The Determination of the Density and the Modulus of Compressibility of Non-cohesive Soils by Soundings

Détermination de la densité et du module de compressibilité des sols pulvérulents par sondages

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SUMMARY

As a continuation of the works submitted to the Fourth and Fifth Congresses, a variety of dynamic and static penetrometers were used in a series of tests conducted in a shaft, filled with sand and having a depth of 5.5 m, to compare their resistances of penetration. In addition, the data gathered during the field tests conducted during the last twelve years were used to ascertain the relation between the number of blows of the standard penetrometer, the cone resistance of a static penetrometer, the density and the compressibility of sand with the aid of statistical methods (correlation calculation) and the relationships established by Moussa. Other tests were also conducted to ascertain the influence of the ground water level on the number of blows and the cone resistance.

SOMMAIRE

Donnant suite aux études présentées lors du 4e et du 5e congrès, nous avons comparé les résistances à la pénétration de différentes sondes statiques et dynamiques dans un puits de 5,5 m de profondeur et rempli de sable. A l'aide de méthodes statistiques (calcul de corrélations), des relations de Moussa et de ces mesures, en plus de celles que nous avons faites au cours des douze dernières années dans les sols naturels, nous avons essayé d'établir des relations, entre le nombre de coups du pénétromètre standard, la résistance de pointe d'un pénétromètre statique, la densité et la compressibilité du sable. En outre, nous avons étudié l'influence du niveau phréatique sur le nombre de coups et sur la résistance de pointe.

THIS REPORT SERVES as a continuation of the reports on soundings submitted previously (Schultze and Menzenbach, 1961; Schultze and Knausenberger, 1957). Subsequent to these reports various tests were conducted on non-cohesive soil in a shaft specially constructed for this purpose. In addition to this, the results of dynamic soundings conducted at construction sites were evaluated.

TESTS

Testing equipment. For the purpose of conducting special experiments, a shaft, with a diameter of 3.0 m and an effective depth of 5.5 m, was constructed in the institute of Aachen (Fig. 1). The loading device was anchored to the base of the shaft. The shaft could be submerged, so that tests could also be conducted below the groundwater level.

Soil. The tests were conducted in a sand, which according to the grouping of Schultze and Moussa (1961) belongs to group I (Fig. 2). The moisture content was between 0 and 6 per cent during the installation.

Density. The sand was inserted in layers of 20 cm and compressed with the aid of a surface vibrator to the desired degree. During the tests, the shaft was filled up twice. The density varied with the depth (Table I). Small samples were extracted at different levels for the purpose of making a rough estimate of their densities. With the aid of isotopic soundings, the density could be ascertained with a higher degree of accuracy. γ-penetrometers were used for determining the bulk specific weight, and neutron-penetrometers were used for the determination of the moisture content. From the measurements, the dry specific weight and the relative density could be estimated.

Groundwater level. For the first installation the work was conducted with the following groundwater levels: −5.5 m (i.e., dry shaft), −3.4 m, and −2.0 m. During the second installation work was conducted initially with a dry shaft, and then with a groundwater level of −2.0 m (in both cases measured from the top edge of the shaft).

Penetrometers. Two different types of penetrometers, static and dynamic, were used for the sake of comparison (Table II).

Readings. The dynamic penetrometers were used for measuring the number of blows n for a particular depth t, termed n/t, whereas the static penetrometers served for the purpose of measuring the cone resistance q_s. The vertical distances between the points of measurements were entered in the last column of Table II. The horizontal distances between the individual penetrometers in the shaft were not less than 0.5 m.

OBSERVATIONS IN THE FIELD

Card index. Results of various penetration tests from soil explorations at construction sites were filled in the index cards. As a result of the application of a strict standard, twenty index cards were selected, which gave full information about the results of the standard penetration tests, along with complete data about the nature of the soil.

Test results. Besides the number of the blows, the files contained exact data about the void ratios and extended to cover sand soils (Fig. 2).

EVALUATION

Correlation Calculation

In order to establish the relations between the test results, especially between density and sounding resistance, sub-

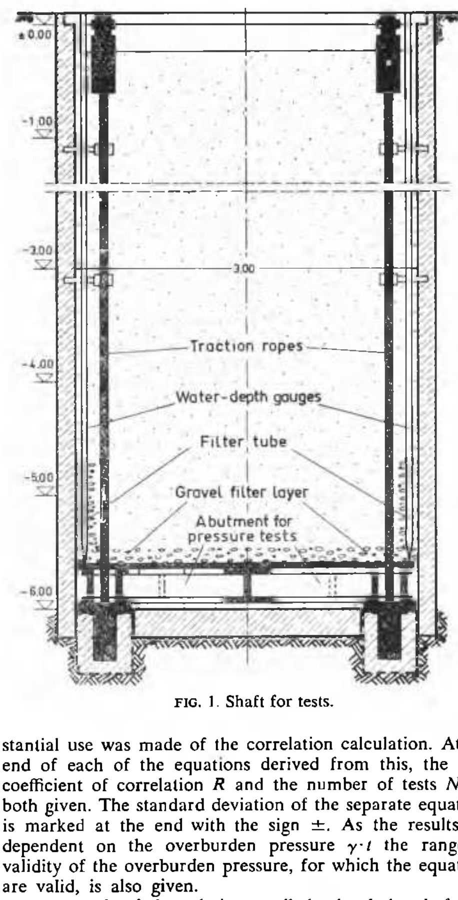

FIG. 1. Shaft for tests.

stantial use was made of the correlation calculation. At the end of each of the equations derived from this, the total coefficient of correlation R and the number of tests N are both given. The standard deviation of the separate equations is marked at the end with the sign ±. As the results are dependent on the overburden pressure $\gamma \cdot t$ the range of validity of the overburden pressure, for which the equations are valid, is also given.

As a result of the relative small depth of the shaft, the results extend for the most part to the layers near the surface, in which the critical depth of the specific penetrometer, according to De Beer (1963), is not reached.

Density

Firstly, a relation was established for the relative density D_r from the experimental results of the dynamic penetrometer 11 and the static penetrometer 21 for such measurements which were taken above the level of the groundwater. The relative density D_r had been measured with isotopic penetrometers.

Dynamic penetrometer 11. The overburden pressure $\gamma \cdot t$ influences the penetrometer results as long as the soundings still lie within the critical depth, since then one must calculate with a linear increase in the number of blows even under conditions of constant density. The influence of $\gamma \cdot t$ disappears below the critical depth. The relation is as follows (Fig. 3):

$$D_r = 0.317 \cdot \log n - 0.226 \cdot \gamma \cdot t + 0.392 \pm 0.067. \quad (1)$$

The total coefficient of correlation is $R = 0.705$ with a number of tests $N = 67$. The equation is valid for values $\gamma \cdot t$ from 0 to 1.2 kg/sq.cm. Units: D_r without units, n in n_{30}, $\gamma \cdot t$ in kg/sq.cm.

Static penetrometer 21. The corresponding equation is (Fig. 4):

$$D_r = 0.351 \cdot \log q_s - 0.421 \cdot \gamma \cdot t + 0.071 \pm 0.067 \quad (2)$$

$R = 0.725$, $N = 90$, valid from $\gamma \cdot t = 0$ to 0.80 kg/sq.cm. Units: D_r without units, q_s and $\gamma \cdot t$ in kg/sq.cm.

TABLE I. DISTRIBUTION OF THE RELATIVE DENSITY D_r OVER THE DEPTH OF THE SHAFT

Installation	Depth (m) to	D_r from	D_r to
1	1.6	0.35	0.40
	3.0	0.70	—
	4.0	0.40	0.50
	5.5	0.55	0.75
2	2.0	0.60	0.70
	3.0	0.50	0.60
	4.5	0.50	0.70
	5.5	0.50	—

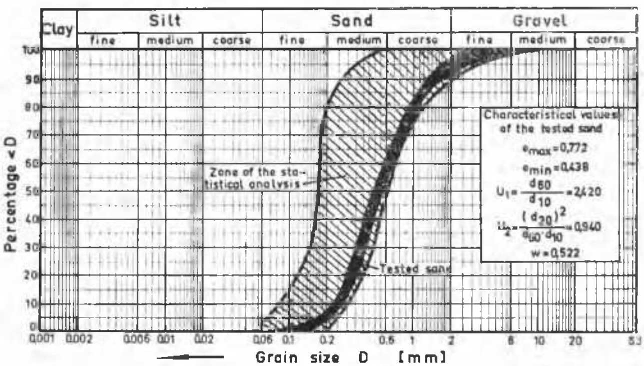

FIG. 2. Zone of the tested grain size distribution curves.

TABLE II. TECHNICAL DATA OF THE EMPLOYED PENETROMETERS

No.	Type of penetrometer	Cone of penetrometer: Diameter d (mm)	Cross-section F (sq.cm.)	Pointed angle α	Diameter of rod d_1 (mm)	Weight of hammer R (kg)	Height of fall h (cm)	Measured value	Driving work A (kg/sq.cm.)	Vertical distance of measured points a (cm)
	Dynamic penetrometers									
11	Standard penetrometer	51.0	20.4	60	—	63.5	76.2	n_{30}	8.0 n	50
12	Heavy dynamic penetrometer	43.7	15	90	32	50	50	n_{20}	8.4 n	20
13	Light dynamic penetrometer	35.6	10	60	20	10	50	n_{20}	2.5 n	20
	Static penetrometers									
21	Static penetrometer 1 (Gouda)	36	10	60	36	—	—	q_s	—	20
22	Static penetrometer 2 (Maihak)	36	10	60	30	—	—	q_s	—	20

n_{20} = number of blows for penetration t = 20 cm.
n_{30} = number of blows for penetration t = 30 cm.
q_s = cone resistance (kg/sq.cm.).
A = driving work = $(R.h/F) \times (n/t)$

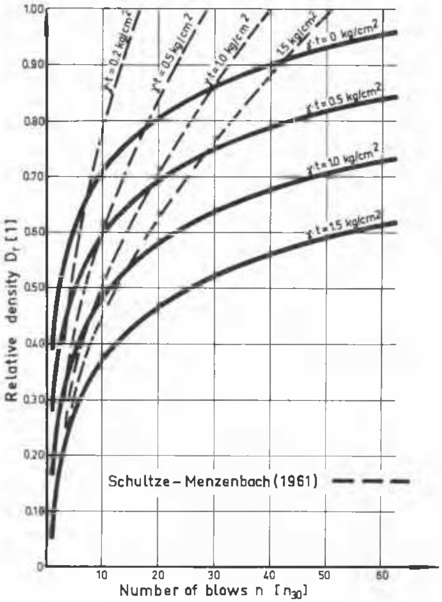

FIG. 3. Relationship between the relative density D_r, the overburden pressure $\gamma \cdot t$, and the number of blows n of the dynamic penetrometer 11 in sands without groundwater.

Modulus of Compressibility

In previous investigations (Schultze and Menzenbach, 1961) the modulus of compressibility was determined by extracting undisturbed soil samples from the immediate neighbourhood of the penetration tests and compressing them in the compression apparatus. A relationship was then established between the modulus of compressibility (tangent modulus) and the number of blows. Since the values of the modulus of compressibility were particularly poor, it was assumed that as a result of its sensitiveness, the sand was no longer in an undisturbed state after extraction and installation into the compression apparatus, and that therefore the compressibility was determined for a partially disturbed state. In order to obtain better results, the present investigations used another method, so as to overcome the interference caused by extraction and installation.

Calculation. According to Schultze and Moussa (1961, Table I) the modulus of compressibility could be computed from the natural voids ratio e, and the voids ratio $e_{\max}$ in the loosest state and $e_{\min}$ in the densest state.

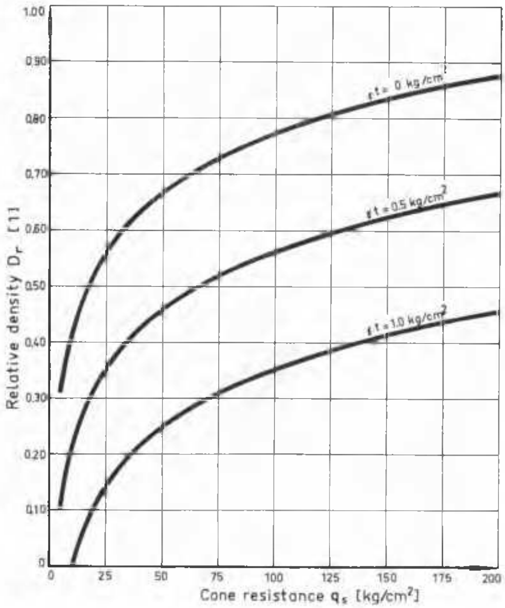

FIG. 4. Relationship between the relative density D_r, the overburden pressure $\gamma \cdot t$, and the cone resistance q_s of the static penetrometer 21 in sands without groundwater.

In the equations of Moussa, derived after performing systematic tests on various sands in the laboratory, one could substitute the value 0.522 for w for the present soil in the equation of the tangent modulus $E_s = 1/m_v = v \cdot \sigma^w$. The order of magnitude for w corresponds with that determined by Chaplin (1961). Therefore the equation for the modulus of compressibility is

$$E_s = 1/m_v = v \cdot \sigma^{0.522}. \qquad (3)$$

The coefficient v could be determined, according to the equations of Moussa, from the voids ratio for the same depth of the readings of the penetration tests. In this way it was possible, with the aid of isotopic soundings, to determine the modulus of compressibility (tangent modulus) of the soil for every depth. The errors that arose from the compression tests with the so-called undisturbed samples of sand vanished. The different values of the coefficient v, determined in this way, were compared with the number of blows of the dynamic penetrometer 11, and the cone-resistance values of the static penetrometer 21, for measurements taken above the groundwater level.

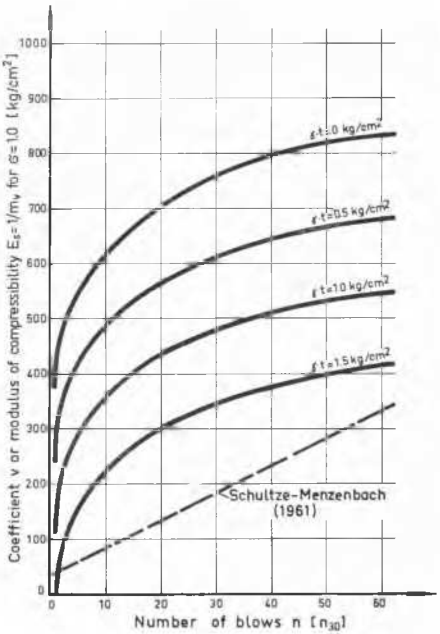

FIG. 5. Relationship between the coefficient v or the modulus of compressibility $E_s = 1/m_v$ for $\sigma = 1.0$ kg/sq.cm., the overburden pressure $\gamma \cdot t$, and the number of blows n of the dynamic penetrometer 11 in sands without groundwater.

Dynamic penetrometer 11. The equation is (Fig. 5):

$$v = 246.2 \cdot \log n - 263.4 \cdot \gamma \cdot t + 375.6 \pm 57.6 \qquad (4)$$

This relationship is valid for the coefficient v as well as the modulus of compressibility E_s for $\sigma = 1$. Total coefficient of correlation: $R = 0.730$; number of tests: $N = 77$, valid from $\gamma \cdot t = 0$ to 1.2 kg/sq.cm. Units: v without units, n in n_{30}, $\gamma \cdot t$ in kg/sq.cm.

Static penetrometer 21. The corresponding equation for v is (Fig. 6):

$$v = 301.1 \cdot \log q_s - 382.3 \cdot \gamma \cdot t + 60.3 \pm 50.3 \qquad (5)$$

Total coefficient of correlation: $R = 0.778$; number of tests: $N = 90$, valid from $\gamma \cdot t = 0$ to 0.8 kg/sq.cm. Units: v without units, q_s and $\gamma \cdot t$ in kg/sq.cm.

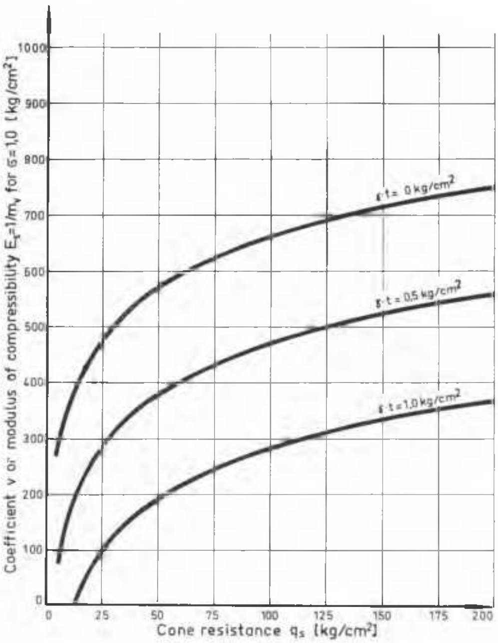

FIG. 6. Relationship between the coefficient v or the modulus of compressibility $E_s = 1/m_v$ for $\sigma = 1.0$ kg/sq.cm., the overburden pressure $\gamma \cdot t$, and the cone resistance q_s of the static penetrometer 21 in sands without groundwater.

Relationship between the Dynamic and Static Penetrometers

For both penetrometers, the following relationship was established between the cone resistance and the number of blows (Fig. 7):

$$\log q_s = 0.982 \cdot \log n + 1.028 \pm 0.102 \qquad (6a)$$

$$\log n = 0.856 \cdot \log q_s - 0.714 \pm 0.096 \qquad (6b)$$

Coefficient of correlation $r = 0.917$; number of tests: $N = 52$. Units: n in n_{30}, q_s in kg/sq.cm. This result approximately satisfies the equation $q_s = 10$ n.

Influence of the Groundwater

For all five types of penetrometers used during the investigation, one saw a noticeable change in the measurements after the groundwater level was penetrated: under the groundwater level the sounding resistances decreased.

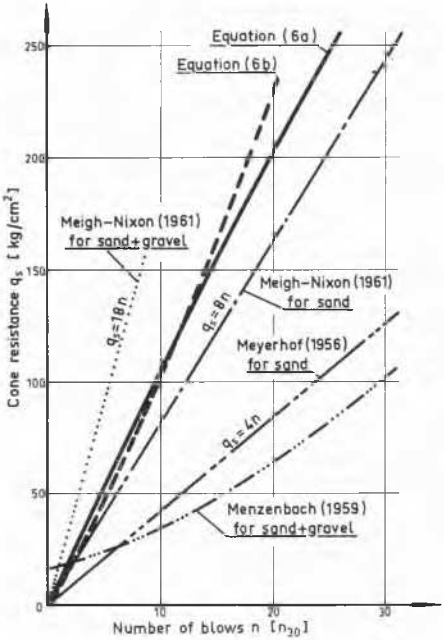

FIG. 7. Relationship between the cone resistance q_s of the static penetrometer 21 and the number of blows n of the dynamic penetrometer 11 for cohesionless soils.

COMPARISON WITH THE RESULTS OF OTHER INVESTIGATIONS

Density. The equation (2) given by Schultze and Menzenbach (1961), should be replaced by Eq (1) of this paper. The reason for this substitution is that the extraction of the undisturbed samples from the boreholes caused unavoidable interferences which lead to a change in the density. The data for the density supplied by the isotopic measurements were more exact. For this reason, a corrected relationship had to be established.

Modulus of compressibility. The relationship between the number of blows of the standard penetrometer and the modulus of compressibility of the soil that was published as Equation (1) for group 3 (Schultze and Menzenbach, 1961) should be replaced by the foregoing Eq (4). Not only the interferences resulting from the extraction of the so-called undisturbed samples of sand are considered, but also the interferences resulting from the installation of the sample into the compression apparatus, and the carrying-out of the compression test. The equations of Moussa that were constructed after conducting numerous compression tests on disturbed soil, whose properties were well known, were used instead of the compression tests.

A comparison of the absolute values resulting from the two equations for an overburden pressure $\gamma \cdot t = 1.0$ kg/sq.cm. shows that the modulus of compressibility of the tests under review, has increased nearly twofold as compared to the earlier results (Fig. 5). In this way, our objection that the results of former investigations lay too much on the safe side was justified.

Number of blows and cone resistance. The present investigations confirm the relationship established by Meigh and Nixon (1961). On the other hand, the relationships established by Meyerhof (1956) and Menzenbach (1959) do not correspond with the present investigations. The reasons for this deviation seem to lie in the fact that the tests mentioned by Meigh and Nixon in their report, and in the present report, were conducted on a single sand, whereas Meyerhof and Menzenbach have evaluated a series of tests on varieties of sands. It was natural that these results were not so exact, because the relationships are evidently dependent on the various grain size distributions of the tested sands.

CONCLUSION

The investigations will be continued in order to explore the various factors which influence soundings in sandy soils.

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