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Geotechnical Properties of Coarse-Grained Soils

Propriétés géotechniques des sols à gros grains

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SUMMARY

The properties of coarse-grained materials as constituents of both natural formations and embankments are considered. The correlations between texture and genesis of these materials are investigated, and a broad picture of identification characteristics is given. According to the results thus obtained, the mechanical behaviour of these materials is examined on the basis of laboratory tests on samples containing particles up to 50 mm, and of field investigations.

SOMMAIRE

On examine les propriétés de matériaux à gros grains constituant des formations naturelles et des remblais. On a fait une recherche sur les corrélations entre la texture et la génèse de ces matériaux et l'on a donné une description d'ensemble de leurs caractéristiques d'identification. D'après les résultats ainsi obtenus, on a examiné le comportement mécanique de ces matériaux au moyen d'essais de laboratoire réalisés sur des échantillons contenant des grains de la dimension de 50 mm au maximum et au moyen d'études *in situ*.

OBJECT OF THE RESEARCH

EXTENSIVE RESEARCH on the behaviour of coarse-grained materials, as constituents of both natural formations and embankments, is under way and the results obtained to date are reported in this paper.

Since it was intended that the investigation should have a fairly broad validity range, it was necessary first to examine the numerous materials found in nature and to choose from these the ones that deserved the most attention. This examination was performed on the basis of texture, as this factor has a determining influence on the mechanical and hydraulic properties of these materials. For this reason consideration was given only to the geometrical characteristics of the particles—grain size distribution and shape and roundness—and not to their compactness, because the former are inherent properties of soils whereas the latter may vary widely within the same soil.

The results of our investigations indicate that the geometrical characteristics are closely linked to the geological environment from which the material originated and to the factors which prevailed in its formation. For this reason, we have grouped the materials lithogenetically in the following four groups: fluvial materials, glacial materials, talus materials, conglomerates. For each group, deposits taken from different locations in our country were examined. The sizes of the individual deposits vary, but are within the limits normally required in solving problems of civil engineering.

GRAIN SIZE DISTRIBUTION, SHAPE AND ROUNDNESS

In order to study the geometrical characteristics of particles, we have examined many samples of each deposit. Statistical treatment of results allowed the determination of

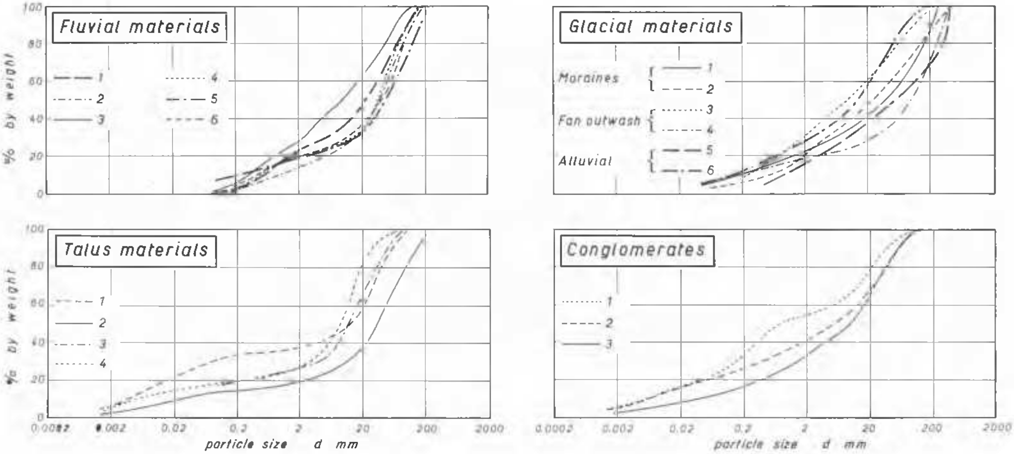

FIG. 1. Average grain size distribution of deposits.

grain size distribution and particle shape and roundness in each deposit as a whole.

The *grain size distributions* (Fig. 1) of deposits belonging to the same lithogenetic group show a marked resemblance both in the general pattern and in the percentages of the individual fractions. Among the four groups there are some marked differences: $d < 0.2$ mm fraction is present in negligible or very small percentages in the fluvial and glacial materials, whereas it is always present in considerable percentages in talus materials and in conglomerates; moreover, talus materials are definitely discontinuous in the $0.2 < d < 2$ mm range. The conglomerates are always well graded.

Our investigation revealed no clear relation between *particle shape** and the genesis of the materials (Table I). This may be due to the random influence of two factors: the properties of the rocks from which the materials originated and the subsequent processes of transportation and deposition.

TABLE I. RANGES OF PERCENTAGES OF DIFFERENT SHAPES, PARTICLES d = 5 TO 50 MM

Group	Per cent particles of shape			
	equant	prolate	bladed	tabular
Fluvial materials	12–24	22–30	15–26	31–44
Glacial materials	8–19	16–26	19–35	34–45
Talus materials	2–37	14–34	8–35	27–47
Conglomerates	16–29	21–30	15–28	27–35

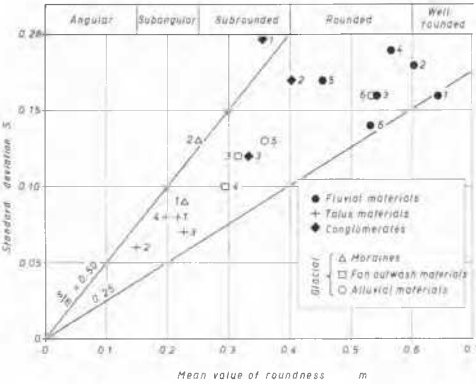

FIG. 2. Roundness of particles $d = 5$ to 50 mm (s/m = coefficient of variation).

Roundness (Fig. 2) is closely related to the duration and manner of transportation of materials from the point of origin to their present location. As a result, the talus materials found at a short distance from their formation point have angular or subangular edges. In glacial materials roundness increases; within this group a similar trend toward increased roundness could be recognized from moraines to fan outwash and further to alluvial materials. The conglomerates follow and then the fluvial materials, in which the particles with rounded and well-rounded edges prevail.

From our investigation it appears evident that the geometrical characteristics are closely related both to the nature and properties of the formation from which the materials originated, and to their subsequent history. Thus, it appears that the investigation on the behaviour of coarse-grained soils should be limited to certain typical materials and that the results should be extended to other materials having the same texture.

COMPACTION

Investigations by Fukuoka (1957) show that for a particular coarse-grained material a relationship exists between dry unit weight and water content similar to the one observed by Proctor for fine-grained materials. Our laboratory tests on different materials, having $d_{max} = 50$ mm and compacted by vibratory means, fully confirm this result and indicate that in the case of coarse-grained materials the relationship $\gamma_d = f(w)$ presents two particular aspects: The optimum condition is reached when the voids between particles are almost completely filled with water; to the left of the optimum condition, the compaction curve is very steep; to the right of the optimum, the compaction curve coincides with the saturation curve.

Tests were performed on samples of fluvial materials and glacial materials. In tested samples the $d < 0.2$ mm fraction was present in very small amounts in fluvial materials and in percentages of 10 to 30 in glacial materials; the 20 to 50 mm fraction content varied within a very wide range (from 0 to 80 per cent).

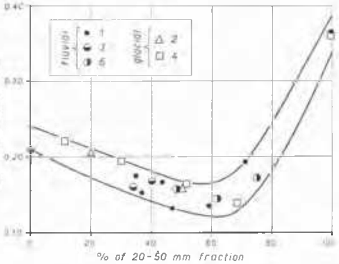

FIG. 3. Influence of grain size distribution on porosity n_{opt} under optimum conditions.

For identical compaction procedures, the optimum porosity values, n_{opt}, differ and appear to depend mainly on the 20 to 50 mm fraction (Fig. 3). As this fraction increases, porosity first decreases and then, after reaching a minimum, increases very rapidly. These results confirm the relationship between grain size distribution and dry unit weight as suggested long ago by U.S.B.R. (1951).

The influence of shape and roundness of particles was investigated but testing results show no definite relation between these factors and compaction.

The loosest state of packing of the same samples has also been investigated; it appears to be considerably affected by the water content. It follows that at a given porosity value the relative density of coarse-grained materials is different for different water contents.

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*The investigation on the shape and roundness was performed on the 5–50 mm fraction with the methods recommended by Zingg and Krumbein (Pettijohn, 1949). The measurements were taken respectively on about 300 and about 100 particles of each deposit.

While taking texture into account among the secondary experimental factors, our research covered the following main experimental factors:

Compaction
1. porosity (n)
2. water content (w_c)

Failure
3. water content (w_r)
4. drainage
5. rate of strain (v)

To date, we have performed about forty triaxial compression tests* on two samples of fluvial materials (Fig. 4).

The influence of factors 2 to 5, at a given porosity, was investigated by varying them one at a time.

Fig. 4 shows the most significant results. Differences in τ_f values, in terms of effective stress, under varying testing conditions are generally below ± 10 per cent and should be considered accidental. The influence of the above factors on shear strength is therefore negligible. In terms of total stress, however, the same factors exert a definite influence if "Q_c" tests are considered.

Influence of compaction on shear strength was investigated (Fig. 5) in the range $\gamma_d \leq \gamma_{d,opt}$. Irrespective of testing conditions (factors 2 to 5) shear strength increases with compaction with the gradient becoming greater as porosity, n, becomes smaller.

It is worth considering the results of our research with regard to the values of effective angle of shearing resistance ϕ' and of effective cohesion intercept c' instead of τ_f. ϕ' values depend on the degree of compaction and not on other experimental factors; rather high values of ϕ' were

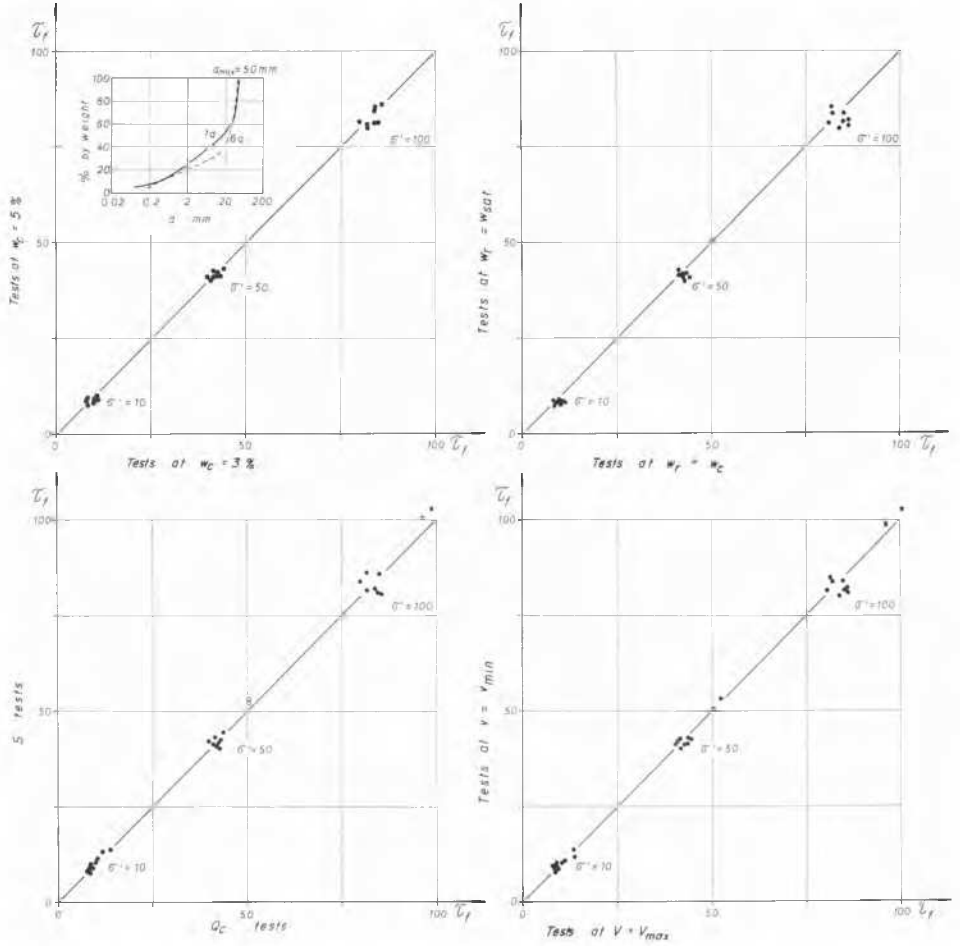

FIG. 4. Influence of test conditions on shear strength (sample 1a).

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*The principal features of triaxial compression tests are: sample: diameter = 35 cm, height = 80 cm; maximum size of particles = 50 mm; compaction by vibration σ_{3max} = 4 kg/sq.cm.; application of σ_1 is performed under controlled strain conditions. Tests were performed at compaction water content ($w_r = w_c$) as well as after saturation of samples with water filtration from the bottom upwards ($w_r = w_{sat}$).

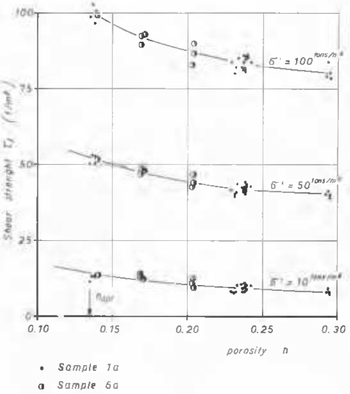

FIG. 5. Influence of compaction on shear strength.

measured (tan $\phi' = 0.75 \div 1$). Cohesion c' of samples as compacted is small (1 to 4 tons/sq.m.). After saturation cohesion drops to zero, probably because particle interlocking is affected by the flow of water during saturation of samples.

COMPRESSIBILITY

Our research on compressibility has been performed by means of full-scale investigations on natural formations and embankments. With respect to coarse-grained materials in natural conditions some conclusions have been reached about thick glacial deposits (Croce, Dolcetta, Finzi, and Martinelli, 1963).

From settlement measurements of the foundation surface of two earth dams the relationship between the vertical normal stress σ_z, due to overlying dams, and the unit vertical deformation ϵ_z has been obtained (Fig. 6). The fan outwash materials compressibility modulus $E = \sigma_z/\epsilon_z$ increases considerably as one moves from shallow and loose soils (deposit 2; n = 28 to 35 per cent) to deep soils. A still higher value of E, on the order of 16,000 tons/sq.m. is reached in morainal soils (deposit 1) in which the porosity is equal to about 12 per cent. It should be pointed out that an appreciable amount of deformation occurred after load application was completed.

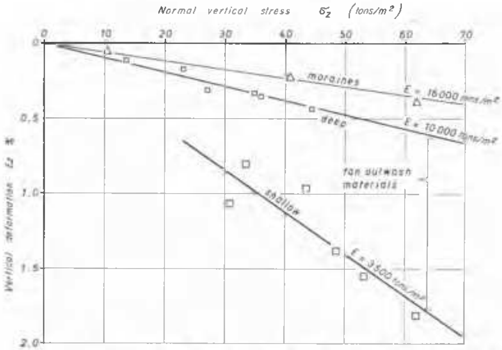

FIG. 6. Compressibility of natural formations of glacial origin.

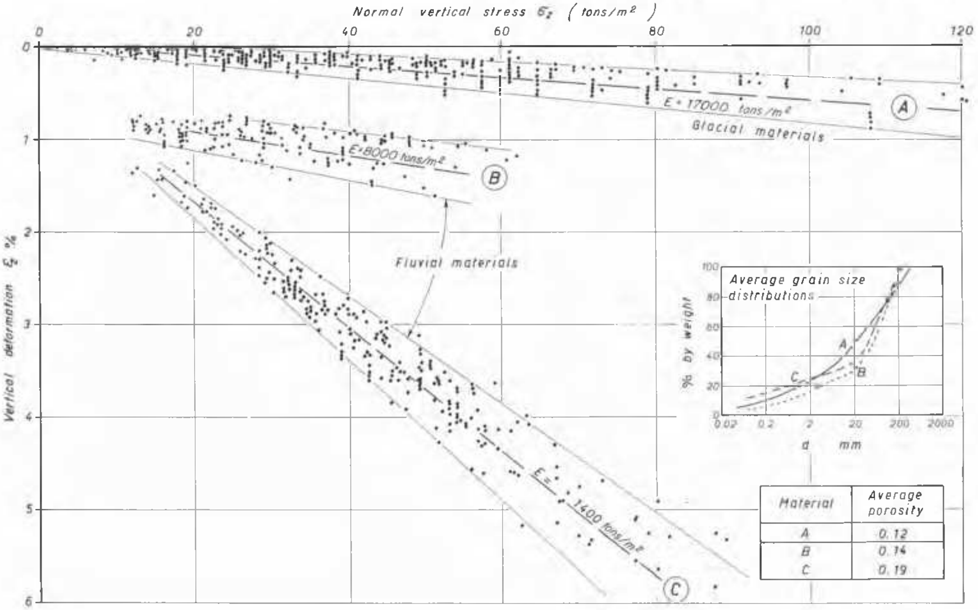

FIG. 7. Compressibility of soils used in the construction of earth dams.

The compressibility of fluvial (deposit 5) and glacial soils (moraines of deposit 2 and fluvioglacial materials) used in the construction of the two earth dams is shown in Fig. 7, in which the unit vertical deformations ϵ_z of horizontal strips having a thickness of 4 to 5 m are correlated with the vertical normal stresses σ_z.* Under small loads the deformation values of fluvial materials are scattered within a wide range; in Fig. 7 only mean values have been considered. At increasing loads the increment of deformation occurs at a much more regular and uniform rate.

The compressibility of glacial materials is definitely smaller and their behaviour under loading is remarkably uniform.

These results seem to indicate that the behaviour under loading of the soils we considered, in natural formations and in embankments, depends primarily on porosity, but also on other textural characteristics. Moreover, the relationship between load and deformation appears to be linear and thus different from the ones observed before.

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*In Fig. 7 the vertical normal stress σ_z was assumed equal to the weight γh of overlying soil column.