The Degree of Compaction of Soil according to the Proctor and Dornii Tests

Le Degré de Compactage des Sols d'après les Méthodes Proctor et Dornii

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Summary

Three ways of compacting soils are compared, viz., according to the Proctor method, the Dornii and the author's method.

It is shown that by the standard Proctor method a sample of loam is compacted to a dry density γ_d, corresponding to an oedometer consolidation pressure $p = 1{\cdot}49$ kg/cm², and a sample of clay is compacted to a dry density corresponding to an oedometer consolidation pressure $p = 0{\cdot}8$ kg/cm².

Embankments of clay higher than 4 m and compacted to the standard Proctor condition would have been insufficiently compacted in their lower parts. Loams are compacted satisfactorily in embankments only up to 7 m in height.

By the Dornii test loam is compacted to a dry density corresponding to an oedometer consolidation pressure $p = 2{\cdot}71$ kg/cm². Embankments built of clays compacted according to Dornii would be sufficiently compacted if not higher than about 14 m.

By the modified Proctor test loam is compacted to a dry density corresponding to a consolidation pressure $p = 58{\cdot}0$ kg/cm², and the clay is compacted to a density corresponding to a consolidation pressure $p = 22$ kg/cm².

Embankments of clay compacted by the modified Proctor method will not settle if the height does not exceed about 110 m.

If clay were compacted to 90 per cent of the modified Proctor test only, the dry density attained would correspond to an oedometer consolidation pressure $p = 1{\cdot}596$–$2{\cdot}3$ kg/cm². An embankment of clay compacted to 90 per cent of the modified Proctor test would not settle if its height were not greater than 8 to 11 m.

Higher embankments of cohesive soils compacted according to the standard Proctor test are overcompacted near the top of the embankment, while in lower parts where greater vertical pressures act the compaction is insufficient. The soil should be compacted at every part of the embankment according to the maximum pressures which are expected to act.

Sommaire

Nous nous sommes proposés de faire la comparaison entre trois méthodes de compactage des sols:

D'après Proctor, d'après Dornii et d'après l'auteur du présent article.

On a constaté qu'en employant l'essai exécuté d'après la méthode-standard Proctor on a atteint, dans le cas d'un limon la densité sèche γ_d, correspondant à une pression $p = 1{\cdot}49$ kg/cm² à l'œdomètre.

Dans le cas d'une argile nous avons obtenu la densité correspondant à une pression de $p = 0{\cdot}8$ kg/cm² à l'œdomètre. Les remblais plus élevés que 4 m, composés d'argile et comprimés par la méthode-standard de l'essai Proctor, seraient donc comprimés d'une façon insuffisante. Dans le cas du limon, on arrive à un bon compactage pour les remblais d'une hauteur de 7 m au maximum.

En exécutant l'essai d'après Dornii on atteint, avec les limons, la densité, correspondant à une pression à l'œdomètre de $2{\cdot}71$ kg/cm². Les remblais en limon, comprimés d'après Dornii, seront comprimés d'une façon suffisante à condition qu'ils ne dépassent pas la hauteur de 14 m.

En utilisant l'essai modifié on est arrivé, dans le cas d'un limon, à la densité, correspondant à la pression à l'œdomètre $p = 58{\cdot}0$ kg/cm². Avec l'argile, on a obtenu avec cette méthode la densité correspondant à une pression à l'oedomètre de $p = 22{\cdot}0$ kg/cm².

Les remblais Proctor en argile et comprimés en employant l'essai modifié, ne tassent pas s'ils ne dépassent pas la hauteur de 110 m.

Si l'argile n'était comprimée qu'à 90 pour cent de l'essai modifié Proctor, on arriverait à une densité, que l'on obtiendrait dans l'œdomètre avec une pression $p = 1{\cdot}596$–$2{\cdot}3$ kg/cm².

Le remblai en argile comprimé à 90 pour cent de l'essai modifié Proctor est suffisant s'il ne dépasse 8 à 11 mètres de hauteur.

Les remblais en sol cohérents suivant l'essai standard Proctor sont comprimés d'une façon excessive à proximité de la surface du talus, par contre dans la partie inférieure, où agissent les contraintes verticales, maxima, le compactage n'est pas suffisant. Le sol devrait être comprimé en tout point à la pression maximum, desquelle sera soumis le remblai.

Highway and railway embankments and earth dams have to be compacted in order to avoid settlement. It is necessary to determine how soils are to be compacted to fulfil this condition. One could proceed by choosing some old and consolidated embankment built of soil similar to that which is to be used for construction of the new embankment. The dry density of the soil in the old embankment would be determined at various elevations and spots. The new embankment would be constructed in such a way as to attain everywhere the same or greater dry density than that found in the old embankment. This procedure would be very wearisome; besides, it would be often very difficult to find a suitable old embankment of the same height and constructed of the same material as the new one which would be submitted to the same traffic or the same water pressure. The task is to obtain a soil consolidated to various normal pressures p, the same as the pressures acting in the old consolidated embankment. A sample of soil is consolidated to various pressures by the test in the oedometer or in the triaxial apparatus where the soil may be consolidated by vertical and horizontal pressures equal to pressures acting in the embankment. It has been shown that even if the horizontal pressure σ_x is rather smaller than the vertical one σ_z the porosity n and consequently the dry density γ_d remain the same, as for the case when $\sigma_z = \sigma_x$. For that reason the oedometer test might be used for determining the dry densities of a soil consolidated to pressures of various values.

A soil specimen having a moisture content somewhat above the plastic limit was remoulded and placed in the oedometer in such a way so that there were no air voids. Then the specimen was loaded by pressure p_1 and consolidated under that pressure. After the completion of consolidation the height H_1 of the specimen was noted. Then the specimen was unloaded to zero and again its height H_1' recorded. Next the soil was loaded by a greater pressure p_2 and its height was recorded after consolidation and after unloading to zero. This unloading of the specimen in the oedometer to zero is necessary, because a specimen taken from an embankment for determination of its dry density is also relieved of pressure. Knowing the total weight of the soil specimen in both the moist and dry conditions, the area F and the height H', the dry densities γ_d were calculated for soil specimens consolidated to various pressures p, see Fig. 1. This dry density of a consolidated soil is called

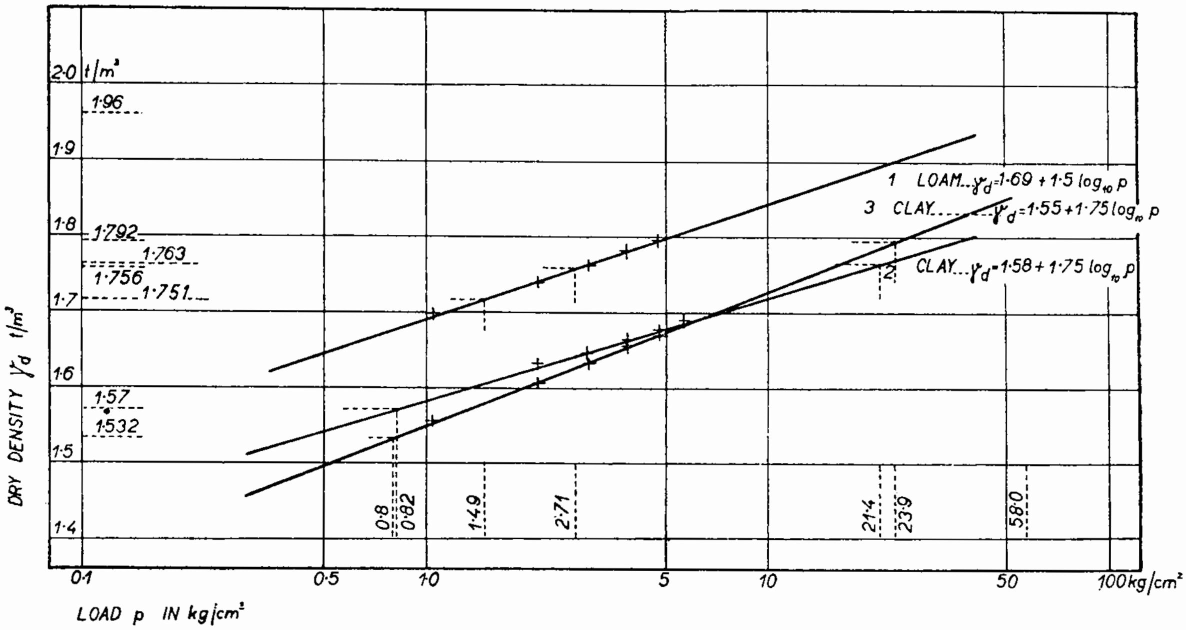

Fig. 1 Relation between consolidation pressure and dry density
Relation entre la pression de consolidation et la densité sèche

the 'equilibrium dry density', because of the equilibrium state between external and internal forces.

The relation between the pressure p and the equilibrium dry density is expressed by a straight line on a semi-logarithmic plot, given by equation

$$\gamma_d = \gamma_{d-1} + A \log_{10} p$$

where γ_{d-1} = dry density after unloading a specimen consolidated to $p = 1{\cdot}0$ kg/cm²; A = a constant equal to the tangent of the straight line, usually having a value 1·1–1·75; p = pressure in kg/cm².

Three soil specimens were examined, of which specimen No. 1 was loam and specimens Nos. 2 and 3 were tertiary clays. Grain size distribution curves for these soils are given in Fig. 2.

Besides the equilibrium dry densities, measurements were made of the dry densities according to the standard and modified Proctor tests and by a test (Dornii) which is a U.S.S.R. standard and is similar to the Proctor test. In the latter test the soil is tamped by 25 blows of a ram weighing 4·5 kg and falling from a height of 30·5 cm. The contact area of the ram is the same as the area of the cylindrical container used for compaction. From the graph in Fig. 1 the pressures corresponding to the dry densities of specimens from the compaction tests are read off. The values obtained in the laboratory tests and the corresponding consolidation pressures are given in the table.

It may be seen from the table that in the standard Proctor test soil specimen No. 1 has a dry density $\gamma_d = 1{\cdot}715$ t/m³ corresponding to that obtained by means of the oedometer after consolidation to $p = 1{\cdot}49$ kg/cm². This pressure acts 7·45 m below the surface of a non-loaded embankment assuming the bulk density of soil $\gamma = 2{\cdot}0$ t/m³. By means of the modified test a dry density of $\gamma_d = 1{\cdot}96$ t/m³ was calculated, which corresponds to consolidation pressure $p = 58{\cdot}0$ kg/cm². Such a pressure acts 290 m below the surface of an embankment.

By means of the Dornii test a dry density $\gamma_d = 1{\cdot}756$ t/m³ was obtained, corresponding to a consolidation pressure $p = 2{\cdot}71$ kg/cm². This pressure acts 13·6 m below the surface. An embankment of height up to 13·6 m and compacted according to Dornii would be sufficiently compacted; a higher embankment would be insufficiently compacted in its lower parts and would therefore settle.

In the standard Proctor test the specimen of clay No. 2 showed a dry density $\gamma_d = 1{\cdot}57$ t/m³ and the specimen of clay No. 3 gave $\gamma_d = 1{\cdot}532$ t/m³. These dry densities correspond to an equilibrium state attained by a compression of 0·8 kg/cm². This vertical pressure acts at depth 4·0 m, so that a higher embankment built of clay would not be sufficiently compacted

Table

Type of soil	*Specific gravity of soil particles* G_s	*Standard Proctor test*		*Corresponding consolidation pressure* p kg/cm²	*Modified Proctor test*		*Corresponding consolidation pressure* p kg/cm²	*Dornii test*		*Corresponding consolidation pressure* p kg/cm²
		Dry density γ_d t/m³	*Optimum moisture content* %		*Dry density* γ_d t/m³	*Optimum moisture content* %		*Dry density* γ_d t/m³	*Optimum moisture content* %	
1. Loam	2·61	1·715	20·0	1·49	1·96	12·2	58·0	1·756	18·0	2·71
2. Clay	2·692	1·57	22·6	0·82	1·763	17·6	21·4	—	—	—
3. Clay	2·688	1·532	23·0	0·80	1·792	17·3	23·9	—	—	—

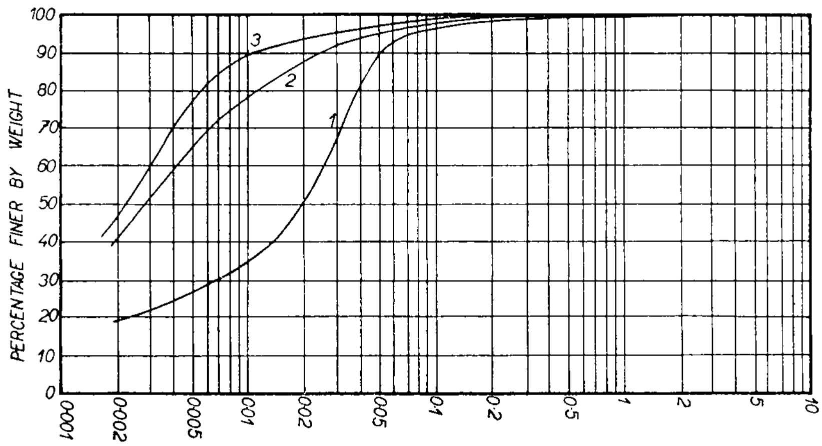

Fig. 2 Grain size distribution of tested samples
Distribution granulométrique des échantillons

and would therefore settle. When clay No. 2 was compacted according to the modified Proctor test a dry density $\gamma_d = 1{\cdot}763$ t/m³ was obtained, which corresponds to a consolidation pressure $p = 21{\cdot}4$ kg/cm². Clay No. 3 had a dry density $\gamma_d = 1{\cdot}792$ t/m³ which would be attained after consolidation to a pressure $p = 23{\cdot}9$ kg/cm². At a depth of 110 m the pressure $p = 22$ kg/cm², so that an embankment of this height would be properly compacted. If it were compacted up to 90 per cent of this dry density (being for specimen No. 2 $\gamma_d = 1{\cdot}596$ t/m³ and for specimen No. 3 $\gamma_d = 1{\cdot}612$ t/m³) the same dry density would be obtained for specimen No. 2 under a consolidation pressure $p = 1{\cdot}32$ kg/cm² and for specimen No. 3 when $p = 2{\cdot}3$ kg/cm². The vertical pressure $p = 1{\cdot}32$ kg/cm² acts at a depth of 6·6 m and the pressure $p = 2{\cdot}3$ kg/cm² acts at a depth of 11·5 m.

From the preceding results we arrive at the conclusion that embankments built of loam and compacted to the dry density obtained by means of the standard Proctor test are properly compacted only for heights up to 7·5 m. In higher embankments the vertical pressure exceeds 1·49 kg/cm², which is the consolidation pressure of soil compacted according to the Proctor standard test. If an embankment were built of clays and compacted according to the standard Proctor test it would be sufficiently compacted only for heights not exceeding 4 m.

For soil compacted according to the modified Proctor test an embankment of clay 110 m high would be sufficiently compacted; if it were built of loam it would be compacted up to a height of 290 m. Strictly speaking the material would be sufficiently compacted at these heights and would be overcompacted at smaller heights.

Pressures exceeding 0·8 kg/cm² act on the surface of a highway or railway embankment, and for this reason the clay would not be sufficiently compacted and the embankment would settle as the result of traffic. Soil in an embankment should therefore be compacted to support without further settlement the maximum pressure acting on the embankment. It is therefore necessary to compute at every point of the embankment the maximum vertical pressure due to live load and dead load, and to find the corresponding equilibrium dry densities for these pressures by means of oedometer or triaxial tests. The soil is compacted to such a degree as to obtain dry densities corresponding to the pressures acting in the embankment. This method has been published in detail in a report by A. Myslivec (1948: Construction of highway and railway embankments. *Proc. 2nd International Conference on Soil Mechanics and Foundation Engineering*, Vol. 4, pp. 222–226).

The optimum moisture content is determined according to specific pressure acting below the roller and according to the dry density which has to be attained. The optimum moisture content is determined preferably in the field from the condition to obtain the desired dry density γ_d by the least number of passes of a given compaction machine.