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Instrument for in situ testing of static penetration of large diameter in boreholes

Un instrument pour essai in-situ de pénétration statique de grand diamètre dans les forages

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SYNOPSIS: An instrument designed and developed to carry out static penetration tests in the bottoms of boreholes is described here. The instrument permits in situ testing of underground levels which would otherwise be practically impossible to sample or to testify (in soils such as gravel, etc). By taking up the reaction in the borehole walls near the bottom, the instrument is able to test very high applied loads while measuring vertical strains during the process of soil identation by the cone. If the conical point is replaced by a flat disk, the test would be equivalent to a small diameter plate load test. Some results obtained in a steel foundry slag tip are described.

1. INTRODUCTION

The specific need for which the instrument was designed, and where the tests described were conducted, is a large waste tip on an iron and steel plant predominantly containing the normal materials of such activity, namely cinder and above all slag.

Determining the geomechanical features of this type of fill involves a number of varied problems, both derived from the actual nature of the constituting materials and from their heterogeneous distribution, type, etc.

Determining the typical characteristics of the fill, even individually, is also very difficult, particularly in the case of slag, where it is virtually impossible to obtain unaltered samples.

With the customary sampling and testing methods thus proving practically invalid, it was necessary to resort to in situ testing in order to attempt to characterize these dumped materials.

If large scale load tests could be viable to determine surface load strain values, for the study of shear strength values (additionally believed to be considerably variable in relation to the depth/effective pressure), both traditional in situ test types such as direct shear test (in view of the impossibility of cutting the test pieces) and normal surface tests using penetrometers, etc, were practically no possible.

What must also be pointed out is the great usefulness of this testing method where materials which are difficult to sample and test, such as coarse gravels, dense sands, etc, are concerned, and which are also located at depths difficult to reach from the surface using regular static or dynamic boring methods.

Thus, in principle, borehole drilling allows any desired depth or level to be reached in materials of this kind. Once the level to be tested has been reached, the device is lowered by simple means into the borehole and the test is performed from the surface. Taking up the reaction from the casing bottom end makes it possible to avoid the problems of transferring loads by means of rods, where the first problem to contend with would be potential rod buckling.

With this method, testing is done independent of the conditions of depth, reaction measuring system, etc, involved and it has high load capacity available (in this particular case up to the order of magnitude close to 35 T) at the required depth.

The "particle size" of the material in question will determine the diameter of the instrument body to be used and the relevant cone size. The smaller the particle size, the simpler and more economical the mechanical system involved will be. What is presented here is the prototype of the instrument and method developed to carry out static penetration tests in the bottom of boreholes, a large diameter one in this case, so the sampling is sufficiently representative in accordance with the particle size of the materials being tested (slag).

It is currently being planned to develop this prototype, improving the devieces to have shown less efficiency (particularly the thrust and displacement measuring devices) and building other types to be used, for instance, on less coarse gravels, sands, etc.

2. INSTRUMENT DESCRIPTION AND OPERATION

The instrument consists on three clearly differentiated bodies, as shown in Fig. 1. With reference to the typical cross-section shown in Fig. 2, the description and operation is as follows:

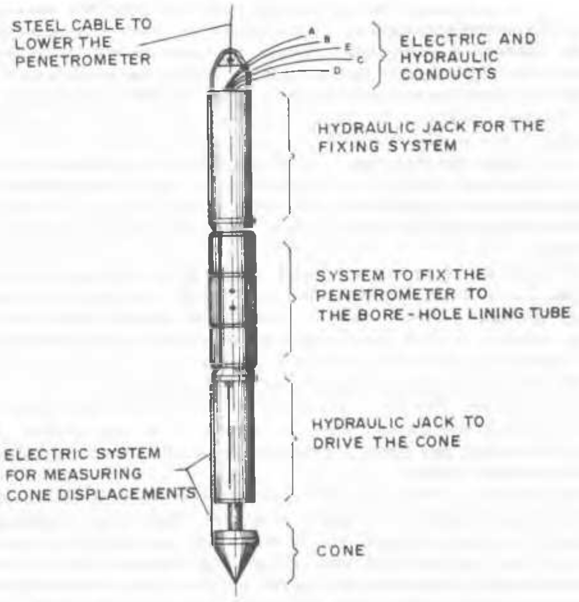
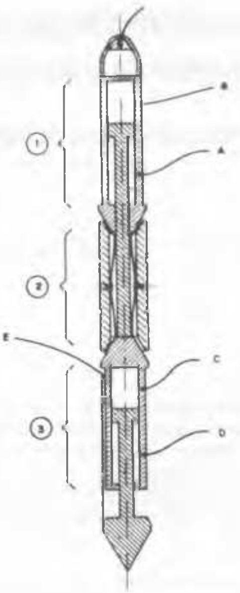


Figure 1. General scheme of the apparatus



A = Flexible tubing for the extension of the fixing system

B = Polietiline tubing for the retraction if the fixing system

C = Flexible tubing for the cone driving actuator

D = Polietilene tubing for cone extractor

E = Electric strand for cone displacement measurement

Figure. 2. Schematic drawing

1. An upper body formed by a double action hydraulic cylinder whose piston shaft is connected to the lower body's hydraulic cylinder or bit driving system opens or closes the anchoring system when activated by a hydraulic system controlled by a precision pressure gauge.
2. A central body is the system that anchors the device into the borehole walls. It consists of four metal segments screwed to an equal number of layered bow springs, bolted to two equal and opposing round tapered pieces linked to the upper and lower bodies of the instrument. The entire system is held together by means of coil springs.
3. A lower body, whose task is to drive the conical point into the soil, is connected to the piston shaft head (135 mm in diameter and 60° conical angle) through the directly applied power of a double action hydraulic cylinder.

An electric system is housed along the outside of the hydraulic cylinder generator line with its moving end connected by a thin rod to the penetrometer's conical point which is the device which measures displacement. The readings thus obtained are carried by an inner cable to the digital and analogical recording systems.

Fig. 3 shows the configuration of the different mechanical parts described here in greater detail. Figs. 4 and 5 present two photographs of the instrument and the auxiliary equipment.

The operating method can be described in a simplified manner as follows. The instrument is introduced thorugh the casing pipe, suspended from a steel cable, and lowered to the borehole bottom. After the correct depth has been reached, the anchoring system fixes onto the borehole walls where reactions are taking up as required to proceed to drive the cone. As this is driven into the material its displacement and applied pressure are measured and both are recorded. Fig. 6 is a diagram of the general testing set-up:

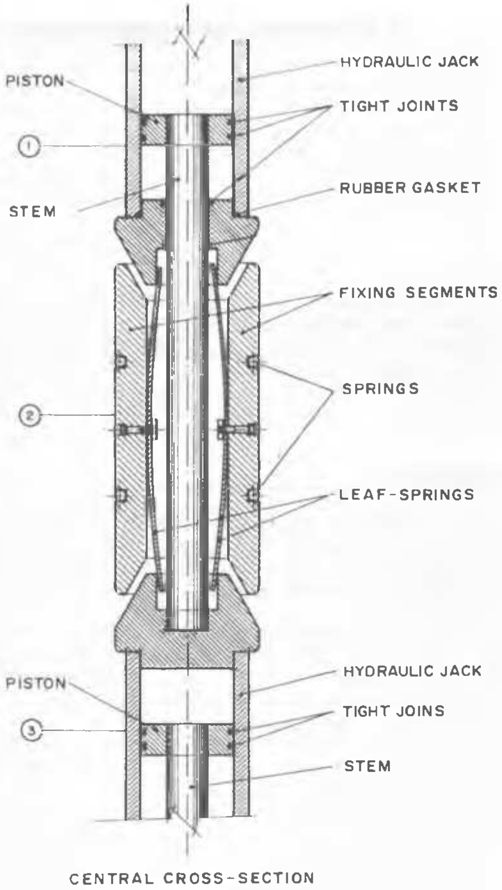
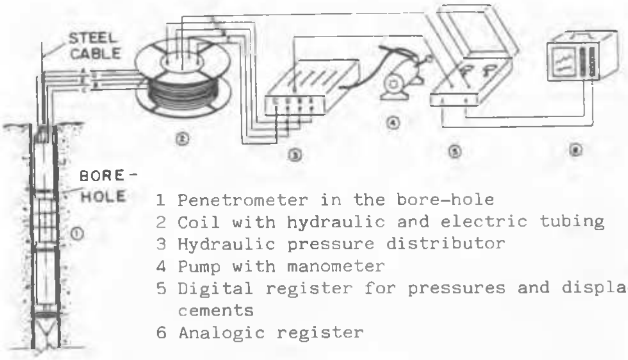


Figure 3. Detailed central section

Figure 4. General, view of the instrument and auxiliary dispositives

Figure 5. Detail of conical point



1 Penetrometer in the bore-hole
2 Coil with hydraulic and electric tubing
3 Hydraulic pressure distributor
4 Pump with manometer
5 Digital register for pressures and displacements
6 Analogic register

A, B, C, D y E = Hydraulic tubing and electric strands with connectors

Figure 6. General scheme of the equipment

- Anchorage. This is performed by the motion of the hydraulic cylinder piston, a part of the upper body of the instrument. Which brings together the two tapered pieces connected to bodies Nos. 1 & 3 in Figs. 2 & 3, therefore causing the anchoring segments to expand radially and hold the device in place by a wedge effect.
- Cone penetration. This is achieved by direct pressure from the hydraulic cylinder of the lower body, No. 3 in Fig. 2.
- Anchorage removal. Same procedure as above but reversed. The laminated springs recover the anchoring segments and the two coil springs ensure that they close fully and are positioned correctly.
- Cone recovery. Same procedure as above but reversed.
- Pulling out the instrument of the borehole assembly.

3. RESULTS

The result of each test is given by the vertical displacement of the cone and by the pressure applied to obtain penetration in the borehole bottom. As the size of this particular cone was considerable, the driving was carried out over a length of more than 15 cm, thus enabling its penetration to be measured.

Fig. 7 shows several results of tests conducted on Boring Site No. 1 at different depths (h) below the surface. Although several digital readings made during the test are available, its is most advisable to record the continuous load-deformation curves graphically.

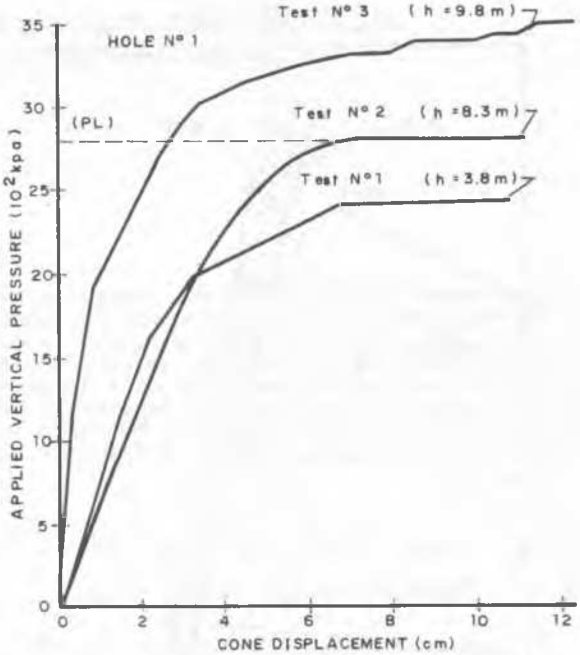


Figure 7. Basic graphics of tests

Aside from other potential applications, curve recording enables the point in time to be observed where the external tip makes contact with the soil and the actual moment when failure is caused by the so-called ultimate or limit pressure (P_L) to be determined.

Fig. 8 is a summary of results (P_L), as a function of the depth involved, obtained in the different borings tested (Sites Nos. 1, 2 & 3). As noticed, occasional drops in strength occur owing to the existance of intermediate layers of soft materials, such as ashes, muds, etc. Summarising the tests, the average dispersion graph was plotted where tests were believed to have gone throug slag.

As discussed above, the purpose of the study for which the instrument was designed was to characterize the strength of slag materials found in the large slopes of the tip (up to 50 m high). At the same time the hypothesis was considered that shear strength parameters varied according to the depth involved or, in short, with the actual ground pressure involved (as a result of reduction of the friction component and increase of soil cohesion).

For this particular casestudy, a linear law of critical pressure variation was applied:

$$(h)\ (10^2\ \text{KPa}) = 30 + 0.8 \times h\ (\text{m})$$

In the subsequent interpretation and analysis, a method was attempted where strains would be taken into account, such as those based on the theory of spherical cavity expansion. A cohesive and frictional model was adopted for the material and the equations developed by Carter et al (1986) were applied. Aside from the various simplifications required to obtain fast results, and to overcome the added difficulty of having to take into account the stress-strain characteristics of the material (E, ν), it can be said that the final results were satisfactory in respect of the objectives proposed.

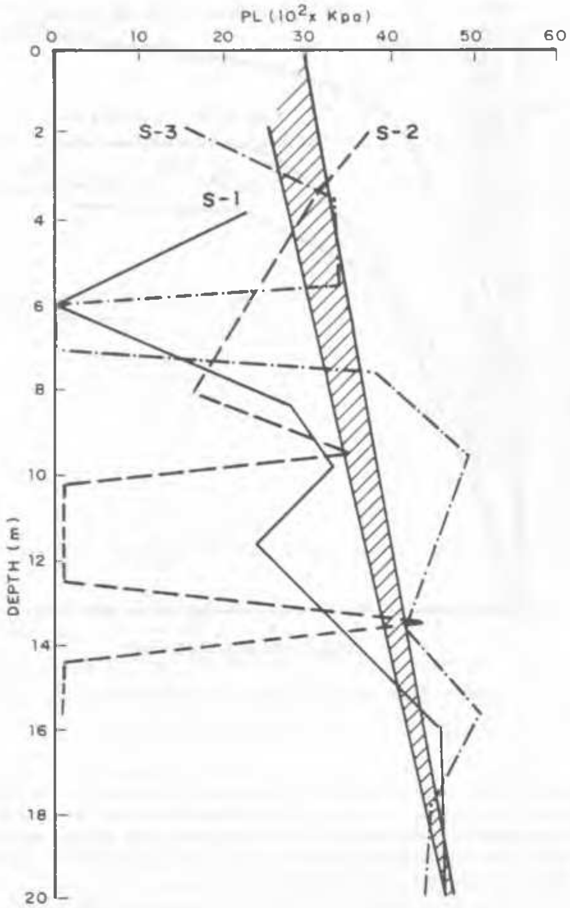


Figure 8. Overall test results

4. CONCLUSIONS

In relation to the problem stated, the objectives proposed and the results discussed above, the following conclusions can be drawn:

a) A prototype for a borehole bottom static penetration testing instrument was developed with the basic idea of enabling tests of soil materials to be carried out which would otherwise be difficult to sample or testify using customary methods. The vertical reaction required to drive the cone is taken from the casing walls near the bottom.

b) Aside from obtaining high reactions, otherwise virtually impossible to convey by the penetration head (buckling), the instrument was set up to measure the soil identation process, recording both the applied pressure and vertical displacement. In this way, the stress-strain curves were obtained for each test.

c) The specific prototype designed was of the so-called "heavy" kind in view of the particle size of the material tested (slag). The cone base diameter was 135 mm and the cone angle 60°. In other instances where the system may be useful (gravels, sands, etc) this diameter can be reduced as a fuction of the specific particle size involved, thus making the instrument lighter, less hydraulically and mechanically complex and more economical. Furthermore, by substituting a flat disk head, a kind of small plate load test can be performed.

d) Results may be interpreted on a varied basis, from the classic failure methods to those involving strains. In this respect, methods based on cavity expansion theories are deemed highly advisable if the geometry of the problem is adapted to the actual surrounding conditions. Along these lines, the stress-strain data obtained should be taken advantage of to the maximum extent.

e) Regardless of the simplifications performed and aside from the added uncertainty caused by the need to introduce other parameters, such as deformability (E) and dilation (ψ) in the equations used, it can be concluded that the results obtained in this specific case were sufficiently satisfactory. At any rate, some aspects, such as vertical strain measurements, offer room for improvement, and the bases for interpretation should be worked on in the future.

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