A Combined Penetration Process for the Exploration of the Foundation Soil

Procédé combiné de pénétration pour l'exploration des sols de fondations

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Summary

The "AG. für Grundwasserbauten" at Berne has constructed a device for sounding purposes based upon combined static and dynamic penetration. This apparatus permits—according to the problem to be solved and the nature of the subsoil—the use of either of the two penetration methods. The changeover from the static to dynamic penetration (driving) makes penetration of relatively hard intermediate layers possible. Particular attention was given to the differentiated measurement of the skin friction directly above the point of the penetrometer. This can be achieved by a special device (friction sleeve), the details of which are described. It also permits the measurement of the increase in the skin friction in relation to time.

Sommaire

La société «Travaux Hydrauliques S. A., Berne» a mis au point une sonde de pénétration basée sur une double combinaison de pénétration, à savoir statique et dynamique. Ce dispositif permet l'investigation du sous-sol à l'aide soit de l'un soit de l'autre des deux procédés selon la nature du problème à résoudre et des terrains examinés. Le passage à volonté du travail par pénétration statique (vérin hydraulique) au travail par pénétration dynamique (battage) permet de traverser les couches intermédiaires relativement dures. La mesure différentielle du frottement latéral agissant directement au-dessus de la pointe de la sonde a fait l'objet de recherches approfondies; elle s'effectue à l'aide d'un dispositif spécial (manchon de frottement) lequel est décrit en détail. Le même dispositif permet également de mesurer l'accroissement du frottement latéral en fonction du temps.

Introduction

On account of the erratic (heterogeneous) subsoil prevalent in Switzerland, where soft and hard layers alternate, it was obvious that an attempt should be made to combine the advantages of static and dynamic penetration methods in one single apparatus. This device, called *press-ram-penetrometer*, constructed by the "AG. für Grundwasserbauten" at Berne, serves, on the one hand, the purpose of obtaining a differentiated picture of the composition of the subsoil layers and, on the other hand, it permits the exploration of certain soil properties important from a technical point of view.

While the dynamic displacement resistance at the point of the penetrometer makes it possible to obtain some determination of the consistency, which gives a general view of the nature and the degree of consolidation of the subsoil, the knowledge of the static displacement resistance permits the establishing of the ultimate load or bearing capacity (*de Beer*, 1945). A necessary assumption is, therefore, the determination of the total skin friction or its elimination by constructive measures. For the measurement of the local specific skin friction above the point of the penetrometer a new process described below has been developed. In order to obtain a more accurate evaluation of the compressibility of the soil a static bearing test can be made at any depth. By means of the various measurements described the solution of the following problems is facilitated: estimation of the ultimate bearing capacity of the soil, examination of the compressibility of the subsoil in connection with the computation of settlements, determination of the bearing capacity of piles based upon point resistance and skin friction (*Huizinga*, 1952).

As the heterogeneity of the soil layers requires a narrow spacing of the points of exploration and a considerable daily output, the device has been constructed in such a way that it can easily be transported, assembled and dismantled (Figs. 1 and 2) (AG. für Grundwasserbauten, 1951).

Method

For the purpose of taking static or dynamic penetration measurements, the sounding device can either be pressed into the soil layers under examination by means of a hydraulic press or it can be driven into the soil by means of a ram. As the cross-section of the point amounts to 25 cm^2, and the pressure-ram-apparatus in its present design permits a static load of over 2000 kg, it is possible to reach specific pressures of about 40 kg/cm^2 even with a total skin friction of 1000 kg. In the static load tests it is necessary to measure the penetration of the rods with the aid of instruments which permit readings to an accuracy of up to $^1/_{100}$ mm.

Fig. 1 Press-Ram-Penetrometer during Transportation
Sonde de pénétration statique et dynamique. Transport

Fig. 2 Press-Ram-Penetrometer at Work
Sonde de pénétration en action

The press-ram-apparatus (penetrometer) consists of a cylindrical rod and a friction sleeve, the latter being fastened to the lower end of the rod and having a slightly larger diameter than that of the rod. In the type shown in Fig. 3, the friction sleeve, which is firmly fixed to the point of the sounding apparatus, is loosely connected to the rod by means of a strong pin which passes through a slot in the rod. As soon as the somewhat larger friction sleeve is firm in the ground, the rod can be raised vertically above the sleeve, but only until the pin strikes against the lower end of the slot and then pulls the friction sleeve along. In order to minimise the friction of the rod, a thixotropic liquid can be pumped through it; this liquid surrounds and lubricates the rod. The penetrometer is operated in the following manner:

After a certain depth has been reached by static or dynamic penetration, the rod is lifted by means of the hydraulic press and the pulling resistance (weight plus skin friction of the rod) is measured with the pressure gauge. Now (i.e. after the pin has struck against the lower end of the slot) the friction sleeve, which up to this moment has been held firmly in the ground, is also raised and the total resistance of the rod plus the friction sleeve is measured. The resistance of the friction sleeve is the difference between the total pulling out resistance and the resistance of the rod (which has been greatly reduced by the above mentioned lubrication); from this the specific skin friction τ of the soil layers which immediately surround the sleeve can be calculated. The specific point resistance is determined by deducting the active friction resistance from the static, resp. dynamic, penetration resistance.

The measuring ranges of the device are the following:

(*a*) specific point resistance:

σ static $= 3 — 70$ kg/cm^2

w dynamic $= 10 — 800$ kg/cm^2

(*b*) specific skin friction:

$\tau = 0.2 — 20$ kg/cm^2.

Experiments Made to date

To date the process has been used for the subsoil investigation of foundations. The diagram in Fig. 4 illustrates a press-

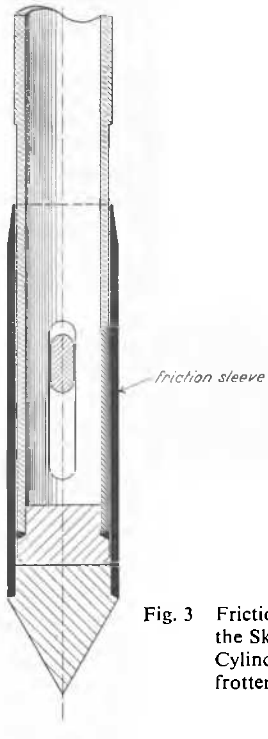

Fig. 3 Friction Sleeve with Rod for the Measurement of the Skin Friction above the Point
Cylindre de friction et tiges pour la mesure du frottement latéral

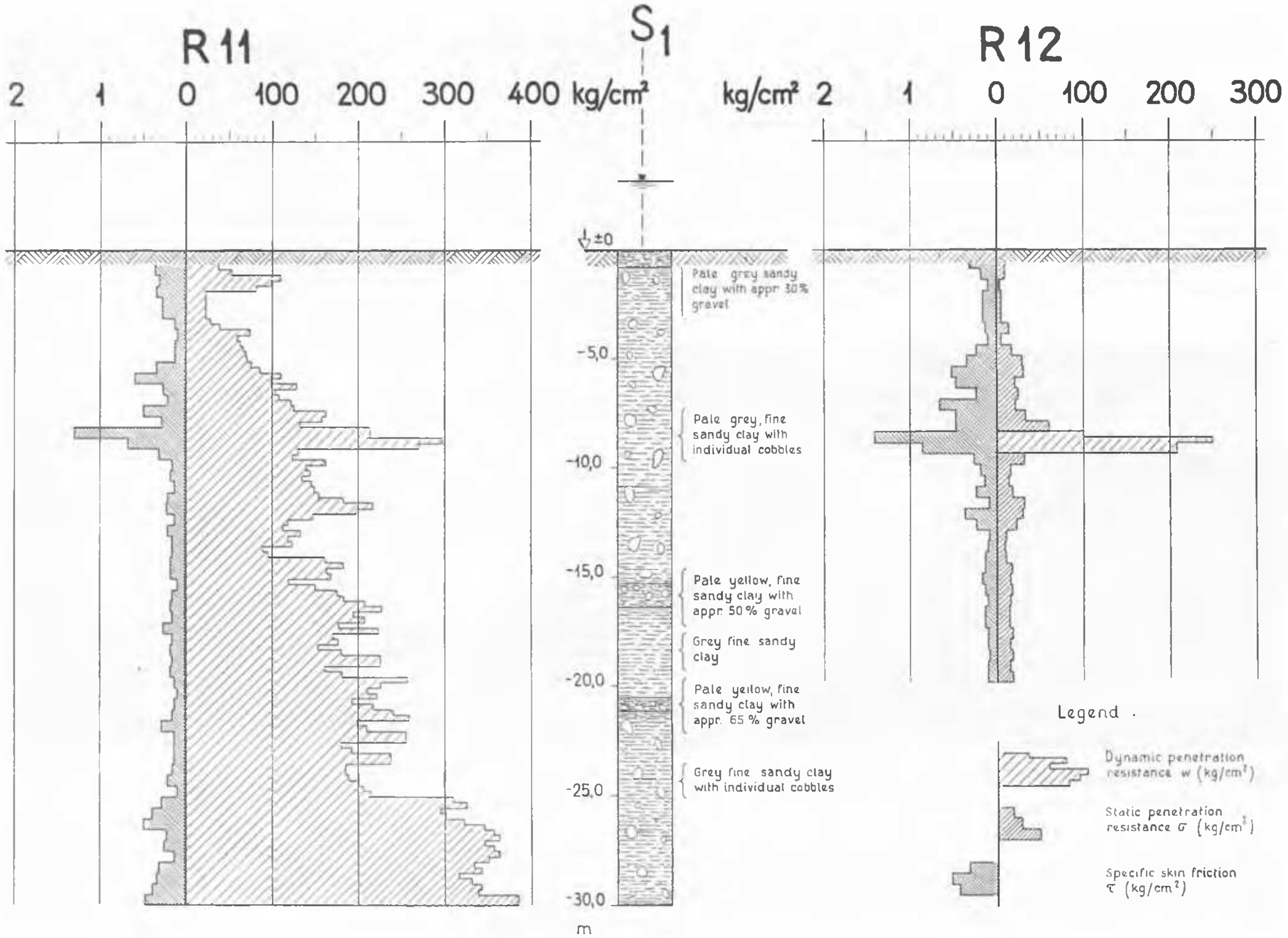

Fig. 4 Exploration of Foundation Soil of a Bridge Abutment. The Bore Hole Profile S_1 was Taken at a Distance of Approximatively 20 Metres from the Ram Profiles R_{11} and R_{12}
Sondages pour la fondation d'un pont. Le sondage S_1 se trouve à environ 20 mètres des profils R_{11} et R_{12}

ram-sounding carried out down to a depth of 30 m in which a thixotropic liquid was used. Attention is drawn to the fact that the values for specific skin frictions and the point resistances for the static load are exceptionally down to a depth varying from 10 to 20 m.

The dynamic profile (driving records), which was measured at a distance of one metre from the static one, shows the same magnitude of specific skin frictions but, on the other hand, much higher values for point resistances. When making a comparison between the values of static and dynamic penetration resistance, it has to be taken into account that the driving resistance (R_{11}) has been calculated by *Stern*'s method under the assumption of a completely elastic ram (coefficient of impact $\mu = 1$).

The following comparison of the profiles R_{11} and R_{12} is in general limited to the 10 m thick zone below the hard intermediate layer (depth 10–20 m), where the conditions are absolutely evident. Here the material is composed of a saturated fine sandy clay with some stones, the properties of which are characterised by the following mean values, determined at the Institute of Hydraulic Research and Soil Mechanics at Zurich from two samples taken from an adjacent borehole: liquid limit ~28%, plastic limit ~13%, water content ~20%, density ~2.1 t/m³. The content of the material obtained by elutriation (<0.002 mm) amounts to ~20% and the silt content (0.002–0.2 mm) to ~60%; index of compressibility $\Delta e = 2.8\%$.

While the *dynamic penetration resistance* of the zone under consideration shows in general a small increase with depth, notwithstanding the great dispersion, this is not the case in the static penetration resistance. The mean value of the former is —with ~160 kg/cm²—roughly eight times larger than that of the latter. According to the type of soil, the pore-water pressure, the apparatus, and the driving depth etc., the relations between the two penetration resistances vary within wide limits, so that it is not possible to state the static penetration resistance, respectively the ultimate bearing capacity—based on the specific driving resistance (*Schenk*, 1951; *Grasshoff*, 1952). For example in the profiles R_{11} and R_{12} under review, for example the proportion between the two penetration resistances varies between 1:2.5 and 1:12. The data obtained improve therefore essentially, if the static penetration resistance also is measured in the softer layers, particularly in the area of the designed level of the foundation. The fact that no increase of the static penetration resistance with depth can be established in the zone under review indicates the predominant influence of the cohesion of the clayey subsoil.

The *specific skin friction* curves of the layer under consideration, as already mentioned, show a more or less similar character in the case of static and dynamic penetration; this fact can be attributed to the similarity of the measuring methods (Fig. 4, R_{11} and R_{12}). When using the static measuring method it is obvious that the skin friction and the point resistance in their general trend follow a parallel course (Fig. 4, R_{12}). Moreover

—in conformity with experiments made elsewhere in cohesive soils—no increase in the skin friction with increasing depth can be established. The mean value of the skin friction measured at depths between 10 and 20 m amounts to 2 t/m² respectively 0.2 kg/cm², i.e. is relatively small. For the evaluation of these values it is in the first place necessary to consider the effect of the pore-water pressure which depends on many factors (permeability of the soil, shape and dimension of apparatus, speed of process, etc.). Therefore all the measured friction values depend upon the course of the penetration in relation to time and upon the measurement itself, which is on a small scale moreover also the case in the penetration resistance (*Haefeli, Amberg, v. Moos*, 1951).

How strongly the time factor interferes with the friction measurement is shown by the fact that at profile R_{12}, at a depth of 20 m, an increase of the specific skin friction from 1.3 t/m² to 5.2 t/m² was ascertained within 12 hours. Assuming a friction coefficient between material and metal of 0.4, the observed ultimate value of the skin friction of 5.2 t/m² corresponds to a mantle pressure of 13 t/m², i.e. roughly 60% of the overlying soil pressure at a depth of 20 m (submerged). Besides continuous friction measurements it is therefore necessary to examine the increase in friction during the release of the pore-water pressure by means of a sufficiently great number of measurements of a certain duration. It may be mentioned for comparison that *Terzaghi-Peck* gave as a guide the following ultimate values of the skin friction of piles in cohesive soils: soft clay and silt 1–3 t/m², sandy silt 2–5 t/m² and stiff clay 4–10 t/m² (*Terzaghi-Peck*, 1948).

Further Prospects

Combined static and dynamic penetrations permit, in accordance with the nature of the ground and the problem to be solved the use either the one or the other of the two processes. If the question raised is to establish the stratification of the layers respectively the composition of the layers in an erratic subsoil with hard intermediate layers, then the dynamic procedure (driving) obtains results quicker, whereby a static penetration test may be inserted at all points of interest. But on the other hand, if soft soils are to be examined, for which pile foundations have to be considered in the first line, then the mere static process, such as it has been developed by the Delft Soil Laboratory since 1934, is to be preferred. The differentiated measurement of the specific skin friction facilitates the dimensioning of friction piles and gives some indication of the nature and the degree of consolidation of the penetrated soil.

The press-ram-apparatus described here can also be used for the investigation of ground water bearers (aquifers). When fitted with a special device, the same serves for the evaluation of the coefficient of permeability, and stands as a complement to the existing apparatuses for the preliminary hydrological examination of ground-water intakes.

Acknowledgment

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