Oct. 5, 1971 **R. L. HANDY** **3,610,035**

SYSTEM FOR DETERMINING SHEAR STRENGTH OF SOIL
INCLUDING EXPANDABLE PROBE

Filed Dec. 29, 1969 2 Sheets-Sheet 1

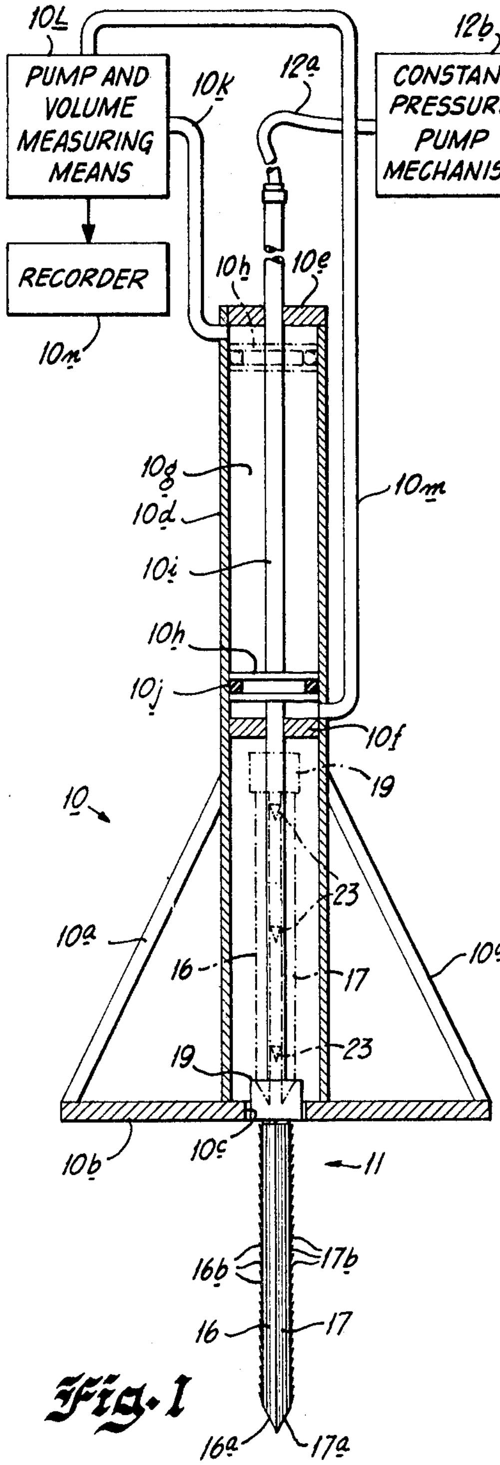

Fig. 1

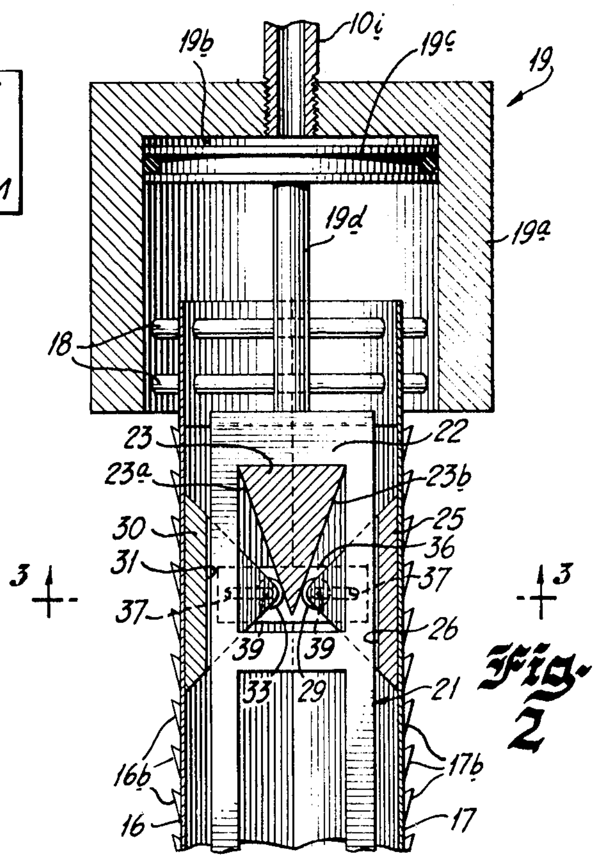

Fig. 2

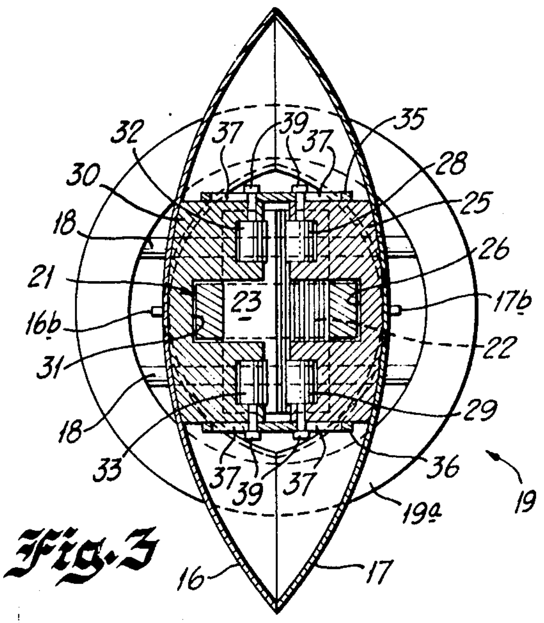

Fig. 3

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Fig. 4

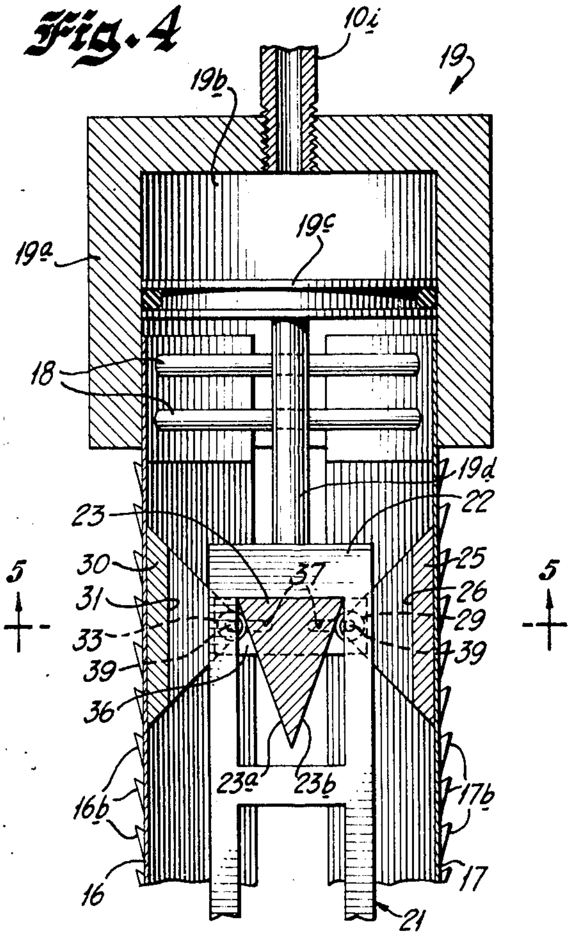


Fig. 6

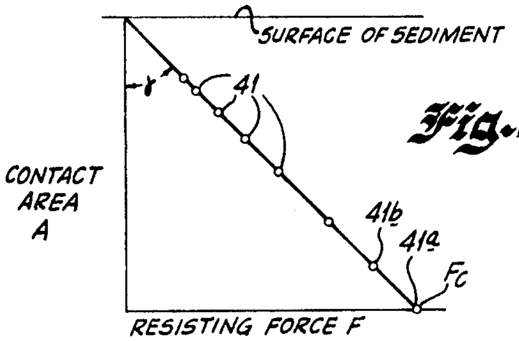


Fig. 7

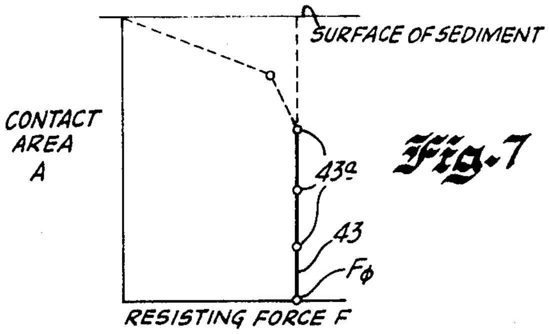


Fig. 8

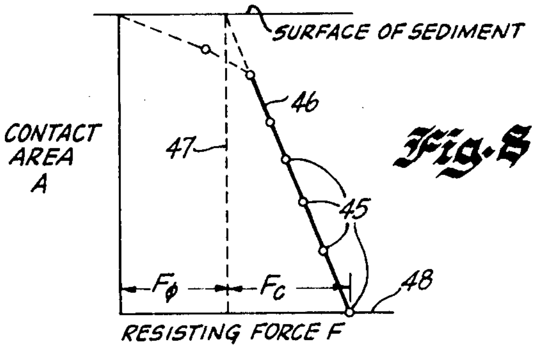


Fig. 5

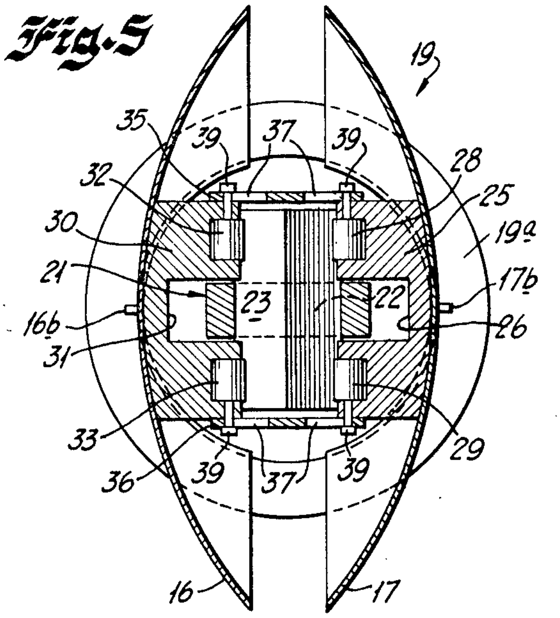
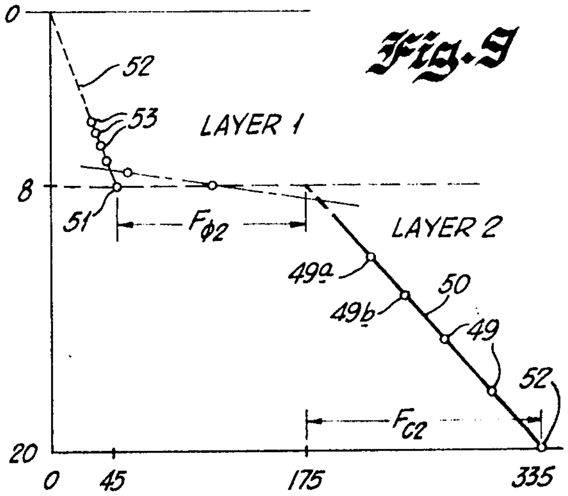


Fig. 9



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United States Patent Office

3,610,035
Patented Oct. 5, 1971

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SYSTEM FOR DETERMINING SHEAR STRENGTH OF SOIL INCLUDING EXPANDABLE PROBE

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Filed Dec. 29, 1969, Ser. No. 888,734
Int. Cl. G01n *3/24*
U.S. Cl. 73—101 6 Claims

ABSTRACT OF THE DISCLOSURE

A probe having elongated, separable side pressure plates is inserted into the soil under test, separating the soil as it penetrates. After the probe is inserted, a lateral force is applied to the pressure plates to compress and consolidate soil engaged by them with a known lateral contact pressure. The exterior surfaces of the pressure plates are provided with metal barbs or teeth to cause shearing within the soil as the probe is removed under force. As the probe is removed, measurements are recorded of the resisting force required for shearing and the displacement of the probe. The segments of the pressure plates extending above the surface of the soil relax so that the entire lateral force causing expansion of the plates is exerted on that section which is embedded in the soil. The probe is pulled out in increments, thus decreasing the area of the pressure plates in contact with the soil. However, the lateral pressure exerted on the soil increases correspondingly—thus forming a new shear plane and allowing independent determination of the cohesion and internal friction of the soil without having to form a bore hole.

BACKGROUND

The present invention relates to measuring shear strength of loose or sandy soil; more particularly, it relates to in situ determination of shear strength of such soil.

The determination of the soil parameters of cohesion and internal friction is essential for the application of classical soil mechanics theory to construction and stability problems.

Two distinct approaches have been developed for measuring soil shear strength. One of these approaches encompasses triaxial and direct shear tests conducted in a laboratory on undisturbed samples of soft material, and is a difficult task. Conventional recovery apparatus includes piston samplers and freezing chambers.

One commonly used method of obtaining a sample is by pushing a thin-wall cylindrical tube called a Shelby tube into the soil. Several types of laboratory tests may be performed, in which the soil is subjected to a pressure and then a load is applied to cause shearing.

In a known direct shear test, a short cylinder of the undisturbed sample is loaded axially with a vertical load, and sheared on a plane normal to the load in a shear box. That is, the top half of the shear box is made to slide laterally with respect to the bottom half; and the necessary force to effect shear is measured.

A more accurate laboratory test is the triaxial test in which a cylinder of soil is sealed in a flexible membrane and confined laterally with fluid pressure. A vertical load is applied until the sample fails or breaks. In this test, the orientation of the shear plane must be determined, and cohesion and internal friction must be calculated using Mohr theory.

In either of these cases of laboratory testing, normal procedure requires taking two or three samples and determining shear strength at different values of confining

pressure in order to define the Coulomb relationship from which cohesion and internal friction may be determined.

Normally, these laboratory tests may take at least two to three days before results are achieved, and they are relatively expensive. In situ shearing tests have the advantage that the results may be determined almost immediately, further, the cost per test is reduced.

In addition to the problems in obtaining samples of firm soil, the recovery of undisturbed samples of soft or loose soil raises additional problems. Obtaining sub-aqueous samples is still more difficult because the original sediment is in a high pressure environment; and the difference in elastic rebound between the sample and the recovery apparatus will cause disturbances in the recovered sample. Further, gases dissolved in the sample will escape from solution and expand and thus further disturb the sample. The sample could, of course, be enclosed within a pressure vessel; but this unduly complicates the recovery equipment as well as the laboratory tests on the sample. Thus, in testing soft soil or subaqueous sediment, it is highly desirable to conduct the tests in situ.

Two commonly used types of in situ testing include probing and vane shear. Heretofore, most in situ testing methods have had the disadvantage that cohesion and internal friction were not capable of being separately measured.

In the vane shear test, a bladed vane is pushed into sediment and a torque is applied to cause circumferential shearing. However, application of a torque requires a base for reaction. It cannot be applied through a cable without some type of laterally disposed anchor. Although in subaqueous applications a limited torque might be applied through the use of a large-diameter vane "messenger" and a maximum resisting torque could be recorded by instrumentation, the vane shear test suffers from another limitation—namely, that it principally measures cohesion. Attempts have been made to measure internal friction angle, but these have had limited success.

In the use of probes for in situ testing, a simple approach is to register maximum depth of penetration for a given insertion force. If the test is rapid, for example by using an impact force, the penetration resistance is a function of viscosity, pore-water pressure, and inertia effects—all of which combine to resist penetration. Thus, the resistance force due to cohesion and internal friction tend to be obscured and is not capable of being separated from the combined resistance force.

The penetration resistance test yields an empirical measurement of soil-bearing capacity, and the exact relationship depends upon the kind of soil. That is, a standard penetration test blow count of 40 in a clay indicates a substantially different bearing capacity than a count of 40 in sand. The reason for this is that the penetration test results are influenced by both cohesion and internal friction.

If an inserted probe is pulled, a value may be determined for skin friction on the probe; however, there is generally no determination on the lateral pressure of the soil on the probe; and, hence, the internal friction of the soil cannot be determined.

U.S. Pat. No. 3,427,871 of Handy and Fox entitled Bore-Hole Soil Testing Apparatus discloses apparatus for in situ testing of soils for determining shear strength. The apparatus of that application includes a device which is lowered into a preformed bore-hole, and the device includes two pressure surfaces which are movable relative to each other for engaging opposite sides of the bore-hole wall in response to a pressurized fluid being transmitted to cylinder and piston rod units within the device. The piston end of the unit is connected to one pressure surface, and the cylinder end is connected to the other pressure surface.

With a constant radial pressure exerted on the pressure surfaces, a shearing force is applied by pulling the device axially of the bore-hole. After a first shearing force is measured, the hydraulic pressure extending the pressure surfaces is increased so that a second shearing force may be applied and measured. The data points relating shearing stress at failure to the normal pressure on the shear plane (that is, the pressure exerted by the hydraulic fluid) defines the classical Coulomb relationship from which cohesion and internal friction may be determined, as described in that patent.

SUMMARY

The present invention contemplates inserting an elongated probe into soft or sandy soil or subaqueous sediment. The probe includes separable pressure plates which are inserted in retracted position and which separate the soil as the probe is inserted. After the probe has been inserted, a force is transmitted to the pressure plates moving them laterally apart thereby compressing and consolidating soil contacted by the pressure plates of the probe with a lateral contact pressure.

A pulling force is exerted on the probe to remove it. The pressure plates are provided with metal barbs or teeth to cause shearing within the sediment as the probe is removed. The maximum force required to remove the probe a given increment (i.e. to cause shearing) is recorded. As one alternative of the invention, the segments of the pressure plates which extend above the soil surface relax so that the entire expansion force is exerted on the segment of the probe buried beneath the soil. In other words, as the probe is retracted incrementally, the net force expanding the pressure plates remains constant whereas the area of the pressure plates decreases thereby increasing the expansion pressure on the plates and compressing the soil to form a new shear plane.

Cohesion and internal friction of the sediment may be obtained from the record of the exerted retraction force, as explained in more detail herein.

Thus, the present invention provides a simple and practical method of determining in situ soil shear strength in soft soil while allowing independent determination of cohesion and internal friction, which have been a major shortcoming of prior testing methods.

Further, the present invention greatly facilitates the in situ determination of soil shear strength by obviating the need for drilling a bore-hole (which, of course, is difficult to do in most sandy soil or soft sediments beneath water). Further, one set of recorded data points, as will be clear from the detailed description below, yields sufficient information to define different strata that exist beneath that top soil level. In the case of testing subaqueous bore-holes, a problem would be encountered in relocating the hole in order to insert a device.

Other features and advantages of the instant invention will be apparent to persons skilled in the art from the following detailed description of a preferred embodiment accompanied by the attached drawings.

THE DRAWINGS

FIG. 1 is a partially schematic view of a system used for the practice of the present invention;

FIGS. 2 and 3 are vertical and horizontal cross section views of the probe of FIG. 1 in a closed position;

FIGS. 4 and 5 are vertical and horizontal cross section views of the probe of FIG. 1 in an open position; and

FIGS. 6–9 are shear diagrams of resultant measurements illustrating the determination of cohesion and internal friction in typical soils according to the present invention.

DETAILED DESCRIPTION

Turning now to FIG. 1, the illustrated embodiment comprises two principal components—tripod supporting means, generally designated **10** and including legs **10***a*, and the penetrating probe generally designated **11**. The legs **10***a* are supported on a base plate **10***b* adapted to be placed on the surface of the soil to be treated and defining a central aperture **10***c* through which the probe **11** is urged to penetrate the soil.

Secured to the top of the legs **10***a* there is a cylindrical member **10***d*. Transverse plates **10***e* and **10***f* are secured to the cylindrical member **10***d* to define a cylindrical cavity **10***g* which receives a piston **10***h* to which is attached a rod **10***i*. An O ring **10***j* seals the periphery of the piston **10***h* with the interior surface of the cylinder wall **10***d*; and the piston is adapted for reciprocation therein. The chamber-defining wall **10***d* and rod **10***i* form a hydraulic cylinder unit which has a stroke approximately equal the length of the probe **11**, or at least of the depth to which the probe is designed to penetrate. Fluid (preferably oil) under pressure is forced into the cylinder cavity **10***g* through a conduit **10***k* from a source including an oil pump and means for measuring the volume of the pump, schematicaly designated by the block **10L**. Fluid forced from the pump through conduit **10***k* will force the piston head **10***h* and its associated rod **10***i* downwardly. Rod **10***i* is received in suitable apertures in the transverse plates **10***e* and **10***f* and it reciprocates through these plates as the piston moves. The volume of the fluid is measured and recorded by any suitable means, but preferably, by a strip chart recorder **10***n*. A return conduit **10***m* communicates the lower section of the cylinder with the suction port of the pump to return the liquid to the pump when the piston is lowered. If the pump is reversed, conduit **10***m* becomes the feed conduit and **10***k* the return conduit. The hydraulic unit is thus a double-acting cylinder and piston rod unit.

The probe **11** is attached to the lower end of the rod **10***i* by means of a threaded connection with a second cylinder-defining member **19** having generally inverted cup shape. The rod **10***i* is hollow to provide a conduit which communicates with the interior of the member **19**. The upper edge of rod **10***i* is connected by means of a flexible conduit **12***a* to a second pump mechanism schematically designated **12***b* and provided with a conventional pressure release valve (not shown) to insure that the pressure of the oil in conduit **10***i* remains constant.

Turning now to the friction **11**, it includes first and second pressure side plates **16** and **17** which are elongated vertically and which provide the lateral contacting surfaces which engage the soil under tests and exert a lateral pressure thereon.

The pressure side plates **16** and **17** are provided at their lowermost ends with tapered shoe portions **16***a* and **17***a* respectively for facilitating penetration of the soil under test in a stabbing or piercing action in which the soil is separated and consolidated laterally—as distinguished from compressing or compacting the lowermost soil in a vertical direction, as would be the case with a blunt end or cylindrically-shaped probe.

As seen slightly exaggerated in FIG. 1 for purposes of illustration, when the side pressure plates **16** and **17** which are embedded in the soil, they are closed as seen in solid. But the side pressure plates are opened (chain line) when the probe is drawn above the level of the soil. Further, the side pressure plates **16** and **17** are laterally flexible so that when the lateral restraining force caused by the soil is released, the entire force causing expansion of these side pressure plates is transmitted only to that portion of the probe buried in the soil. Thus, as the probe is withdrawn, the pressure plates will separate for that portion which is above the soil. The plates **16** and **17** are provided with barbs **16***b* and **17***b* respectively for engaging the soil.

Referring now to FIGS. 2 and 3, the side pressure plates **16** and **17** are attached adjacent to the lower open edge of the cup member **19** by means of horizontal rods **18** secured to the interior sides of that member and extending through receiving apertures in the side pressure plates **16** and **17**. Thus, the side pressure plates **16** and **17** are free to slide along the rods **18**; however, when the member **19** is raised or lowered, the side pressure plates **16** and **17** are raised or lowered with it. As best seen in FIGS. 3 and 5, the cross section of the plates **16** and **17** has a crescent shape to maximize the contact area while minimizing the volume of soil displaced upon insertion.

The second pneumatic cylinder and piston rod unit **19** includes a housing **19***a* which defines a piston chamber **19***b* which sealingly receives a piston **19***c*. To the lower end of the piston **19***c* there is secured a piston rod **19***d* extending centrally of and downward into the probe **11**. The lower portion of the piston rod **19***d* is connected to the upper portion of a ladder **21** to move the same downwardly when oil under pressure is forced into the piston chamber **19***b* via input conduits **10***i* from the source of constant pressure oil **12***b*.

The ladder **21** acts as a force-transmission member; and it extends in a plane which is parallel to the direction of lateral expansion of the side plates **16** and **17**. A top rung on the ladder **21** is designated by reference numeral **22**; and mounted beneath the rung **22** and extending perpendicular to the plane of the page of FIG. 2 is an arm **23** having a wedge-shaped cross section providing inclined bearing surfaces **23***a* and **23***b*. As seen more clearly in FIG. 5, the wedge-shaped arm **23** extends beyond the transverse width of the ladder **21**. A first shoulder member **25** is secured to the concave surface of side plate **15**, and it defines a vertical central aperture **26** for receiving the the ladder **21**. First and second rollers **28** and **29** are journalled in the shoulder member **25** for engaging the bearing surface **23***b* of the arm **23** on each side of ladder **21**.

A second shoulder member **30** similar to the shoulder **25**, is attached to the interior surface of the side plate **16**; and it too, defines a center aperture **31** for receiving the ladder **21** and first and second rollers **32** and **33** for engaging the bearing surface **23***a* of the arm **23** on each side of the ladder **21**.

First and second end plates identified in FIG. 3 by reference numerals **35** and **36** are coupled to the sides of the shoulders **25** and **30** by means of horizontally-elongated slots (see reference numerals **37** in FIG. 2) for receiving studs **39** thereby permitting lateral expansion of the side plates **16** and **17** while defining a limit to this lateral expansion FIG. 5 shows the side plates opened and the limiting function of slots **37**.

It will be appreciated that as the ladder **21** is forced downward, the transverse wedge-shaped arm **23** will be forced between the associated pair of rollers mounted within the shoulders **25** and **30** and thereby force the pressure plates **16** and **17** from each other in opposite directions. As schematically illustrated in FIG. 1, there are a number of these same arrangements of transverse wedge-shaped arms (**23**) engaging rollers within supporting shoulders (**25** and **30**) attached to the side plates **16** and **17** and spaced vertically along the probe **11**.

Since the ladder **21** is a rigid force-transmitting member, it will urge each of the shoulder-pairs apart (see FIG. 4) if a constant distributed restraining force is exerted on the sides of the probe; however, if the restraining force is greater along one section of the probe (as in the case when a portion of the probe embedded in soil) the flexibility of the side plates **16** and **17** will cause a lateral yielding of the probe at the portion not embedded in soil; and hence, the full expansion force will be applied to the position of the pressure plates which is embedded in the soil. In practice, when pressurized gas expands the piston and cylinder unit **19**, that portion of the probe **11** which is embedded in the soil will have a constant force (determined by the regulated pressure of the CO_2 in chamber **19***b*) forcing the pressure plates in lateral expansion. The corresponding pressure exerted by the plates on the sediment, of course, is a function of the contacting surface area which depends on the depth to which the probe penetrates. Further, as the probe is retracted, it will be noted that the normal pressure will increase since the expansion force remains a constant and the total contacting area of the pressure plates decreases.

OPERATION

With the above-described apparatus, the present invention contemplates embedding the probe **10** in soil so that it penetrates and separates the soil as it penetrates. Although the illustrated embodiment is designed for tests to be taken on land, it will be appreciated by persons skilled in the art that the method presently to be described is equally suitable for subaqueous measurements. The main features of the disclosed apparatus will also be suitable for an underwater environment, and in such case it is contemplated that the probe would be provided with a cylindrical shroud to stabilize it during descent to insure a perpendicular insertion relative to the horizontal. Further, a line would be secured to the top of the rod **10***i* for recovery of the apparatus.

After the bottom plate **10***b* of the tripod support is resting on the soil to be tested, the pump of means **10L** is energized to force oil into line **10***k* to force piston **10***h* downward to insert the probe. During insertion, the depth of penetration is determined by the volume of oil pumped by the means **10L**, knowing the volume of line **10***k* and cylinder **10***g*. The cylinder and piston rod unit **19** is then actuated to exert a predetermined force on the ladder **21**. As the ladder **21** is forced downwardly, the wedge-shaped members **23** will bear against their associated rollers **28**, **29**, **32** and **33**, to urge the pressure plates **16** and **17** laterally apart. Thus, the downward force of the piston rod **19***d* is transmitted into a lateral force to urge the pressure plates apart and to compact the soil adjacent their outer surfaces. Since there are a number of these structures spaced along the direction of elongation of the probe **11**, the two pressure plates will be urged apart in substantially parallel relationship, and those portions of the pressure plates which are retracted from the soil will not be restrained laterally by the soil so they will relax slightly. Nevertheless, because the pressure plates **16** and **17** remain parallel, the entire downward force exerted by the cylinder **19** will be transmitted as a lateral pressure onto the compacted soil as long as the probe is even partially embedded in the soil (until the very tip alone is embedded, of course).

The lateral pressure may be calculated by observing the penetration depth and knowing the contact area of the pressure plates. Next the pressure in the inserting hydraulic cylinder and piston rod unit is released, and the pump **10L** reversed to force oil into line **10***m* to withdraw the probe. This causes pressure in the cylinder **10***g* to be built up to a point sufficient to cause shearing of the soil. The pressure in the line **10***m* is recorded on the recorder **10***n* in relation with the volume measurement of means **10L**. Vertical displacement or movement of the probe is monitored by knowledge of the volume of oil forced from the time the pump is energized and the constant rate at which it pumps. The use of a constant rate pump produces a linear strain rate. Thus, strain is noted directly on the strip recorder **10L** since pressure in line **10***m* is directly related.

The metal teeth or barbs **16***b* and **17***b* cause shearing within the sediment as the probe **10** is removed. Further, water pore pressure is dissipated (through the use of porous pressure plates **16** and **17**, if necessary) sufficiently to allow consolidation and formation of a dense layer of soil on the pressure plates. As the probe **11** is withdrawn, the force generated by the hydraulic unit **19** causing lateral expansion of the pressure plates **16** and **17** (by means of the transverse wedge-shaped arms **23** connected to the rungs of the ladder **21** and bearing against shoulders fastened to the pressure plates) is transmitted solely to that portion of the probe which is buried beneath the soil.

It will be noted that once shear has started it will continue until built-up pressures in the line to cylinder **10***g* are dissipated, after which shear will cease until pressures have built up sufficiently to re-initiate movement. Hence, the retraction of the probe **11** is intermittent (or incremental) rather than a constant, steady withdrawal. Thus, a shearing occurs and then the probe is halted whereupon the portion of the side plates **16** and **17** emerging from the soil expand so that the entire expansion force is transmitted to the portion of the side plates beneath the soil thereby increasing the pressure exerted by the probe pressure plates on the sediment in forming a new shear plane.

THEORY OF OPERATION

The fundamental equation for determining the shear strength of soil, as derived by Coulomb, is as follows:

$$S=c+(N-u)\tan\phi$$

where

S is the shearing strength,
c is cohesion (or cohesion shearing strength),
u is the pore water pressure, and
tangent ϕ is the coefficient of internal friction.

S, *c*, and N all have units of force per unit area, such as pounds per square inch. The term *c* represents the previously-described cohesion, and tan ϕ is the internal friction.

On land, the above equation forms the basis for calculations of parameters such as stability of slopes, foundation bearing capacity, bearing capacity of piles, etc. In subaqueous structures, these parameters include predictions of slope stability, pile bearing capacity and depth of sinking and force for retrieval of objects on the bottom. In order to perform such calculations, three soil parameters must be known—cohesion, internal friction and pore water pressure. Pore water pressure is often ignored if the test loading conditions approximate those anticipated in the field, as in the case of in situ testing. The shear strength of soft soil and bottom sediments is of direct engineering importance for founding stable marine cables structures, retrieving objects, etc.

In an ideal clay, pore water pressures dissipate so slowly there is no apparent internal friction. That is, *u* equals N in the equation. Hence, the force resisting shear is directly proportional to the contact area regardless of the applied normal pressure N. An idealized plot of the contact area A vs. resisting force F, for this case is illustrated in FIG. 6. It will be appreciated that the contact area of the probe is directly related to the depth of the probe. As mentioned, if the initial insertion of the probe is incomplete, the maximum contact area A_0, may be obtained from an inspection of probe side plates, or there may be an accessory provided with the probe for marking the top level of the sediment. Data points **41** are plotted on the graph, with the initial data point **41***a* being obtained with knowledge of the maximum depth of penetration of the probe, and subsequent data points being obtained from a knowledge of the amount of probe movement between two successive applications of peak resisting force, for example, between the data points **41***a* and **41***b* in FIG. 6. It will be observed that the line defined by the data points **41**, **41***a*, and **41***b* is a straight line passing through the origin and defining an angle, τ, with the ordinant. The cohesion is equal to the maximum resisting force F_c divided by the initial contact area A_0. Hence, tan $\tau=c$ (cohesion).

An idealized shear diagram for the case in which the sediment is sand is illustrated in FIG. 7. In this case, the cohesion is zero; and, as the device is retracted, the reduction in contact area will be compensated by an increase in the normal pressure, and the total shearing resistance remains constant, as illustrated by the vertical straight line **43** defined by the data points **43***a*.

In the case of a sand, since cohesion equals zero, the total restraining force is equal to the normal force times the coefficient of the internal friction or, the internal friction equals the normal force divided by the lateral expansion force W, supplied by the pneumatic unit **19** and a source of regulated pressure for the apparatus shown.

In FIG. 8, the data points **45** define a line **46** which does not pass through the origin and which is not vertical. Hence, the total restraining force is composed partly of a friction force and partly of a cohesion force, that is to say, the sediment is a sand-clay. The component of the total resisting force caused by cohesion is indicated F_c in FIG. 8; and that component of the total force which is caused by internal friction is designated F_ϕ. These values are obtained by extending line **46** until it intersects with the abscissa, and then constructing a vertical line **47** to intersect the horizontal line **48** representative of the total resisting force. The cohesion is then:

$$c=F_c/A_0$$

and internal friction

$$\tan\phi=F_\phi/W$$

EXAMPLE

FIG. 9 illustrates an idealized shear diagram for the case of a layered sediment wherein the upper layer is denoted layer **1** and the lower layer as layer **2**. In the example, it is assumed that the initial contact area is 50 sq. in. per foot of probe length; and the expansion force W, is 200 pounds. The data points **49** define a line **50**, the tangent of which is F_{c1}/A_0. The initial contact area is the depth of the probe times the contact area per unit length of the probe.

It will be observed that the shear diagram of FIG. 9 is divided into the top layer and the lower layer, but the inventive concept need not be limited to two layers. It will be appreciated that the beginning of each successive layer is marked by its own shear diagram defined by a point of maximum contact area and its maximum restraining force. The two points illustrating this in FIG. 9 are denoted **51** and **52**. To complete the calculation, $\tan\phi_2=F_{\phi 2}/200=130/200$; hence $\phi=33°$. The cohesion for the lower layer, $160/(12)(50)=0.3$ p.s.i.

For the top layer, the internal friction is zero since the line **52** defined by the data points **53** passes through the origin, and cohesion $c=45/(8)(50)=0.1$ p.s.i.

Since the probe is actually inserted into the sediment, some disturbance is inevitable, and the extent of the disturbance will depend upon the volume displaced by the instrument in relation to the area tested. Hence, the probe is preferably designed with a crescent or diamond-shaped cross section to minimize volume displacement while maximizing plate contact area. This is the reason for the above-described insertion or penetrating motion being more of a cutting or piercing action with lateral compressions and displacements of the soil rather than a "punching" in to cause vertical compression and displacement. Expansion of the probe causes a further lateral compression and consolidation at the probe surfaces which is desirable. Simultaneously, tension occurs at the edges, but this is insignificant as long as water flows through the center of the probe to equalize pressure.

PORE PRESSURE

The sequence of application of normal pressure is a stepwise increase; and as disclosed in the above-identified patent of Handy and Fox, if pore pressure becomes excessive, it may be measured as described therein. However, measurement of pore pressure is probably less important in marine soil mechanics than in land investigations where excess pore pressure during testing will more or less dissipate during the slower loading of construction. In other words, in foundation engineering the "consolidation drained" test may be very pertinent, whereas in a marine landslide, an undrained test condition appears justifiable and may give more meaningful data. Two methods of correcting for pore pressure are to minimize pore pressure, and to measure it. A correction should be made if only the maximum and minimum excess pore pressure are measured and recorded by pressure transducers and instruments fitted near the top and bottom of the probe, thus avoiding use of electrical cables. Alternatively, transducers and electrical lines might be used to give a continuous record of pore pressure.

Stress-strain curves may be drawn either by recording the maximum penetration of the probe and assigning strain increments to each test point, based on oil volume. The resulting graph which might appear is illustrated in FIG. 7.

In the example of FIG. 9, allowing 5 minutes per point, a total testing time would be one hour plus the time for lowering and raising the instrument.

Thus, with the inventive principle and apparatus disclosed herein, a complete shearing diagram for a layered sediment beneath a body of water may be obtained in a relatively short time as compared to the heretofore long laboratory testing times. Further, all the advantages of in situ testing are obtained without the need for drilling a separate borehole and placing an instrument within it. In addition, a complete shearing diagram as a function of depth is obtained thereby identifying a sublayer within the sediment.

It will be apparent that a hydraulic piston and cylinder rod until could replace the dead weight messenger in forcing the ladder down, but this would require the addition of hydraulic feed lines, whereas in its simplest form, the illustrated embodiment has only one cable connected between the probe and the ship.

Having thus described a preferred method and apparatus for carrying out my invention, it will be obvious to persons skilled in the art that various other probes (for instance, expandable packer types) may be substituted for that which has been described while continuing to practice the method. Further, the particular probe described may be used to accomplish other purposes. It is, therefore, intended that all such equivalents and substitutions be covered as they are embraced within the spirit and scope of the appended claims.

I claim:

1. In a method of determining cohesion and internal friction of a soil in situ, the steps comprising: inserting a probe into the soil without a borehole and with a minimum of compression in the direction of insertion, said probe including two elongated separable pressure plates frictionally engaging said soil throughout the inserted length of the probe; urging said pressure plates apart with a constant force to exert a known pressure on soil engaged by said pressure plates, thereby compacting said soil laterally; inducing a retraction force on said probe sufficient to cause a shearing of said soil; partially removing said probe from the soil during the exertion of said retraction force to thereby reduce the contact area of said pressure plates against said soil so that the expansion force increases the lateral pressure applied to said soil; measuring said retraction force; then inducing a second retraction force on said probe sufficient to cause a second shearing of the soil; and measuring said second retraction force.

2. A system for determining the shear strength of soil comprising: a probe insertable in the soil under test without a borehole and including first and second elongated, laterally separatable pressure plates for penetrating the soil, each plate including an outer surface for frictionally engaging soil under test; a first set of bearing members connected in longitudinal space relation along one of said pressure plates; a second set of bearing members connected in longitudinal space relation along the other of said pressure plates, a bearing member from each of said sets forming an opposing pair of bearing members; forcing means engaging said bearing members for forcing opposing pairs of said bearing members laterally apart, thereby compacting the soil in contact with said pressure plates, said probe being adapted to transmit all of said applied force to the soil engaged by said pressure plates, thereby increasing the normal pressure applied to the soil as said pressure plates are withdrawn from the soil; means for retracting said probe to cause shearing of the soil; and means for measuring the shearing force.

3. The system of claim **2**, wherein said bearing members each include roller members, rotatable about a horizontal axis and rotatably mounted to the interior of an associated pressure plate in opposing relation to a bearing member mounted on the interior of the other pressure plate, and wherein said forcing means includes a frame, and a plurality of wedge members rigidly connected to said frame and arranged between opopsing pairs of said roller members, whereby as said frame is forced in one direction, said wedge members urge said pairs of bearing members apart in a transverse direction to exert lateral pressure on said soil.

4. The system of claim **3**, wherein said forcing means includes fluid pressure means in said probe and having a rod connected to said frame to urge the same in said one direction upon the appliction of fluid pressure.

5. The system of claim **2**, further comprising hydraulic means for inserting said probe into soil under pressure.

6. The system of claim **2**, wherein the cross section of said pressure plates transverse of the direction of insertion is formed in the shape of a crescent to minimize displacement of soil laterally of said probe as said probe enters said soil while maximizing the lateral contact area of said plates.

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U.S. Cl. X.R.

73—84