A LABORATORY STUDY OF CONE PENETRATION RESISTANCE IN DRY SAND USING A MINIATURE SOLID CONE

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(ABSTRACT)

This research has been conducted as a preliminary study to develop a miniature cone and its applicability for future use with special attention to liquefaction susceptibility. Previous studies have shown that Static Cone Penetration Test (CPT) results can be used successfully to derive information on soil types and strength. Owing to this fact, this research is performed to try to correlate the cone penetration resistance with the density of the sand and to check the validity of formulas derived from previous works related to prediction of cone tip bearing resistance q_c, in normally consolidated sand.

For this purpose, a large sample of sand is prepared in a box of 2'x2' (.61mx.61m) and 4'(1.22 m) high using a funnel with adjustable diameter and dropping height as to produce diferent densities of the sand. The CPT is performed using two solid miniature cones, one with 0.625 in.(15.875 mm) diameter (Cone 1) and the other with the same diameter shaft but with enlarged tip of .825 in.(20.955 mm) (Cone 2).

The results are compared to predicted values of q_c or angle of

internal friction using the available theories. From the comparison, it is concluded that Schmertmann's experimental equation best fitted the data and that the angle of internal friction varies with depth.

In addition, review on the factors influencing the cone penetration resistance are presented to help anticipate the predictions and understanding of the penetration test phenomena.

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1. INTRODUCTION

1.1. Aim of Research

Previous studies have shown that Static Cone Penetration Test results can be used successfully to derive information on soil types and strength. Owing to this fact, it is the aim of this research to correlate the cone penetration resistance with the density of the sand and to check the validity of formuli derived from previous works related to prediction of cone tip bearing resistance, q_c, in normally consolidated sand. In addition a review of the factors affecting the penetration resistance of sand is presented. The research is limited to the use of a miniature cones and the applicability for future use and it serves as a preliminary investigation to develop a relatively simple and highly portable set of tools which can produce sub-surface information which would greatly enhance the ability to explain observed liquefaction phenomena.

For this purpose, a large sample of sand is prepared in a box of 2'x2'(.61m x.61m) and 4' (1.22m) high using funnel with adjustable diameter opening and dropping height as to produce different densities of the sand. The CPT is performed using two types of cones, one with .625 in. (15.875 mm) diameter (cone 1) and the other one of the same diameter shaft but with enlarged tip of .825 inches (20.955 mm) diameter (cone 2).

By using funnel to drop the sand, it is possible to obtain very uniform and reproducable specimens of the desired density in a range or relative density that varies from 40% to about 70%. The denser sample can be obtained by pouring the sand and tamping it every layer.

To give a better look at the problem, it is necessary to present the general theories and practice of CPT and methods of interpretation that are available. In addition, the relationship between various parameters of sand properties and tip resistance, q_c, obtained from previous experimental works by some authors are also presented. In such a way, the penetration resistance of the sand can be predicted using those theories to compare with the test result.

1.2. Ideas of CPT

The main idea of the CPT remains a simple one, it is to advance a rod into the soil, measure the forces required to produce such movement and interpret these forces in terms of soil strength (angle of internal friction and cohesion) and other parameters such as density, compressibility etc.

Static Penetrometers are of two basic types

(1) The Movable Cone-Tip Static Penetrometer.

The point resistance alone is measured by advancing a cone located immediately below a static sleeve which serve as a casing and prevents soil from acting against the rod pushing the cone downward.

(2) The Fixed Cone-tip Static Penetrometer.

Both cone tip and rod move simultaneously. This type of apparatus measures both tip resistance and side friction.

1.3. Mechanical and Electrical Tips

The main difference in penetrometers commonly used concerns the difference between the electric and the mechanical tips (de Ruiter, 1971). This is not only a matter of the shape of the cone, but also the method of operation. The mechanical tips give a discontinuous measurement by telescoping the cone ahead of the stationary push rods. The electric penetrometers are advanced continuously and the only interuption occurs when another push rod is added to the string. The mechanical penetrometers have their advantages in the simplicity of operation and the low cost of the tips. Cone measurement with mechanical penetrometers can be subject to various errors, which are difficult to quantify exactly, but which can be significant. However careful operation of the mechanical penetrometer should get result which is not inferior to the electrical one.

When one wishes to measure the local skin friction using mechanical cone beside the skin friction along the rod, the equipment 'Begemann' can be used. The principle of this penetrometer is that the tip is advanced prior to the shaft and then the friction jacket is moved while the other portion of the shaft remain in their position. Electrical penetrometers have built in load cells that record separately the end bearing and the side friction. Strain gages are most commonly used for the load cells as they are simple and rugged. The load cells have normally a capacity of 10 kips (500 kgf) to 20 kips (1000 kgf) for end bearing, and 1.5 - 5 kips (75 - 250 kgf) for side friction, depending on the soils to be penetrated.

The electric penetrometer offers obvious advantages in the quality of the test. The repeatability ot the electric cone test is exellent, provided that the system is well calibrated. Electrical cones provide a much more accurate and consistent result than the mechanical types, which is best demonstrated by the virtually complete repeatability of the test.

The advantages of Electrical Cone include continuous (usually in one meter rod length increments) logging of tip resistance, a more accurate separation of the q_c and f_s components of resistance, greater overall sounding speed because of avoiding the stopping and starting necessary for each measurement as required with the telescoping mechanical penetrometers. In addition it also has the ability to test very weak soils by appropriate adjustment of tranducer sensitivity, and the ability to relatively easily incorporate instruments such as inclinometers and pore pressure devices. But one must consider the added cost of the tips and the support facilities needed to use and maintain them.

The mechanical influences that effect the accuracy of the penetrometer in the field are mostly a matter of soil particles that enter into the joints between the tip, the sleeve and the body of the penetrometer. These particles become tightly packed and cause friction between the free moving parts. The effect is greatest on the measurement of the side friction, as the friction sleeve becomes slightly engaged by the minute movements of the tip.

The principle of the electric penetrometer offers more latitude for variations in size and shape. Non standard types may have advantages for special applications. It is for this purpose also that this research is being forwarded. This research, using solid cones,is a preliminary work for other research which later in the near future will be developed using electrical cones to asess liquefaction phenomena.

1.4. CPT in U.S.A.

Because of its versatility the Standard Penetration Test (SPT) has evolved as by far the most common type of penetration test in the U.S.A. This has happened despite the quantitatively crude results obtained from the SPT and a common lack of controlled research to support the various correlations often used in design. As was pointed out by Kellog (1959), the Static Penetrometer is a rather slow test which allows the pore pressure to dissipate. This is not to be expected with the case of the Dynamic Test. Kellog also remarks that the Static Penetrometer is more sensitive to minute changes in the soil properties than the dynamic test and yields a more complete record of all layer being tested.

In U.S.A. and many other regions, Static Penetration Tests are ussually carried out in accordance with the 'Tentative Method for Deep Quasi Static Cone Penetration Test, ASTM'. The standard A.S.T.M. static cone has a 60 degree point angle and base diameter of 1.4 in. (36 mm) with a 5.3 in.(134 mm) long friction sleeve of the same outside diameter as the cone. The penetrometer tip is pushed into the ground at a rate of 2 to 4 ft/min. (10 to 20 mm/sec), and the cone resistance and local friction are recorded. In the dynamic cone penetration test, a 60 cone of 2.25 in.(57mm) base diameter at the end of 1.75 in.(44 mm) outside diameter rod is driven into the ground without borehole by a hammer weighing 140 lbs (63.5 kg) and falling freely by 30 in. (760 mm) The number of blows per foot (305 mm) of penetration are recorded as the dynamic cone resistance. The same energy is used in the SPT when a standard split tube sampler of 2 in (51 mm) outside diameter and 27 in (686 mm) length at the end of 1.625 in (41 mm) diameter rod is driven into the bottom of a (usually cased) borehole and the number of blows per foot of penetration below 6 in (152 mm) depth is recorded as the Standard Penetration Resistance.

The rapid expansion of CPT capability in U.S.A. in the past 10 years demonstrates a rapid and continuing growth in interest in this form of penetration testing. Almost all of the commercial CPT equipment in the U.S.A. uses the mechanical mantle of Begemann friction cone tips manufactured in Holland. Fugro California, Inc. uses electrical tips. (Schmertmann, 1974).

Although CPT is used for a wide variety of purposes, especially by the engineers who have experience with the CPT methods, the most common use of CPT in the U.S.A. is to explore the stratigraphy, uniformity and engineering characteristic of cohesionless soil.

1.5. Recent Development, Usage and Interpretation

One of the key question which produced more or less consensus at the Stockholm ESOPT (1974) was the broad superiority of the quasi-static over dynamic methods to produce data of quantitative usefulness for design, including in-situ shear strength. (Schmertmann, 1975)

Among the major advantages of the CPT are, it is quick, easy and economical. The CPT provides test data that are more susceptible to analytical interpretation than are obtained by the SPT (Durgunoglu & Mitchell, 1975) and it is particularly good investigative tool for sands, where undisturbed sampling is difficult. It does suffer however, the disadvantage of having no samples for direct observation of soil types. CPT is not recommended either for gravelly soils and for soils with Standard Penetration Value N greater than 50. In such soils, dynamic cone tests are more prevalent (Desai et.al, 1974). Gravelly sands tend to produce sharp peaks in the q_c profile. Static sounding often reach refusal when attempting to penetrate gravel layers. Intersecting very large particles usually abruptly stops a sounding. Brushing against them can deflect and permanently bends the tip.

The CPT has proven valuable for soil profiling, as the soil type can be identified from the combined measurement of end resistance and side friction. The test lends itself furthermore for the derivation of normal soil properties, such as density, friction angle and cohesion. Various theories have been developed in the course of time and continued research in this direction is adding to the usefulness of the CPT for foundation design.

The use of CPT data has been summarized by Durgunoglu and Mitchell (1975)

(1) To derive information on soil types and soil strength

(2) As a basis for determination of pile supporting capacity

(3) To estimate compressibility and insitu density of cohesionless soils. There is currently considerable interest in the deduction of relative density values of cohesionless soils from cone resistance data for use in the assesment of liquefaction potential

(4) For estimation of settlement of sands

(5) To characterize vehicle trafficability over unpaved soils.

Recent developments in methods of interpretation show promise. Many empirical correlations have been used to predict soil behavior from the results of cone penetration tests. In addition, many theoretical solutions for the penetration resistance of flat ended penetrometers are available and have been used. The use of these theories for penetrometers with half tip cone angle of less than 90 is not justified in many cases.

Few analytical and numerical solutions for wedge and cone shaped penetrometers which account for both apex angle and penetrometer roughness have been available previously. Meyerhof (1961), provided solutions for both cohesive and cohesionless soils for certain condition assuming the failure mechanism shown in Figure 2.1. To provide information on the failure mechanism, with particular reference to the influence of apex angle and tip roughness, Durgunoglu and Mitchell (1973) have carried out a series of model tests using wedge and cone-tipped penetrometers of different base apex angle and different surface roughness.