.122	5.660	0.437	0.163
15.165	3.390	1.311	0.842
25.609	1.198	2.185	1.119
35.853	-0.845	3.059	1.135
46.096	-3.038	3.933	0.896
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

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS
1	0.05	4.648	5.760	235.954
2	0.10	4.861	17.280	237.303
3	0.15	4.532	28.800	224.288
4	0.20	4.259	40.320	197.231
5	0.25	3.785	51.840	158.446
6	0.30	3.060	63.360	102.246
7	0.35	1.790	74.880	34.275

WORK DONE IN SECTION - FOOT POUNDS			
STATIC FORCES	SEDIMENT INERTIA	BUOYANT FORCES	FORM DRAG FORCES
8.536	56.215	0.437	7.035
25.839	-0.321	1.311	6.547
42.682	-3.101	2.185	6.385
59.754	-6.445	3.059	5.827
76.899	-8.717	3.933	4.890
93.827	-12.913	4.807	3.543
110.912	-16.027	5.681	1.783

CUBE

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

IMPACT VELOCITY EQUALS 10.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE APE

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	5.335	210.540	0.437	27.273
2	0.15	8.968	10.000	878.418	16.006	-1.261	1.311	24.376
3	0.20	8.894	18.000	864.018	26.676	-1.430	2.185	24.104
4	0.25	8.774	25.000	840.712	37.346	-1.551	3.059	23.581
5	0.30	8.605	32.000	808.719	48.017	-1.653	3.933	22.817
6	0.35	8.387	39.000	768.155	58.687	-1.753	4.807	21.813
7	0.40	8.116	46.000	719.353	69.358	-1.853	5.681	20.576
8	0.45	7.788	54.000	667.710	80.028	-1.952	6.555	19.142
9	0.50	7.393	61.000	612.432	90.688	-2.050	7.429	17.421
10	0.55	6.931	68.000	524.710	101.369	-2.148	8.303	15.512
11	0.60	6.396	76.000	446.432	111.945	-2.240	9.177	13.424
12	0.65	5.795	82.000	383.532	122.508	-2.332	10.051	11.229
13	0.70	5.060	85.000	328.491	133.089	-2.422	10.925	8.961
14	0.75	4.181	85.608	268.491	143.871	-2.513	11.799	6.618
15	0.80	3.137	85.632	205.573	154.353	-2.604	12.673	4.157
16							13.547	1.577

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CURE

SIDE = 2.000
 WEIGHT = 792.8 LBS
 BULK WET DENSITY = 2.72 SLUGS 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	1926.113	6.509	466.510	0.437	60.925
2	0.15	11.213	13.176	1926.222	19.527	-17.588	1.311	53.735
3	0.20	12.134	21.960	1188.620	13.545	-12.064	2.185	51.710
4	0.25	12.956	30.744	1177.621	19.563	-14.952	3.059	49.953
5	0.35	12.466	39.512	1169.227	45.598	-17.167	4.801	47.827
6	0.40	12.163	47.880	1152.618	71.634	-19.430	5.681	45.441
7	0.45	11.422	55.856	1142.606	97.652	-21.644	6.555	43.800
8	0.50	11.977	73.648	1131.603	109.670	-23.809	7.429	40.910
9	0.55	10.494	88.648	1120.209	112.653	-25.981	8.303	37.936
10	0.60	9.988	90.216	1109.418	113.700	-26.997	9.151	35.700
11	0.65	9.457	91.884	976.650	113.603	-27.013	10.925	33.562
12	0.70	8.292	94.384	749.150	113.603	-27.044	11.709	29.421
13	0.75	8.629	96.968	520.150	114.400	-27.044	12.673	25.278
14	0.80	7.913	98.556	304.943	114.400	-27.044	13.547	21.152
15	0.85	6.913	98.556	204.943	114.400	-27.044	14.421	17.027
16	0.90	5.193	99.720	160.943	115.000	-27.044	15.295	12.897
17	0.95	4.068	101.308	116.943	115.000	-27.044	16.169	9.768
18	1.00	2.386	102.576	62.157	116.909	-28.154	17.043	6.648
19	1.05						17.917	3.515

CUBE

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

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

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	9.003	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	3220.068	40.014	-19.213	1.185	92.779
4	0.20	17.173	37.800	3113.030	56.020	-21.605	3.059	90.386
5	0.25	16.894	48.600	3016.951	72.025	-21.725	3.933	87.643
6	0.30	16.579	59.400	2901.984	88.031	-27.390	4.807	84.946
7	0.35	16.238	70.200	2779.478	104.036	-29.296	5.681	81.313
8	0.40	15.887	81.000	2653.420	120.043	-29.544	6.555	77.680
9	0.45	15.432	91.800	2523.513	136.050	-35.036	7.429	73.755
10	0.50	14.975	102.600	2393.540	152.058	-37.474	8.303	69.543
11	0.55	14.517	113.400	2272.402	168.065	-39.740	9.177	65.115
12	0.60	14.058	124.200	2159.177	184.073	-38.982	10.051	60.603
13	0.65	13.597	135.000	2045.782	199.081	-39.099	10.925	56.051
14	0.70	13.134	145.800	1932.240	214.089	-39.212	11.799	51.001
15	0.75	12.668	156.600	1818.551	229.097	-39.334	12.673	46.438
16	0.80	12.200	167.400	1704.808	244.105	-39.453	13.547	42.401
17	0.85	11.730	178.200	1591.026	259.113	-39.572	14.421	38.861
18	0.90	11.257	189.000	1477.305	274.121	-39.690	15.295	35.247
19	0.95	10.781	199.800	1363.545	289.129	-39.808	16.169	32.366
20	1.00	10.303	210.600	1249.849	304.137	-39.925	17.043	29.849
21	1.05	9.824	221.400	1136.116	319.145	-39.743	17.917	27.439
22	1.10	9.344	232.200	1022.346	334.153	-39.435	18.791	25.439
23	1.15	8.863	243.000	908.527	349.161	-38.727	19.665	23.435
24	1.20	8.381	253.800	794.660	364.169	-38.031	20.539	21.438

CORE USAGE

OBJECT CODE= 8032 BYTES, ARRAY AREA= 4200 BYTES, TOTAL AREA AVAILABLE= 43104
COMPILE TIME= 0.69 SEC, EXECUTION TIME= 0.66 SEC, WATFIV - VERSION 1 LEVEL 1 JANUARY 1973 DATE= 70/281


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

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C      REA=PI*A*B
C      PRINT,A,B,REA
C
C      400  AMASS(I-1)=EK*(2./3.)*8WD*PI*A**2*B
C          CONTINUE
C
C      AMASS REMAINS THE SAME AFTER THE MAX AREA
C
C      450  DO 450 I=N,100
C          AMASS(I)=AMASS(N)
C          PRINT,AMASS(N)
C          CONTINUE
C
C      COMPUTE CHANGE IN AMASS FROM SECTION TO SECTION
C      DMASS(I)=0.0
C      500  DO 500 I=2,N
C          DMASS(I)=AMASS(I)-AMASS(I-1)
C          PRINT,DMASS(N)
C          CONTINUE
C
C      600  CONTINUE
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
C      CT=CFOOT*CNC
C      600  DO 600 I=1,100
C          WS(I)=CT*COH*AREA(I)*DX
C          CONTINUE
C
C      CALCULATE WORK DONE BY BUOYANCY
C
C      GAMMA=RWD*G
C      WB(1)=(GAMMA*AREA(1)*DX**2)/2.
C      SUMSUB(1)=2.0*WB(1)
C      700  DO 700 I=2,N
C
C      WORK TO SUBMERGE SECTION
C      US(I)=(GAMMA*AREA(I)*DX**2)/2.
C
C      WORK TO CONTINUE SECTION AFTER SUBMERGING
C      WBSUB(I)=2.0*US(I)
C
C      TOTAL WORK OF THE SUBMERGED SECTIONS
C      SUMSUB(I)=SUMSUB(I-1)+WBSUB(I)

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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

FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
AVERAGE OF THE LAST THREE AND CALL IT CONSTANT

IF(DEPTH.GT.4.0) GO TO 9

FORMULAS FOR SHEAR STRENGTH FOLLOW
LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED

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.

SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
SPS=SS*144.
CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
ULT. BEARING CAPACITY EQUALS C*FOOT X CNC X AVG AREA X SPS X DX
CT=C*FOOT*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)

SECTION TO COMPUTE THE WORK DONE BY DRAG

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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=(V(I)+V(I+1))/2.
WDRAG=.5*WDC*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
CALCULATE E AT NEXT SECTION
E(I+1)=BMASS*V(I+1)**2/2.
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
COMPUTE PENETRATION DEPTH
XXX=I*DX
C
PRINT THE SECTION, DEPTH OF PENETRATION, VELOCITY AT THE END OF
SECTION, SHEAR STRENGTH IN SECTION, BODY ENERGY AT END OF SECTION,
WORK DONE BY SEDIMENT, ADDED MASS PLUS DISPLACED MASS, BUOYANCY,
AND DRAG
WRITE(6,2600) I,XXX,V(I+1),SPS,E(I+1),WS(I),EAM,WB(I),WDRAG
2600 CONTINUE
1000 CONTINUE
2050 FORMAT(15)
2060 FORMAT(F5.1,6X,F5.2)
2100 FORMAT(F5.1,6X,F5.2)
2200 FORMAT(F5.1,6X,F5.2)
2300 FORMAT(F5.1,6X,F5.2)
2500 FORMAT(F5.1,6X,F5.2)
2600 FORMAT(F5.1,6X,F5.2)
2700 FORMAT(F5.1,6X,F5.2)
2800 FORMAT(F5.1,6X,F5.2)
2900 FORMAT(F5.1,6X,F5.2)
3000 FORMAT(F5.1,6X,F5.2)
3100 FORMAT(F5.1,6X,F5.2)
3200 FORMAT(F5.1,6X,F5.2)
3300 FORMAT(F5.1,6X,F5.2)
3400 FORMAT(F5.1,6X,F5.2)
3500 FORMAT(F5.1,6X,F5.2)
3600 FORMAT(F5.1,6X,F5.2)
3700 FORMAT(F5.1,6X,F5.2)
3800 FORMAT(F5.1,6X,F5.2)
3900 FORMAT(F5.1,6X,F5.2)
4000 FORMAT(F5.1,6X,F5.2)
4100 FORMAT(F5.1,6X,F5.2)
4200 FORMAT(F5.1,6X,F5.2)
4300 FORMAT(F5.1,6X,F5.2)
4400 FORMAT(F5.1,6X,F5.2)
4500 FORMAT(F5.1,6X,F5.2)
4600 FORMAT(F5.1,6X,F5.2)
4700 FORMAT(F5.1,6X,F5.2)
4800 FORMAT(F5.1,6X,F5.2)
4900 FORMAT(F5.1,6X,F5.2)
5000 FORMAT(F5.1,6X,F5.2)
5100 FORMAT(F5.1,6X,F5.2)
5200 FORMAT(F5.1,6X,F5.2)
5300 FORMAT(F5.1,6X,F5.2)
5400 FORMAT(F5.1,6X,F5.2)
5500 FORMAT(F5.1,6X,F5.2)
5600 FORMAT(F5.1,6X,F5.2)
5700 FORMAT(F5.1,6X,F5.2)
5800 FORMAT(F5.1,6X,F5.2)
5900 FORMAT(F5.1,6X,F5.2)
6000 FORMAT(F5.1,6X,F5.2)
6100 FORMAT(F5.1,6X,F5.2)
6200 FORMAT(F5.1,6X,F5.2)
6300 FORMAT(F5.1,6X,F5.2)
6400 FORMAT(F5.1,6X,F5.2)
6500 FORMAT(F5.1,6X,F5.2)
6600 FORMAT(F5.1,6X,F5.2)
6700 FORMAT(F5.1,6X,F5.2)
6800 FORMAT(F5.1,6X,F5.2)
6900 FORMAT(F5.1,6X,F5.2)
7000 FORMAT(F5.1,6X,F5.2)
7100 FORMAT(F5.1,6X,F5.2)
7200 FORMAT(F5.1,6X,F5.2)
7300 FORMAT(F5.1,6X,F5.2)
7400 FORMAT(F5.1,6X,F5.2)
7500 FORMAT(F5.1,6X,F5.2)
7600 FORMAT(F5.1,6X,F5.2)
7700 FORMAT(F5.1,6X,F5.2)
7800 FORMAT(F5.1,6X,F5.2)
7900 FORMAT(F5.1,6X,F5.2)
8000 FORMAT(F5.1,6X,F5.2)
8100 FORMAT(F5.1,6X,F5.2)
8200 FORMAT(F5.1,6X,F5.2)
8300 FORMAT(F5.1,6X,F5.2)
8400 FORMAT(F5.1,6X,F5.2)
8500 FORMAT(F5.1,6X,F5.2)
8600 FORMAT(F5.1,6X,F5.2)
8700 FORMAT(F5.1,6X,F5.2)
8800 FORMAT(F5.1,6X,F5.2)
8900 FORMAT(F5.1,6X,F5.2)
9000 FORMAT(F5.1,6X,F5.2)
9100 FORMAT(F5.1,6X,F5.2)
9200 FORMAT(F5.1,6X,F5.2)
9300 FORMAT(F5.1,6X,F5.2)
9400 FORMAT(F5.1,6X,F5.2)
9500 FORMAT(F5.1,6X,F5.2)
9600 FORMAT(F5.1,6X,F5.2)
9700 FORMAT(F5.1,6X,F5.2)
9800 FORMAT(F5.1,6X,F5.2)
9900 FORMAT(F5.1,6X,F5.2)

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IMPACT VELOCITY EQUALS 0.0
 RECTANGLE
 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 = 2.00 FEET
 LENGTH = 3.00 FEET
 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	1.431	3.600	32.272	8.003	9.598	0.656	0.210
2	0.10	1.700	10.800	50.536	24.008	5.632	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	46.582	58.020	-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	330.880	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	356.588	28.010	2.349	3.278	9.203
4	0.20	4.743	17.640	354.778	39.218	-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	4.624	27.720	322.804	61.622	-6.141	7.211	8.694
7	0.35	4.310	32.760	293.019	72.825	-8.959	8.523	8.033
8	0.40	4.015	37.800	254.765	84.039	-11.521	9.833	7.136
9	0.45	3.621	42.840	206.657	95.233	-14.130	11.144	6.004
10	0.50	3.091	47.880	150.657	106.237	-16.696	12.455	4.639
11	0.55	2.284	55.224	82.237	122.763	-20.348	13.766	2.977

RECTANGLE

WIDTH = 2.0 FEET
 LENGTH = 3.00 FEET
 WEIGHT = 1014.75 LBS
 BULK REL 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

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	8.758	3.672	1219.820	8.163	362.771	0.656	36.373
2	0.10	8.774	11.870	1214.055	24.714	-1.714	1.947	31.761
3	0.20	8.705	23.704	1184.946	40.714	-5.683	1.278	31.437
4	0.30	8.587	33.032	1152.755	57.140	-9.572	1.589	30.767
5	0.35	8.419	40.734	1117.190	73.466	-13.332	1.900	29.759
6	0.40	8.199	47.334	1060.372	89.791	-17.781	2.211	28.420
7	0.45	7.924	52.024	999.609	106.117	-20.259	2.523	26.753
8	0.50	7.589	55.768	919.259	122.768	-24.885	2.834	24.473
9	0.55	7.106	59.464	819.706	138.094	-27.831	3.145	22.869
10	0.60	6.524	63.110	706.248	155.979	-31.473	3.455	19.018
11	0.65	5.797	71.460	582.969	176.462	-34.337	3.766	17.034
12	0.70	4.916	79.408	462.182	187.304	-35.009	4.077	14.970
13	0.75	3.916	84.455	341.096	187.746	-36.810	4.388	12.821
14	0.75	2.737		118.096			17.699	10.970
15	0.75						19.010	4.564

RECTANGLE

WIDTH = 2.00 FEET
LENGTH = 3.00 FEET
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 2.80 2.96

CONDITIONS AT THE END OF SECTION

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	2706.221	6.092	804.823	0.556	81.305
2	0.10	13.927	18.288	2675.613	18.246	-9.102	1.967	70.331
3	0.15	12.904	19.682	2658.532	30.411	-1.979	1.278	69.306
4	0.20	12.657	19.124	2652.572	42.739	-14.799	5.589	68.711
5	0.30	12.485	20.098	2641.520	54.903	-17.562	7.211	66.051
6	0.35	12.285	20.558	2632.018	66.068	-22.270	8.833	63.105
7	0.40	11.814	21.512	2620.904	79.232	-25.526	9.522	61.076
8	0.45	11.558	21.952	2611.039	91.236	-28.075	9.145	58.623
9	0.50	11.294	22.416	2603.104	103.560	-30.769	11.455	56.101
10	0.55	11.034	22.880	2597.197	115.628	-32.569	11.777	53.323
11	0.60	10.775	23.344	2593.499	126.451	-34.569	11.088	50.798
12	0.65	10.530	23.808	2591.137	136.475	-36.576	10.399	47.923
13	0.70	10.303	24.272	2590.962	146.498	-38.581	9.710	43.902
14	0.75	10.091	24.736	2592.373	156.522	-40.586	9.021	40.500
15	0.80	9.874	25.200	2594.759	166.545	-42.591	8.332	36.940
16	0.85	9.671	25.664	2597.133	176.568	-44.596	7.643	33.250
17	0.90	9.471	26.128	2599.505	186.591	-46.601	6.954	29.586
18	0.95	9.275	26.592	2601.877	196.614	-48.606	6.265	25.982
19	1.00	9.075	27.056	2604.250	206.637	-50.611	5.576	22.440
20	1.05	8.873	27.520	2606.623	216.660	-52.616	4.887	18.877
21	1.10	8.673	27.984	2609.000	226.683	-54.621	4.198	15.299
22	1.15	8.475	28.448	2611.377	236.706	-56.626	3.509	11.722
23	1.20	8.275	28.912	2613.754	246.729	-58.631	2.820	8.149
24	1.25	8.075	29.376	2616.131	256.752	-60.636	2.131	4.576

WIDTH = 2.00 FEET
 LENGTH = 3.00 FEET
 WEIGHT = 1014.75 LBS
 BULK NET 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 2.75 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	13.099	2.880	2705.577	6.402	804.751	0.657	81.302
2	0.15	12.022	12.400	2663.360	19.201	-9.318	1.967	70.215
3	0.25	12.792	12.100	2631.729	34.622	-15.337	3.278	69.053
4	0.35	12.644	12.500	2620.530	57.420	-15.293	5.900	66.058
5	0.45	12.225	12.600	2549.773	70.423	-11.034	8.123	62.893
6	0.55	11.713	12.700	2475.149	83.234	-23.517	10.345	60.693
7	0.65	11.165	12.800	2375.877	96.843	-31.703	12.445	58.554
8	0.75	10.546	12.900	2253.717	121.244	-30.847	14.567	52.721
9	0.85	9.922	13.000	2113.629	146.924	-30.157	16.699	49.131
10	0.95	9.293	13.100	1953.079	172.202	-30.561	18.899	44.893
11	1.05	8.634	13.200	1777.269	197.430	-29.357	21.010	41.821
12	1.15	7.969	13.300	1594.492	222.961	-28.781	23.123	39.841
13	1.25	7.309	13.400	1405.302	248.757	-27.018	25.234	37.943
14	1.35	6.639	13.500	1210.094	274.987	-26.234	27.345	36.041
15	1.45	6.000	13.600	1010.311	298.757	-25.514	29.455	34.167
16	1.55	5.399	13.700	810.357	323.157	-25.029	31.567	32.304
17	1.65	4.822	13.800	610.340	347.987	-25.092	33.677	30.404
18	1.75	4.269	13.900	410.351	372.987	-25.092	35.787	28.505
19	1.85	3.744	14.000	210.357	397.987	-25.092	37.899	26.610
20	1.95	3.244	14.100	10.357	422.987	-25.092	39.980	24.710
21	2.05	2.769	14.200	10.357	447.987	-25.092	42.041	22.810
22	2.15	2.309	14.300	10.357	472.987	-25.092	44.093	20.910
23	2.25	1.869	14.400	10.357	497.987	-25.092	46.134	19.010
24	2.35	1.444	14.500	10.357	522.987	-25.092	48.165	17.110
25	2.45	1.039	14.600	10.357	547.987	-25.092	50.186	15.210
26	2.55	0.644	14.700	10.357	572.987	-25.092	52.197	13.310
27	2.65	0.269	14.800	10.357	597.987	-25.092	54.198	11.410
28	2.75	0.000	14.900	10.357	622.987	-25.092	56.189	9.510
29	2.85	0.000	15.000	10.357	647.987	-25.092	58.170	7.610
30	2.95	0.000	15.100	10.357	672.987	-25.092	60.151	5.710
31	3.05	0.000	15.200	10.357	697.987	-25.092	62.132	3.810
32	3.15	0.000	15.300	10.357	722.987	-25.092	64.113	1.910

RECTANGLE

WIDTH = 2.00 FEET
LENGTH = 3.00 FEET
WEIGHT = 1014.75 LBS
BULK 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	421	1.572	4786.410	161	1423.468	0.656	144.199
2	0.10	298	1.572	4715.758	1487	-21.905	1.278	124.039
3	0.15	162	9.360	4665.555	120.807	-21.905	3.278	122.193
4	0.20	155	13.248	4480.246	237.133	-25.557	5.590	118.045
5	0.25	133	16.592	4289.281	377.776	-27.053	7.212	113.745
6	0.30	102	20.360	4100.844	54.099	-28.392	8.523	111.709
7	0.35	93	24.216	4033.351	62.745	-31.444	9.145	110.799
8	0.40	88	27.144	3853.924	79.670	-31.444	12.455	107.911
9	0.45	84	29.839	3739.139	87.453	-34.347	12.767	105.136
10	0.50	80	32.434	3621.655	93.433	-34.347	13.089	102.110
11	0.55	77	35.030	3503.409	99.131	-35.513	13.411	96.061
12	0.60	73	37.238	3383.403	104.745	-35.513	13.733	92.989
13	0.65	70	39.446	3303.403	104.745	-35.513	13.733	89.748
14	0.70	68	41.654	3223.403	104.745	-35.513	13.733	86.507
15	0.75	65	43.862	3143.403	104.745	-35.513	13.733	83.266
16	0.80	63	45.729	3063.403	104.745	-35.513	13.733	80.025
17	0.85	61	47.596	2983.403	104.745	-35.513	13.733	76.784
18	0.90	59	49.463	2903.403	104.745	-35.513	13.733	73.543
19	0.95	57	51.330	2823.403	104.745	-35.513	13.733	70.302
20	1.00	55	53.197	2743.403	104.745	-35.513	13.733	67.061
21	1.05	53	55.064	2663.403	104.745	-35.513	13.733	63.820
22	1.10	51	56.931	2583.403	104.745	-35.513	13.733	60.579
23	1.15	49	58.798	2503.403	104.745	-35.513	13.733	57.338
24	1.20	47	60.665	2423.403	104.745	-35.513	13.733	54.097
25	1.25	45	62.532	2343.403	104.745	-35.513	13.733	50.856
26	1.30	43	64.399	2263.403	104.745	-35.513	13.733	47.615
27	1.35	41	66.266	2183.403	104.745	-35.513	13.733	44.374
28	1.40	39	68.133	2103.403	104.745	-35.513	13.733	41.133
29	1.45	37	70.000	2023.403	104.745	-35.513	13.733	37.892
30	1.50	35	71.867	1943.403	104.745	-35.513	13.733	34.651
31	1.55	33	73.734	1863.403	104.745	-35.513	13.733	31.410
32	1.60	31	75.601	1783.403	104.745	-35.513	13.733	28.169
33	1.65	29	77.468	1703.403	104.745	-35.513	13.733	24.928
34	1.70	27	79.335	1623.403	104.745	-35.513	13.733	21.687
35	1.75	25	81.202	1543.403	104.745	-35.513	13.733	18.446
36	1.80	23	83.069	1463.403	104.745	-35.513	13.733	15.205
37	1.85	21	84.936	1383.403	104.745	-35.513	13.733	11.964
38	1.90	19	86.803	1303.403	104.745	-35.513	13.733	8.723
39	1.95	17	88.670	1223.403	104.745	-35.513	13.733	5.482
40	2.00	15	90.537	1143.403	104.745	-35.513	13.733	2.241
41	2.05	13	92.404	1063.403	104.745	-35.513	13.733	-1.000
42	2.10	11	94.271	983.403	104.745	-35.513	13.733	-4.241
43	2.15	9	96.138	903.403	104.745	-35.513	13.733	-7.482
44	2.20	7	98.005	823.403	104.745	-35.513	13.733	-10.723
45	2.25	5	99.872	743.403	104.745	-35.513	13.733	-13.964
46	2.30	3	101.739	663.403	104.745	-35.513	13.733	-17.205
47	2.35	1	103.606	583.403	104.745	-35.513	13.733	-20.446
48	2.40	0	105.473	503.403	104.745	-35.513	13.733	-23.687
49	2.45	0	107.340	423.403	104.745	-35.513	13.733	-26.928
50	2.50	0	109.207	343.403	104.745	-35.513	13.733	-30.169
51	2.55	0	111.074	263.403	104.745	-35.513	13.733	-33.410
52	2.60	0	112.941	183.403	104.745	-35.513	13.733	-36.651
53	2.65	0	114.808	103.403	104.745	-35.513	13.733	-39.892
54	2.70	0	116.675	23.403	104.745	-35.513	13.733	-43.133
55	2.75	0	118.542	-17.403	104.745	-35.513	13.733	-46.374
56	2.80	0	120.409	-97.403	104.745	-35.513	13.733	-49.615
57	2.85	0	122.276	-177.403	104.745	-35.513	13.733	-52.856
58	2.90	0	124.143	-257.403	104.745	-35.513	13.733	-56.097
59	2.95	0	126.010	-337.403	104.745	-35.513	13.733	-59.338
60	3.00	0	127.877	-417.403	104.745	-35.513	13.733	-62.579
61	3.05	0	129.744	-497.403	104.745	-35.513	13.733	-65.820
62	3.10	0	131.611	-577.403	104.745	-35.513	13.733	-69.061
63	3.15	0	133.478	-657.403	104.745	-35.513	13.733	-72.302
64	3.20	0	135.345	-737.403	104.745	-35.513	13.733	-75.543
65	3.25	0	137.212	-817.403	104.745	-35.513	13.733	-78.784
66	3.30	0	139.079	-897.403	104.745	-35.513	13.733	-82.025
67	3.35	0	140.946	-977.403	104.745	-35.513	13.733	-85.266
68	3.40	0	142.813	-1057.403	104.745	-35.513	13.733	-88.507
69	3.45	0	144.680	-1137.403	104.745	-35.513	13.733	-91.748
70	3.50	0	146.547	-1217.403	104.745	-35.513	13.733	-94.989
71	3.55	0	148.414	-1297.403	104.745	-35.513	13.733	-98.230
72	3.60	0	150.281	-1377.403	104.745	-35.513	13.733	-101.471
73	3.65	0	152.148	-1457.403	104.745	-35.513	13.733	-104.712
74	3.70	0	154.015	-1537.403	104.745	-35.513	13.733	-107.953
75	3.75	0	155.882	-1617.403	104.745	-35.513	13.733	-111.194
76	3.80	0	157.749	-1697.403	104.745	-35.513	13.733	-114.435
77	3.85	0	159.616	-1777.403	104.745	-35.513	13.733	-117.676
78	3.90	0	161.483	-1857.403	104.745	-35.513	13.733	-120.917
79	3.95	0	163.350	-1937.403	104.745	-35.513	13.733	-124.158
80	4.00	0	165.217	-2017.403	104.745	-35.513	13.733	-127.399
81	4.05	0	167.084	-2097.403	104.745	-35.513	13.733	-130.640
82	4.10	0	168.951	-2177.403	104.745	-35.513	13.733	-133.881
83	4.15	0	170.818	-2257.403	104.745	-35.513	13.733	-137.122
84	4.20	0	172.685	-2337.403	104.745	-35.513	13.733	-140.363
85	4.25	0	174.552	-2417.403	104.745	-35.513	13.733	-143.604
86	4.30	0	176.419	-2497.403	104.745	-35.513	13.733	-146.845
87	4.35	0	178.286	-2577.403	104.745	-35.513	13.733	-150.086
88	4.40	0	180.153	-2657.403	104.745	-35.513	13.733	-153.327
89	4.45	0	182.020	-2737.403	104.745	-35.513	13.733	-156.568
90	4.50	0	183.887	-2817.403	104.745	-35.513	13.733	-159.809
91	4.55	0	185.754	-2897.403	104.745	-35.513	13.733	-163.050
92	4.60	0	187.621	-2977.403	104.745	-35.513	13.733	-166.291
93	4.65	0	189.488	-3057.403	104.745	-35.513	13.733	-169.532
94	4.70	0	191.355	-3137.403	104.745	-35.513	13.733	-172.773
95	4.75	0	193.222	-3217.403	104.745	-35.513	13.733	-176.014
96	4.80	0	195.089	-3297.403	104.745	-35.513	13.733	-179.255
97	4.85	0	196.956	-3377.403	104.745	-35.513	13.733	-182.496
98	4.90	0	198.823	-3457.403	104.745	-35.513	13.733	-185.737
99	4.95	0	200.690	-3537.403	104.745	-35.513	13.733	-188.978
100	5.00	0	202.557	-3617.403	104.745	-35.513	13.733	-192.219

APPENDIX H: COMPUTATION OF THE PENETRATION OF A CONE

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


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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
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)
C      DATA PI/3.141593/,.6/32.1725/,AREA/500*.0/,VOL/500*.0/,AMASS/500*
20.0/,DMASS/500*.0/,SVOL/500*.0/,WS/500*.0/,WB/500*.0/,WBSUB/50
30*.0/,US/500*.0/,SUMSUB/500*.0/,E/500*.0/,V/500*.0/
C
C      INPUT DATA ON OBJECT
C      OBJECT CCONE
C      RAD=35.375/24.
C      DIM=5.50
C      WT=1127.402/G
C      BWD=87.402/G
C      CFOOT=1.
C      THE CONE'S ANGLE AT THE TIP IS 30 DEGREES
C      CNC=4.7
C      COHESION OR SHEAR STRENGTH IN PSI EQUALS .3
C      COH=43.2
C
C      FOR A CONE USE A COEFFICIENT OF DRAG EQUAL TO 0.3
C      CD=0.3
C
C      SET INCREMENT
C      DX=.05
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
C      Y=DX/2.
C      YMAX=DIM
C      Z=DIM/DX
C      N=Z+.1.
C      THE ONE ACCOUNTS FOR INTEGER TRUNCATION IN THIS PROBLEM
C      FIND HALF THE ANGLE AT THE TIP OF THE CONE
C      ALFA=ATAN(RAD/DIM)

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

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

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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)

CALCULATE ORIGINAL ENERGY OF BODY AT INTERFACE
BMASS=WT/G
E(1)=BMASS*VO**2/2.

CALCULATE POTENTIAL ENERGY FOR EACH INCREMENT
EP=WT*DX

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
SLOPE9=(SS405-SS40)/.5
BINT9=-SLOPE9*4.0+SS40
SLOPEA=(SS500-SS405)/.5
BINTA=-SLOPEA*4.5+SS405

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SLOPEB=(SS505-SS500)/.5
BINTB=-SLOPEB*5.0+SS500
SLOPEC=(SS600-SS505)/.5
BINTC=-SLOPEC*5.5+SS505
VELOCITY OF SEDIMENT AT INTERFACE IS ALWAYS 0 AT INSTANT OF IMPACT
V(I)=0.0
DO 2000 I=1,500
SECTION TO COMPUTE SHEAR STRENGTH
NOTE THAT THE SHEAR STRENGTH IS COMPUTED IN INCHES THEN CONVERTED
TO POUNDS PER SQUARE FOOT FOR THE CALCULATION
FOR THE CONE TAKE THE DEPTH FOR SHEAR STRENGTH TO BE THE
PENETRATION DEPTH MINUS ONE HALF THE PENETRATION DEPTH
DEPTH=I*DX-Y-(I*DX-Y)/2
WHEN THE DEPTH OF PENETRATION EQUALS ONE HALF THE LENGTH OF THE
CONE THE DEPTH FOR SHEAR STRENGTHS EQUALS THE PENETRATION DEPTH
MINUS ONE HALF THE LENGTH
IF((I*DX-Y).GT.DJM) DEPTH=I*DX-Y-DJM/2.
CONVERT THE DEPTH TO INCHES FOR EASY COMPARISON WITH DATA
DEPTHI=DEPTH*12.
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
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 12
IF((DEPTH.LE.5.5).AND.(DEPTH.GT.5.0)) GO TO 11
IF((DEPTH.LE.6.0).AND.(DEPTH.GT.5.5)) GO TO 13
FOR DEPTHS LARGER THAN LAST SHEAR STRENGTH TAKE THE ARITHMETIC
AVERAGE OF THE LAST THREE AND CALL IT CONSTANT
IF(DEPTH.GT.6.0) GO TO 14
FORMULAS FOR SHEAR STRENGTH FOLLOW
LINEAR VARIATION BETWEEN MEASURED POINTS IS ASSUMED

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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.

SPS IS THE SHEAR STRENGTH IN POUNDS PER SQUARE FOOT
SPS=SSS*144.
CALCULATE THE SEDIMENT STATIC STRENGTH AND WORK DONE BY SEDIMENT
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))/(RMASS+DMASS(I)+AMASS(I))
IF (VELOSQ.LE.0.0)GO TO 1000
V(I+1)=SQRT(VELOSQ)

SECTION TO COMPUTE THE WORK DONE BY DRAG
APPROXIMATE AVERAGE VELOCITY OVER A SECTION BY NEGLECTING THE DRAG
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

VELOSQ=2.0*(E(I)+EP+AMASSI-WS(I)-WB(I)-WDRAG)/(BMASS+DMASS(I)+AMAS
2S(I))
IF (VELOSQ.LE.0.0)GO TO 1000

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CONE

RADIUS = 1.474 FEET
 LENGTH = 5.500 FEET
 WEIGHT = 1127.0 LBS
 BULK WEIGHT 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	56.357	0.000	0.000	0.000	0.000
2	0.15	1.537	5.184	119.697	0.002	0.001	0.000	0.001
3	0.25	3.107	5.940	116.935	0.007	0.004	0.001	0.002
4	0.35	3.020	12.032	228.632	0.020	0.010	0.002	0.003
5	0.40	4.383	11.944	337.958	0.076	0.036	0.007	0.005
6	0.45	4.743	12.350	350.032	0.193	0.089	0.017	0.016
7	0.50	5.073	22.360	504.937	0.123	0.127	0.025	0.023
8	0.55	5.643	33.644	617.138	0.330	0.377	0.038	0.035
9	0.60	6.164	44.205	727.267	0.695	0.509	0.080	0.072
10	0.70	6.681	55.205	883.520	1.127	0.395	0.163	0.136
11	0.85	7.088	66.424	994.578	1.706	0.738	0.153	0.145
12	0.95	7.367	67.440	1047.009	2.068	0.888	0.121	0.129
13	0.95	7.717	68.236	1047.643	2.455	1.224	0.265	0.260
14	0.95	7.915	69.376	1047.643	3.017	1.681	0.354	0.356
15	0.95	8.263	71.200	1107.162	3.892	1.824	0.498	0.499
16	1.15	8.502	72.412	1107.162	5.447	1.436	0.534	0.535
17	1.15	8.742	77.443	1107.162	6.675	2.103	0.605	0.605
18	1.15	8.803	77.894	1107.162	7.849	3.015	0.682	0.682
19	1.15	9.033	80.472	1107.162	8.349	3.346	0.745	0.745
20	1.15	9.297	81.340	1107.162	8.626	3.694	0.820	0.820
21	1.15	9.459	86.508	1107.162	9.630	4.483	0.876	0.876
22	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
23	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
24	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
25	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
26	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
27	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
28	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
29	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
30	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
31	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
32	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285
33	1.15	9.754	88.600	1107.162	11.322	5.247	1.285	1.285

COVE

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	BUDYANT FORCES	FORM DRAG FORCES
1	2	0.05	5.312	2.340	494.225	0.000	0.000	0.000	0.000
2	3	0.15	5.607	7.020	550.569	0.001	0.001	0.001	0.001
3	4	0.25	6.153	11.720	663.183	0.002	0.002	0.002	0.002
4	5	0.35	6.409	21.060	715.515	0.003	0.003	0.003	0.003
5	6	0.45	6.654	30.420	731.503	0.004	0.004	0.004	0.004
6	7	0.55	6.891	39.780	743.194	0.005	0.005	0.005	0.005
7	8	0.65	7.138	49.140	748.641	0.006	0.006	0.006	0.006
8	9	0.75	7.351	58.500	748.790	0.007	0.007	0.007	0.007
9	10	0.85	7.527	67.860	743.525	0.008	0.008	0.008	0.008
11	12	0.95	7.956	116.200	698.162	0.010	0.010	0.010	0.010
13	14	1.05	8.143	167.540	623.702	0.012	0.012	0.012	0.012
15	16	1.15	8.316	214.880	510.623	0.014	0.014	0.014	0.014
17	18	1.25	8.664	262.220	372.454	0.016	0.016	0.016	0.016
19	20	1.35	9.024	309.560	231.455	0.018	0.018	0.018	0.018
21	22	1.45	9.337	356.890	105.527	0.020	0.020	0.020	0.020
23	24	1.55	9.627	404.220	55.666	0.022	0.022	0.022	0.022
25	26	1.65	9.889	451.550	27.157	0.024	0.024	0.024	0.024
27	28	1.75	10.129	498.880	8.848	0.026	0.026	0.026	0.026
29	30	1.85	10.346	546.220	0.533	0.028	0.028	0.028	0.028
31	32	1.95	10.535	593.550	0.221	0.030	0.030	0.030	0.030
33	34	2.05	10.697	640.880	0.000	0.032	0.032	0.032	0.032

COKE

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

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	0.5	10.0	1357	10.4	0.001	0.010	0.000	0.003
2	0.15	13.7	1357	14.0	0.004	0.031	0.000	0.008
3	0.25	17.3	1357	22.2	0.012	0.062	0.001	0.016
4	0.35	21.0	1357	30.5	0.020	0.093	0.002	0.021
5	0.45	24.6	1357	38.8	0.029	0.124	0.003	0.027
6	0.55	28.2	1357	47.1	0.037	0.155	0.004	0.031
7	0.65	31.8	1357	55.4	0.045	0.186	0.005	0.035
8	0.75	35.4	1357	63.7	0.053	0.217	0.006	0.039
9	0.85	39.0	1357	72.0	0.061	0.248	0.007	0.043
10	0.95	42.6	1357	80.3	0.069	0.279	0.008	0.047
11	1.05	46.2	1357	88.6	0.077	0.310	0.009	0.051
12	1.15	49.8	1357	96.9	0.085	0.341	0.010	0.055
13	1.25	53.4	1357	105.2	0.093	0.372	0.011	0.059
14	1.35	57.0	1357	113.5	0.101	0.403	0.012	0.063
15	1.45	60.6	1357	121.8	0.109	0.434	0.013	0.067
16	1.55	64.2	1357	130.1	0.117	0.465	0.014	0.071
17	1.65	67.8	1357	138.4	0.125	0.496	0.015	0.075
18	1.75	71.4	1357	146.7	0.133	0.527	0.016	0.079
19	1.85	75.0	1357	155.0	0.141	0.558	0.017	0.083
20	1.95	78.6	1357	163.3	0.149	0.589	0.018	0.087
21	2.05	82.2	1357	171.6	0.157	0.620	0.019	0.091
22	2.15	85.8	1357	179.9	0.165	0.651	0.020	0.095
23	2.25	89.4	1357	188.2	0.173	0.682	0.021	0.099
24	2.35	93.0	1357	196.5	0.181	0.713	0.022	0.103
25	2.45	96.6	1357	204.8	0.189	0.744	0.023	0.107
26	2.55	100.2	1357	213.1	0.197	0.775	0.024	0.111
27	2.65	103.8	1357	221.4	0.205	0.806	0.025	0.115
28	2.75	107.4	1357	229.7	0.213	0.837	0.026	0.119
29	2.85	111.0	1357	238.0	0.221	0.868	0.027	0.123
30	2.95	114.6	1357	246.3	0.229	0.899	0.028	0.127
31	3.05	118.2	1357	254.6	0.237	0.930	0.029	0.131
32	3.15	121.8	1357	262.9	0.245	0.961	0.030	0.135
33	3.25	125.4	1357	271.2	0.253	0.992	0.031	0.139
34	3.35	129.0	1357	279.5	0.261	1.023	0.032	0.143
35	3.45	132.6	1357	287.8	0.269	1.054	0.033	0.147
36	3.55	136.2	1357	296.1	0.277	1.085	0.034	0.151
37	3.65	139.8	1357	304.4	0.285	1.116	0.035	0.155
38	3.75	143.4	1357	312.7	0.293	1.147	0.036	0.159
39	3.85	147.0	1357	321.0	0.301	1.178	0.037	0.163
40	3.95	150.6	1357	329.3	0.309	1.209	0.038	0.167
41	4.05	154.2	1357	337.6	0.317	1.240	0.039	0.171
42	4.15	157.8	1357	345.9	0.325	1.271	0.040	0.175
43	4.25	161.4	1357	354.2	0.333	1.302	0.041	0.179
44	4.35	165.0	1357	362.5	0.341	1.333	0.042	0.183
45	4.45	168.6	1357	370.8	0.349	1.364	0.043	0.187
46	4.55	172.2	1357	379.1	0.357	1.395	0.044	0.191
47	4.65	175.8	1357	387.4	0.365	1.426	0.045	0.195
48	4.75	179.4	1357	395.7	0.373	1.457	0.046	0.199
49	4.85	183.0	1357	404.0	0.381	1.488	0.047	0.203
50	4.95	186.6	1357	412.3	0.389	1.519	0.048	0.207
51	5.05	190.2	1357	420.6	0.397	1.550	0.049	0.211
52	5.15	193.8	1357	428.9	0.405	1.581	0.050	0.215
53	5.25	197.4	1357	437.2	0.413	1.612	0.051	0.219
54	5.35	201.0	1357	445.5	0.421	1.643	0.052	0.223
55	5.45	204.6	1357	453.8	0.429	1.674	0.053	0.227
56	5.55	208.2	1357	462.1	0.437	1.705	0.054	0.231
57	5.65	211.8	1357	470.4	0.445	1.736	0.055	0.235
58	5.75	215.4	1357	478.7	0.453	1.767	0.056	0.239
59	5.85	219.0	1357	487.0	0.461	1.798	0.057	0.243
60	5.95	222.6	1357	495.3	0.469	1.829	0.058	0.247
61	6.05	226.2	1357	503.6	0.477	1.860	0.059	0.251
62	6.15	229.8	1357	511.9	0.485	1.891	0.060	0.255
63	6.25	233.4	1357	520.2	0.493	1.922	0.061	0.259
64	6.35	237.0	1357	528.5	0.501	1.953	0.062	0.263
65	6.45	240.6	1357	536.8	0.509	1.984	0.063	0.267
66	6.55	244.2	1357	545.1	0.517	2.015	0.064	0.271
67	6.65	247.8	1357	553.4	0.525	2.046	0.065	0.275
68	6.75	251.4	1357	561.7	0.533	2.077	0.066	0.279
69	6.85	255.0	1357	570.0	0.541	2.108	0.067	0.283
70	6.95	258.6	1357	578.3	0.549	2.139	0.068	0.287
71	7.05	262.2	1357	586.6	0.557	2.170	0.069	0.291
72	7.15	265.8	1357	594.9	0.565	2.201	0.070	0.295
73	7.25	269.4	1357	603.2	0.573	2.232	0.071	0.299
74	7.35	273.0	1357	611.5	0.581	2.263	0.072	0.303
75	7.45	276.6	1357	619.8	0.589	2.294	0.073	0.307
76	7.55	280.2	1357	628.1	0.597	2.325	0.074	0.311
77	7.65	283.8	1357	636.4	0.605	2.356	0.075	0.315
78	7.75	287.4	1357	644.7	0.613	2.387	0.076	0.319
79	7.85	291.0	1357	653.0	0.621	2.418	0.077	0.323
80	7.95	294.6	1357	661.3	0.629	2.449	0.078	0.327
81	8.05	298.2	1357	669.6	0.637	2.480	0.079	0.331
82	8.15	301.8	1357	677.9	0.645	2.511	0.080	0.335
83	8.25	305.4	1357	686.2	0.653	2.542	0.081	0.339
84	8.35	309.0	1357	694.5	0.661	2.573	0.082	0.343
85	8.45	312.6	1357	702.8	0.669	2.604	0.083	0.347
86	8.55	316.2	1357	711.1	0.677	2.635	0.084	0.351
87	8.65	319.8	1357	719.4	0.685	2.666	0.085	0.355
88	8.75	323.4	1357	727.7	0.693	2.697	0.086	0.359
89	8.85	327.0	1357	736.0	0.701	2.728	0.087	0.363
90	8.95	330.6	1357	744.3	0.709	2.759	0.088	0.367
91	9.05	334.2	1357	752.6	0.717	2.790	0.089	0.371
92	9.15	337.8	1357	760.9	0.725	2.821	0.090	0.375
93	9.25	341.4	1357	769.2	0.733	2.852	0.091	0.379
94	9.35	345.0	1357	777.5	0.741	2.883	0.092	0.383
95	9.45	348.6	1357	785.8	0.749	2.914	0.093	0.387
96	9.55	352.2	1357	794.1	0.757	2.945	0.094	0.391
97	9.65	355.8	1357	802.4	0.765	2.976	0.095	0.395
98	9.75	359.4	1357	810.7	0.773	3.007	0.096	0.399
99	9.85	363.0	1357	819.0	0.781	3.038	0.097	0.403
100	9.95	366.6	1357	827.3	0.789	3.069	0.098	0.407

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CONC

RADIUS = 1.474 FEET
LENGTH = 5.500 FEET
WEIGHT = 1127.0 LBS
BULK WEI 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 0.28 0.76 1.77 1.67 2.11 2.90 3.40 3.89 3.84 3.89

CONDITIONS AT THE END OF SECTION

ITERATION SECTION	PENETRATION FEET	VELOCITY FT/SEC	SHEAR STRENGTH PSF	BODY ENERGY FT-LBS	WORK DONE IN SECTION - FOOT POUNDS		
					STATIC FORCES	SEDIMENT INERTIA	BUDYANT FORCES

1	0.05	15.07	1.09	3997.2077	0.001	0.022	0.000	0.001
2	0.10	12.18	1.25	4053.7777	0.004	0.024	0.000	0.005
3	0.20	8.42	1.35	4104.9820	0.009	0.025	0.002	0.017
4	0.30	6.76	1.43	4127.4457	0.012	0.026	0.004	0.033
5	0.40	5.60	1.49	4133.2567	0.015	0.027	0.007	0.054
6	0.50	4.80	1.53	4139.9456	0.017	0.028	0.011	0.079
7	0.60	4.23	1.56	4146.3320	0.019	0.029	0.015	0.106
8	0.70	3.80	1.58	4152.6602	0.021	0.030	0.017	0.136
9	0.80	3.47	1.60	4158.9657	0.023	0.031	0.020	0.167
10	0.90	3.22	1.62	4165.2567	0.025	0.032	0.023	0.199
11	1.00	3.03	1.64	4171.5456	0.027	0.033	0.025	0.232
12	1.10	2.89	1.66	4177.8320	0.029	0.034	0.027	0.266
13	1.20	2.78	1.68	4184.1189	0.031	0.035	0.029	0.301
14	1.30	2.69	1.70	4190.4057	0.033	0.036	0.031	0.336
15	1.40	2.62	1.72	4196.6920	0.035	0.037	0.033	0.371
16	1.50	2.56	1.74	4202.9789	0.037	0.038	0.035	0.406
17	1.60	2.51	1.76	4209.2657	0.039	0.039	0.037	0.441
18	1.70	2.46	1.78	4215.5520	0.041	0.040	0.039	0.476
19	1.80	2.42	1.80	4221.8389	0.043	0.041	0.041	0.511
20	1.90	2.38	1.82	4228.1257	0.045	0.042	0.043	0.546
21	2.00	2.35	1.84	4234.4120	0.047	0.043	0.045	0.581
22	2.10	2.32	1.86	4240.6989	0.049	0.044	0.047	0.616
23	2.20	2.30	1.88	4246.9857	0.051	0.045	0.049	0.651
24	2.30	2.28	1.90	4253.2720	0.053	0.046	0.051	0.686
25	2.40	2.26	1.92	4259.5589	0.055	0.047	0.053	0.721
26	2.50	2.24	1.94	4265.8457	0.057	0.048	0.055	0.756
27	2.60	2.23	1.96	4272.1320	0.059	0.049	0.057	0.791
28	2.70	2.22	1.98	4278.4189	0.061	0.050	0.059	0.826
29	2.80	2.21	1.99	4284.7057	0.063	0.051	0.061	0.861
30	2.90	2.20	2.00	4290.9920	0.065	0.052	0.063	0.896
31	3.00	2.19	2.01	4297.2789	0.067	0.053	0.065	0.931
32	3.10	2.18	2.02	4303.5657	0.069	0.054	0.067	0.966
33	3.20	2.17	2.03	4309.8520	0.071	0.055	0.069	1.001
34	3.30	2.16	2.04	4316.1389	0.073	0.056	0.071	1.036

IMPACT VELOCITY EQUALS 20.0

SEDIMENT SHEAR STRENGTHS IN HALF FOOT INTERVALS FROM SURFACE ARE

0.54 0.67 1.14 2.13 2.34 2.65 2.47 2.34 2.69 2.86 2.92 3.19

CONE

RADIUS = 1.474 FEET
LENGTH = 5.500 FEET
HEIGHT = 1127.0 LBS
BULK WGT 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	20.0	1.0	706	0.002	0.004	0.000	0.001
2	0.10	19.9	1.3	713	0.002	0.039	0.000	0.010
3	0.15	19.8	1.7	719	0.002	0.114	0.001	0.029
4	0.20	19.7	2.0	723	0.002	0.227	0.002	0.058
5	0.25	19.6	2.3	726	0.002	0.372	0.004	0.095
6	0.30	19.5	2.6	728	0.002	0.542	0.007	0.145
7	0.35	19.4	2.9	729	0.002	0.819	0.014	0.204
8	0.40	19.3	3.2	730	0.002	1.177	0.023	0.275
9	0.45	19.2	3.5	731	0.002	1.695	0.033	0.355
10	0.50	19.1	3.8	732	0.002	2.379	0.046	0.446
11	0.55	19.0	4.1	733	0.002	3.217	0.063	0.549
12	0.60	18.9	4.4	734	0.002	4.209	0.083	0.663
13	0.65	18.8	4.7	735	0.002	5.353	0.106	0.789
14	0.70	18.7	5.0	736	0.002	6.647	0.133	0.925
15	0.75	18.6	5.3	737	0.002	8.091	0.163	1.071
16	0.80	18.5	5.6	738	0.002	9.683	0.196	1.228
17	0.85	18.4	5.9	739	0.002	11.423	0.232	1.395
18	0.90	18.3	6.2	740	0.002	13.311	0.271	1.572
19	0.95	18.2	6.5	741	0.002	15.347	0.313	1.759
20	1.00	18.1	6.8	742	0.002	17.531	0.358	1.956
21	1.05	18.0	7.1	743	0.002	19.862	0.406	2.163
22	1.10	17.9	7.4	744	0.002	22.340	0.456	2.380
23	1.15	17.8	7.7	745	0.002	24.965	0.508	2.607
24	1.20	17.7	8.0	746	0.002	27.737	0.562	2.844
25	1.25	17.6	8.3	747	0.002	30.655	0.618	3.091
26	1.30	17.5	8.6	748	0.002	33.719	0.675	3.348
27	1.35	17.4	8.9	749	0.002	36.928	0.734	3.615
28	1.40	17.3	9.2	750	0.002	40.282	0.794	3.892
29	1.45	17.2	9.5	751	0.002	43.781	0.856	4.179
30	1.50	17.1	9.8	752	0.002	47.425	0.919	4.476
31	1.55	17.0	10.1	753	0.002	51.213	0.984	4.783
32	1.60	16.9	10.4	754	0.002	55.145	1.050	5.099
33	1.65	16.8	10.7	755	0.002	59.221	1.118	5.425
34	1.70	16.7	11.0	756	0.002	63.441	1.187	5.761
35	1.75	16.6	11.3	757	0.002	67.805	1.258	6.107
36	1.80	16.5	11.6	758	0.002	72.313	1.330	6.463
37	1.85	16.4	11.9	759	0.002	76.965	1.404	6.829
38	1.90	16.3	12.2	760	0.002	81.761	1.479	7.205
39	1.95	16.2	12.5	761	0.002	86.699	1.556	7.591
40	2.00	16.1	12.8	762	0.002	91.779	1.634	7.987
41	2.05	16.0	13.1	763	0.002	96.999	1.714	8.393
42	2.10	15.9	13.4	764	0.002	102.359	1.795	8.809
43	2.15	15.8	13.7	765	0.002	107.858	1.878	9.235
44	2.20	15.7	14.0	766	0.002	113.496	1.962	9.671
45	2.25	15.6	14.3	767	0.002	119.272	2.048	10.117
46	2.30	15.5	14.6	768	0.002	125.186	2.135	10.573
47	2.35	15.4	14.9	769	0.002	131.237	2.224	11.039
48	2.40	15.3	15.2	770	0.002	137.424	2.314	11.515
49	2.45	15.2	15.5	771	0.002	143.747	2.406	11.999
50	2.50	15.1	15.8	772	0.002	150.204	2.500	12.491
51	2.55	15.0	16.1	773	0.002	156.795	2.595	12.991
52	2.60	14.9	16.4	774	0.002	163.519	2.692	13.498
53	2.65	14.8	16.7	775	0.002	170.375	2.790	14.012
54	2.70	14.7	17.0	776	0.002	177.362	2.890	14.533
55	2.75	14.6	17.3	777	0.002	184.480	2.991	15.060
56	2.80	14.5	17.6	778	0.002	191.728	3.094	15.593
57	2.85	14.4	17.9	779	0.002	199.106	3.198	16.132
58	2.90	14.3	18.2	780	0.002	206.613	3.304	16.677
59	2.95	14.2	18.5	781	0.002	214.249	3.411	17.228
60	3.00	14.1	18.8	782	0.002	222.014	3.520	17.785
61	3.05	14.0	19.1	783	0.002	229.907	3.630	18.348
62	3.10	13.9	19.4	784	0.002	237.928	3.742	18.916
63	3.15	13.8	19.7	785	0.002	246.075	3.855	19.489
64	3.20	13.7	20.0	786	0.002	254.348	3.970	20.067
65	3.25	13.6	20.3	787	0.002	262.745	4.086	20.650
66	3.30	13.5	20.6	788	0.002	271.265	4.204	21.238
67	3.35	13.4	20.9	789	0.002	279.907	4.323	21.831
68	3.40	13.3	21.2	790	0.002	288.671	4.444	22.429
69	3.45	13.2	21.5	791	0.002	297.556	4.566	23.032
70	3.50	13.1	21.8	792	0.002	306.561	4.690	23.640
71	3.55	13.0	22.1	793	0.002	315.685	4.815	24.253
72	3.60	12.9	22.4	794	0.002	324.928	4.942	24.871
73	3.65	12.8	22.7	795	0.002	334.289	5.070	25.494
74	3.70	12.7	23.0	796	0.002	343.767	5.200	26.122
75	3.75	12.6	23.3	797	0.002	353.361	5.331	26.755
76	3.80	12.5	23.6	798	0.002	363.071	5.464	27.393
77	3.85	12.4	23.9	799	0.002	372.896	5.598	28.036
78	3.90	12.3	24.2	800	0.002	382.835	5.734	28.684
79	3.95	12.2	24.5	801	0.002	392.887	5.871	29.337
80	4.00	12.1	24.8	802	0.002	403.051	6.010	29.994
81	4.05	12.0	25.1	803	0.002	413.326	6.150	30.656
82	4.10	11.9	25.4	804	0.002	423.711	6.292	31.322
83	4.15	11.8	25.7	805	0.002	434.205	6.436	31.993
84	4.20	11.7	26.0	806	0.002	444.807	6.581	32.668
85	4.25	11.6	26.3	807	0.002	455.517	6.728	33.348
86	4.30	11.5	26.6	808	0.002	466.334	6.876	34.032
87	4.35	11.4	26.9	809	0.002	477.257	7.026	34.720
88	4.40	11.3	27.2	810	0.002	488.285	7.177	35.412
89	4.45	11.2	27.5	811	0.002	499.417	7.330	36.108
90	4.50	11.1	27.8	812	0.002	510.653	7.484	36.808
91	4.55	11.0	28.1	813	0.002	521.992	7.640	37.512
92	4.60	10.9	28.4	814	0.002	533.434	7.797	38.220
93	4.65	10.8	28.7	815	0.002	544.978	7.956	38.932
94	4.70	10.7	29.0	816	0.002	556.623	8.116	39.648
95	4.75	10.6	29.3	817	0.002	568.369	8.278	40.368
96	4.80	10.5	29.6	818	0.002	580.215	8.441	41.092
97	4.85	10.4	29.9	819	0.002	592.161	8.606	41.820
98	4.90	10.3	30.2	820	0.002	604.306	8.772	42.552
99	4.95	10.2	30.5	821	0.002	616.550	8.940	43.288
100	5.00	10.1	30.8	822	0.002	628.893	9.109	44.028

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