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Cone Penetrometer operated by Rotary Drilling Rig

Sondage au pénétromètre à cône exécuté au moyen d'une foreuse rotative type «Rotary»

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Summary

Equipment for static soundings to great depths and operation by means of a rotary drilling rig has been developed by the Waterways Experiment Station. The sounding rod passes through the rotating drill rod and its auger-type bit to a conical drive point, and it is advanced automatically with the drill rod but not rotated. Circulating drilling fluid removes cuttings, stabilizes the walls of the hole, and practically eliminates skin friction on the drill rod. This arrangement makes it possible to perform soundings to depths of 150 to 200 feet by means of a standard rotary drilling rig, even in firm and cohesionless soils, whereas other static sounding methods require special and heavy jacking equipment and that soundings beyond depths of 70 to 100 feet often be performed through previously drilled and cased bore holes.

Sommaire

Une sonde pour essais statiques en grande profondeur et sondage au moyen d'une sondeuse rotative, a été mise au point par le «Waterways Experiment Station». La tige du pénétromètre passe à travers la tige rotative de sondage et sa tarière hélicoïdale jusqu'à une pointe conique; elle est avancée automatiquement à mesure que la tige de sondage avance, mais sans rotation. Le bouc de forage circulant élimine les déblais, stabilise les parois du trou et supprime le frottement superficiel de la tige. Ce dispositif permet d'exécuter des essais de pénétration jusqu'à 45 et 60 mètres de profondeur au moyen d'un appareil de sondage rotatif ordinaire, aussi bien dans des sols compacts que dans les sols pulvérulents, tandis que d'autres appareils de pénétration en profondeur demandent un vérin spécial et de grandes dimensions, et nécessitent, pour des pénétrations au-delà de 20 à 30 mètres, le forage et le tubage préalable du trou de sondage.

Introduction

Subsurface explorations conducted by the Waterways Experiment Station often involve soundings, boring, and sampling in massive sand deposits to depths of 150 to 200 feet. Ordinary static sounding methods require the use of special and heavy jacking equipment for deep penetrations in firm and cohesionless soils, because of the influence of skin friction, and soundings beyond depths of 70 to 100 feet must often be performed through previously drilled and cased bore holes. It was desired to facilitate the sounding operations by development of methods and equipment which would eliminate preliminary boring for deep soundings and also permit the use of standard rotary drilling rigs, capable of exerting a thrust of about six tons, for soundings as well as boring and sampling. Early attempts to reduce the skin friction sufficiently by jetting or simple rotation of the sounding rod were not successful, but a combination of rotary drilling and sounding yielded satisfactory results. The original equipment has been described in official reports (*Hvorslev*, 1949; *WES*, April 1952). Initial mechanical difficulties were encountered but have now been eliminated by minor changes in design. The redesigned equipment and its operation are described in this paper. Mr. *W. J. Turnbull* suggested the use of drilling fluid in sounding operations, and the writer proposed sounding during rotary boring and designed the equipment, but its full development is the result of combined suggestions and observations by many engineers in the Soils Division of the Waterways Experiment Station.

Principles of Method

A truck-mounted rotary drilling rig with a portable, sheet-metal sump for drilling fluid is shown in Fig. 1 and the principal parts of the sounding equipment in Fig. 2. The sounding rod has a conical point with a base area of 10 cm² and a sleeve or mantle, which fits over a downward extension of the hollow stem of a helical auger bit on the drill rod. The sounding or cone rod is tubular above the auger bit and extends up through the drill rod and a swivel to a proving frame, attached by tie rods to the flange of the swivel. The drill rod is rotated and advanced by means of the rotary drilling rig, and the auger cuts a hole with a diameter slightly larger than that of the drill

Fig. 1 Rotary Drilling Rig with Penetrometer
Appareil de sondage rotatif et sonde

rod. Drilling fluid is pumped through the tubular cone rod and an outflow coupling into the lower part of the drill rod, from where it passes out through vents above the auger and returns to the ground surface and the sump. The drilling fluid removes cuttings, stabilizes the walls of the hole, and practically eliminates skin friction on the drill rod.

The cone rod and point are advanced automatically with the drill rod but not rotated. The cone if forced into the soil at a distance below the auger bit which is sufficient, for practical purposes, to eliminate the disturbing influence of stress changes caused by the open hole and pressure of the drilling fluid. The longitudinal friction between the cone rod and the drill rod is negligible because only the drill rod but not the cone rod is rotated. The hole is always full of drilling fluid, and constant rates of rotation and advance of the drill rod and circulation of drilling fluid are maintained. The proving frame indicates the penetration resistance minus the weight of the cone rod and the influence of fluid pressures and friction, determined during calibration of the equipment. Cuttings carried to the surface by the circulating fluid give some indication of the type of soils penetrated.

Some Design Details

The drive point, Fig. 3, consists of a conical point of hardened tool steel and a sleeve or mantle of tough stainless steel. The

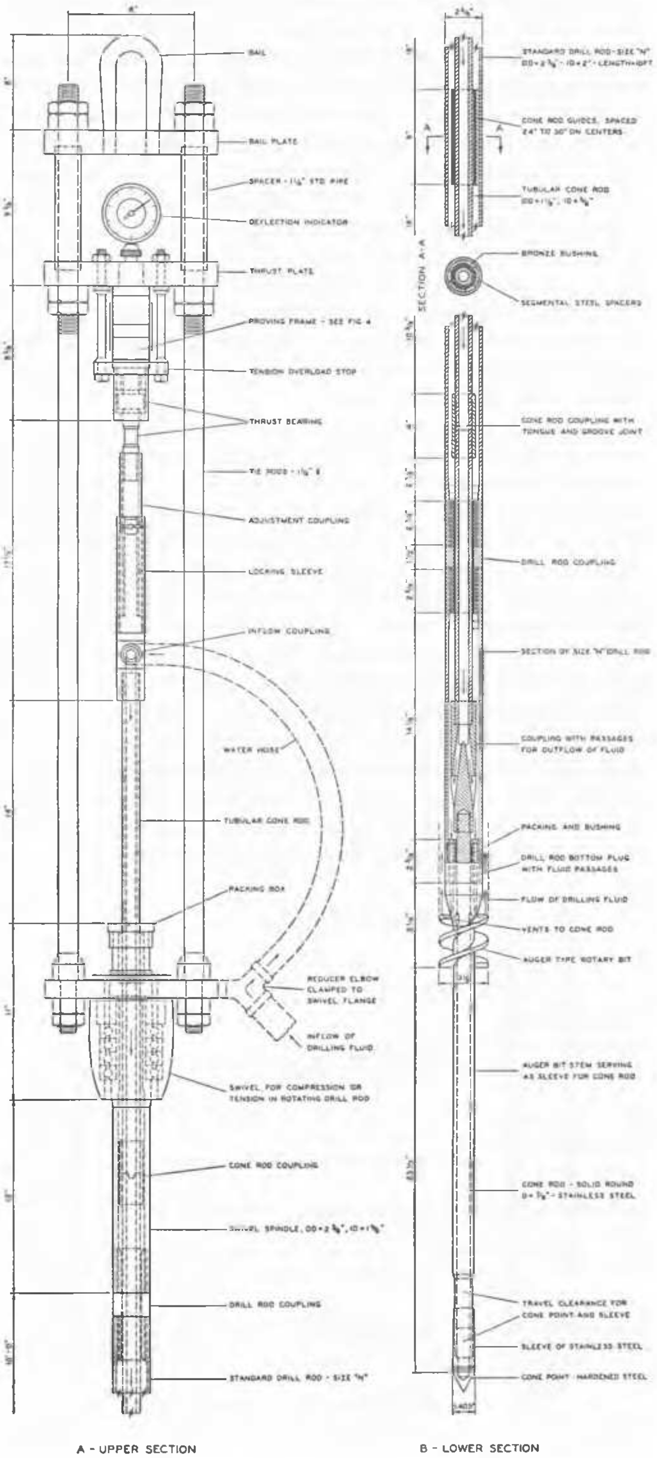

Fig. 2 General Assembly of Penetrometer
Vue générale de la sonde

point is divided into these two parts in order to avoid formation of incipient cracks in the thin mantle during heat treatment. Rotation of the mantle and unscrewing of the point is prevented by a hexagonal section in the connection between the mantle and the cone rod. Friction between soil and mantle is reduced by a slight outside taper. The taper shown corresponds to an outside clearance of 6.6 per cent.

Recent investigations (*E. de Beer*, 1951; *R. Haefeli, G. Amberg* and *A. von Moos*, 1952; *H. N. Kahl* and *H. Muhs*, 1952; *B. Kantey*, 1951) have shown that the taper of the mantle, or the outside clearance between the cone point and the rod or sleeve pipe, exerts a great influence on the indicated point resistance. An outside clearance which is too large facilitates displacement of soil and causes a material deficiency in point resistance. Too small a clearance results in active skin friction on the mantle and the auger stem or sleeve pipe and in a consequent excessive point resistance. It is probable that there exists an optimum value of the clearance which, at least for a given soil type, will cause the influences of various extraneous factors to compensate each other. The mantle of the original cone point had a taper which provided an outside clearance of 11 per cent, which now is believed to be excessive and therefore is reduced in the revised design. However, systematic experiments to determine the optimum value of the clearance or taper have not yet been performed.

Deflection of the proving frame and a difference in compressions of the cone rod and the drill rod cause the cone and mantle to move with respect to the auger stem. The movement varies with the point resistance encountered and the lengths of the rods. The travel clearance shown is sufficient for a point resistance of 5 tons at a depth of 200 feet. Small vents above the auger and a slight clearance between the lower cone rod and the auger stem permit water to flow to or from the space created by the travel clearance. The required travel clearance can be reduced to an insignificant amount or entirely eliminated when the point resistance is determined by means of electrical strain gages near the point, and when the cone rod extension is replaced with an electrical cable (*E. de Beer*, 1951; *H. Kahl* and *H. Muhs*, 1952). However, this arrangement is difficult to apply in combined sounding and rotary boring, where the drill rod is rotated and drilling fluid circulated through it.

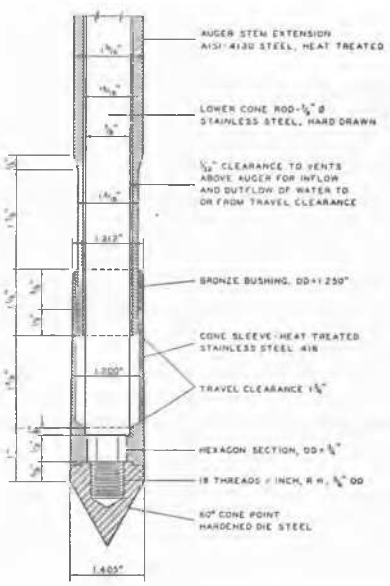

Fig. 3 Details of Conical Point
Détails de la pointe conique

The diameter of the auger bit and the bore hole is determined by the requirement that chips of tough clay, cut during specified rates of rotation and advance of the bit, shall pass through the annular space between the drill rod and the walls of the hole. The edges of the auger blades are hard-surfaced in order to reduce wear and maintain the gage diameter. Theoretical changes in pore-water pressure at the cone point, caused by pressure of the drilling fluid above the auger, are less than four per cent of the pressure in the fluid. Comparative tests have been made with auger stems 6 inches longer and 6 inches shorter than shown in Fig. 2, and a definite difference in indicated point resistances could not be determined.

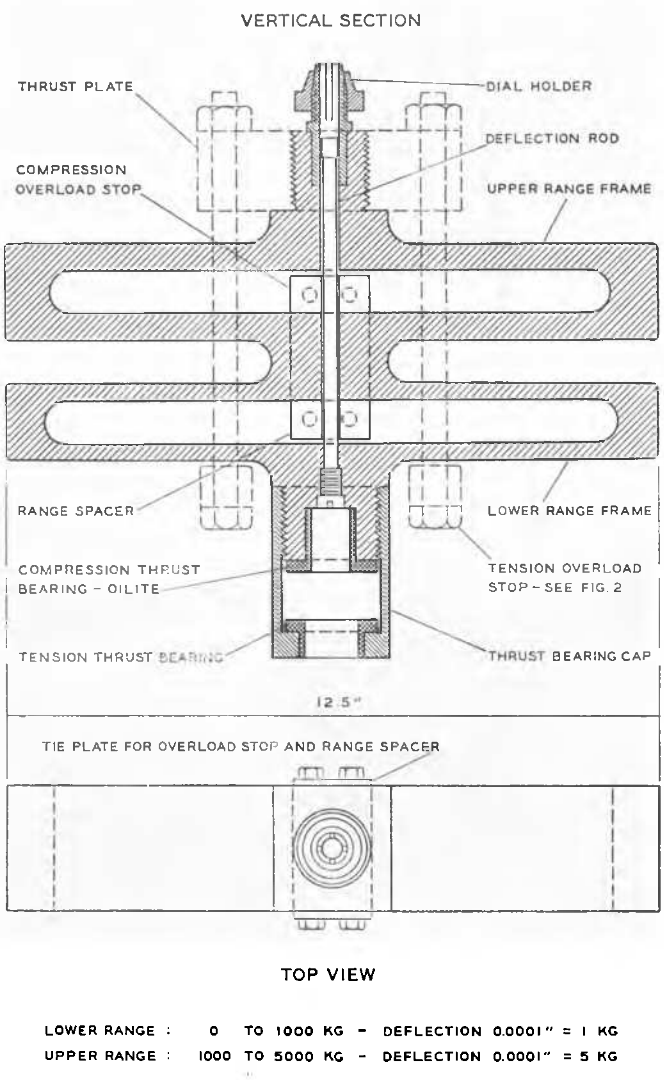

Fig. 4 Double Range Proving Frame
Cadre élastique à double portée

Guide bushings inside the drill rod provide lateral support for the cone rod. The latter may be subjected to either right-hand or left-hand torque, and accidental unscrewing of the couplings is prevented by use of tongue-and-groove joints. The adjustment coupling between the cone rod and the proving frame is released when new cone and drill rods are to be added, and it permits slight changes in the length of the cone rod and corresponding adjustment of the travel clearance for the cone point.

The proving frame consists of two units in order to provide two ranges and adequate accuracy in measuring both low and high values of the point resistance. The combined deflections of the upper and lower frames, Fig. 4, are measured when the load on the proving frame is small. The clearance between the range spacer block and the bottom of the lower frame is closed when the thrust reaches 1000 kg, and larger forces cause only an increase in stresses and deflections of the upper frame. Tensile forces up to 1000 kg can also be measured, and accidental overloading is prevented by compression and tension overload stops. The deflections are measured by means of a standard, shockless type dial indicator with divisions to 0.0001 inch. The deflections of this type of proving frame increase linearly with the load throughout both ranges, and the accuracy of the load measurements is governed by the accuracy of the dial indicator.

Drilling fluid is pumped into the upper end of the cone rod through a short and light hose between the inflow coupling and a reducer elbow. The latter is clamped to the flange of the drill rod and connected to the regular heavy hose of the drilling rig. This arrangement reduces the forces exerted on the cone rod by the water hose. In the original equipment, drilling fluid was pumped through a stem type water swivel and into the cone rod through an inflow coupling, but sand occasionally accumulated in the swivel and caused excessive friction. Pumping directly into the cone rod eliminates such accumulations of sand and reduces the friction between the cone rod and the drill rod and swivel to such a small amount that friction between the cone point and soil is sufficient to prevent rotation of the cone rod.

Calibration and Operation

The proving frame is calibrated by direct loading in the laboratory. The influence of the weight of the cone rod and the friction and pressure of drilling fluid flowing through the rod is determined by field tests during actual sounding operations. The equipment is withdrawn a short distance at a selected depth, and the downward pull on the proving frame is observed by means of the deflection dial while rotation of the drill rod and pumping of drilling fluid are continued at the normal rate. Observations are made for both upward and downward movements of the cone rod with respect to the drill rod, obtained by rotation of the adjustment coupling. The difference between the two values of the tension is equal to twice the longitudinal friction between the cone rod and the drill rod, swivel, and packings. This friction was found to be only 10 to 25 pounds when the drilling fluid is pumped directly into the cone rod. The correction for the weight of the cone rod and influence of fluid friction and pressures increases nearly linearly with the length of the rod at a rate of about 2.6 pounds per foot.

Drilling fluid is prepared by mixing the wash water with a commercial bentonite drilling clay, such as Aquagel. The required amount of Aquagel varies with the character of the soil penetrated; it is about 5 percent by weight of water for clean sand, but it increases with increasing coarseness of the soil and decreases with increasing amounts of natural clay in the wash water. The average specific gravity of the drilling fluid used is about 1.1, but a heavier fluid may be required for deep soundings in very soft clay and can be obtained by mixing a weighting agent, such as Baroid, with the fluid in addition to Aquagel.

The drilling fluid is circulated at the rate of 25 gallons per minute. The drill rod is rotated 25 revolutions per minute, and a

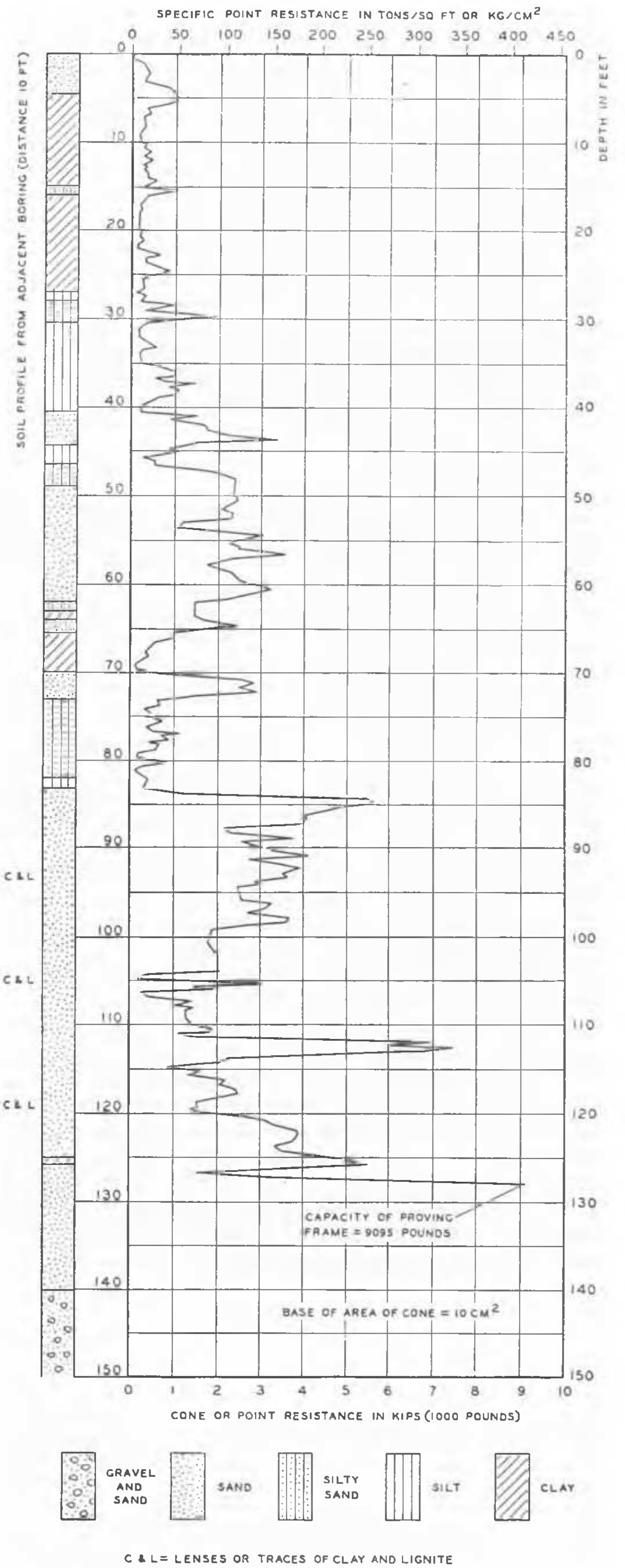

Fig. 5 Penetration Resistance Diagram
Diagramme de la résistance de pénétration

constant rate of advance or feed of 1.0 foot per minute is maintained by means of a flow control valve in the feed lines to the hydraulic cylinders of the drilling rig. The penetration resistance indicated by the proving frame, the pump pressure, and the oil pressure in the hydraulic drive cylinders are observed and recorded for each 6-inch advance in depth. Usually there is but little difference between the penetration resistance and the thrust exerted by the hydraulic cylinders.

The hydraulic cylinders have a stroke of 30 inches. A short interruption of the sounding is required for resetting the hydraulic drive at the end of each stroke, and a somewhat longer interruption when new drill rods and cone rods are to be added. An uninterrupted advance of 10 to 20 feet can be obtained by use of modern rotary drilling rigs with a chain pulldown instead of a hydraulic drive, and the use of such a pulldown drive would accelerate the sounding operation considerably.

Results and Comments

An example of a penetration resistance diagram obtained with the rotary sounding equipment is shown in Fig. 5 and there compared with a detailed soil profile from an adjacent boring. A proving frame with a maximum capactiy of 9,095 pounds was provided in the original equipment and used in soundings so far performed. It will be seen in Fig. 5 that a penetration resistance equal to the capacity of the proving frame was reached at a depth of 128 feet. In other soundings the maximum capacity was reached at slightly greater depths, up to 144 feet, and in a few cases at smaller depths when strata of gravel or very dense sand were encountered. The cone rod has been strengthened and the capacity of the proving frame increased to 5,000 kg in the redesigned equipment now under construction.

The penetration resistance depends on the depths below ground surface and ground-water level and on various physical properties of the soil, such as internal friction, cohesion, compressibility, relative density and/or sensitivity to disturbance. In many investigations performed by the Waterways Experiment Station it is of particular interest to determine the relative density and corresponding stability of sand deposits. Attempts have been made to correlate penetration resistance obtained with the equipment described with the relative densities of sand strata, as determined by tests on undisturbed samples taken in adjacent borings. The penetration resistance furnishes a qualitative indication of the relative density, but as yet it has not been possible completely to separate the influence of the relative density from that of other factors on which the penetration resistance depends. Correlation of data so far obtained was difficult because the deposits investigated were very irregular in character, and the grain diameters and the natural and relative densities tended to increase with increasing depth. It must also be considered that the natural density of sands may be subject to changes during sampling operations, even when the best available methods of sampling are used (*A. Bishop*, 1948; *M. Hvorslev*, 1949; *W. G. Shockley* and *P. K. Garber*, 1953; *WES*, June 1952).

Although a reliable correlation between the penetration resistance and the relative density of sands has not yet been obtained, soundings with the equipment described have furnished very valuable data and reduced the over-all costs of exploration. The penetration resistance diagrams are continuous and indicate relative changes in density and strength, the point bearing capacity of piles, and the existence of stratifications which can not be discerned by inspection of the samples. The location of critical strata can be determined by soundings before boring and sampling operations, and this permits a material reduction in the required number of borings, undisturbed samples to be taken, and laboratory tests to be performed.

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