Stable Density

Densité Stable

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Summary

The most salient question to be answered is 'What should be the stable density and moisture content at which soils should be compacted?' By 'stable density' we mean the minimum density of the compacted fill at which there will not be any future settlement under the existing conditions of load and moisture content.

Proctor's compaction test only tells the experimenter that a particular soil when compacted at a specified moisture content called the 'optimum moisture content' would attain the maximum density. This does not take into consideration the type and nature of the construction for which that density is needed.

This paper discusses the determination of the 'stable density' of different types of soils from load/density curves, obtained in the consolidation apparatus where the 'stable density' is the density under a load equivalent to the height of an embankment or the probable pressure to which it is to be subjected.

Density moisture curves are also drawn by using varying loads, and from these curves the true value of the compactive effort required for attaining a particular density in relation to the moisture content to be used in the field is also known.

The results of the above investigations have afforded information of greater practical importance than Proctor's moisture density curves.

Sommaire

Quelle est la densité et la teneur en eau à laquelle les sols doivent être compactés? Telle est la question essentielle à laquelle il faut érouver une réponse. L'auteur emploie le terme 'densité stable' pour désigner la valeur minima de la densité à obtenir pour qu'il n'y ait pas de tassements du remblai dans les conditions existantes de charge et de teneur en eau.

L'essai de compactage de Proctor permet simplement de déterminer, pour un sol donné, une teneur en eau appelée teneur en eau optima, à laquelle il est possible de compacter le remblai à sa densité maxima. En effectuant cet essai, on ne se préoccupe nullement de savoir si cette densité est nécessaire compte tenu de la nature de l'ouvrage à construire.

La présente communication montre comment on détermine la 'densité stable' de différents sols à partir de courbes charge-densité obtenues à l'aide d'un appareil de consolidation. La densité stable est la densité qui correspond à une charge équivalente à la hauteur du remblai ou à la pression présumée à laquelle celui-ci sera soumis.

Des courbes densité-teneur en eau ont été tracées pour différentes charges. Il est possible d'en déduire en fonction de la teneur en eau l'effort de compaction réel qui sera nécessaire pour obtenir sur le chantier une densité donnée.

Ces recherches ont permis d'obtenir des résultats d'une utilité pratique plus grande que les courbes de Proctor.

The main considerations for compacting a soil in a sub-grade or in an embankment are: (a) reduction in water absorption and permeability; (b) reduction in settlement; and (c) increase in shear-strength and bearing capacity.

KOZENY (1942) deduced a formula relating to permeability and grain size with voids for non-cohesive soils in which permeability is a function of $e/(1 - e^2)$, where e is the ratio of voids to total volume.

BUCHANAN (1942) gave permeability for a silty clay as follows:

S. No.	*Number of blows*	*Permeability (cm/sec)*
(1)	6	13×10^{-9}
(2)	60	$2{\cdot}8 \times 10^{-9}$

ALLEN (1938) correlated settlement with the degree of compaction. He showed that by increasing the ramming from 15 to 25 blows, the maximum settlement was reduced from 2·4 to 1·2 per cent, while with 35 blows the settlement was further reduced to 0·9 per cent.

The effect of compaction on cohesive soils was investigated by BUCHANAN (1942). His results showed that the shear strength of the soil increased with the amount of compaction.

KNIGHT (1948) published the following figures for the angle of internal friction of dry sand. They indicate the dependence of the stability on the density of the sand.

S. No.	*Density* (lb./cu. ft.)	*Void ratio (e)*	*Angle of internal friction*
(1)	100	0·56	47°
(2)	94	0·75	32°–34°

The main factors influencing the compaction of soils are: (a) type of soil; (b) moisture of compaction; and (c) amount of compaction applied.

There is a direct relation between soil type and degree of compaction. Heavy clays have densities of from 90 to 105 lb. per cu. ft., while silty clays run up to 105 to 115 lb. per cu. ft. (KNIGHT, 1948). The effect of grading of soils on compaction had been studied by SHAW (1943). As a result of his work, he has proposed the following best grading for stabilized soils.

Table 1

Showing suggested grading for dense and mechanically stable soils
Granulometrie proposée pour sols denses et stables

B.S. sieves	*Suggested percentage passing*	*A.A.S.H.O.M. 56–42 percentage passing*
1 in.	100	100
¾ in.	87	70–100
½ in.	77	—
⅜ in.	72	50–80
$\frac{3}{16}$ in.	63	35–65
No. 7	55	25–50
No. 36	36	15–30
No. 200	18	5–15

There is a specific maximum density to which each soil can be compacted by a given amount of compactive effort at a particular moisture content, termed the 'optimum moisture content of soil'. PROCTOR (1933) established the relation between maximum density, optimum moisture content and the compactive effort, and evolved a standard method for the determination of optimum moisture for obtaining the maximum density of soils. If the amount of compaction is increased beyond the amount defined by the standard Proctor test, an increase in dry soil density is obtained with corresponding decrease in optimum moisture content varying with the type of soil and the amount of compaction applied.

The most salient question to be answered is: 'What should be the most stable density and moisture content at which the soils should be compacted?' By 'stable density' we mean the minimum density of the compacted fill at which there will not be any future settlement under the existing conditions of load and moisture content.

The standards prescribed for roads and runways cannot be applied to canals. In the former case the question of bearing capacity is the predominant factor, while in the latter permeability is the main consideration. DHAWAN *et al.* (1953) concluded from their experiments that for canal embankments 20 to 25 ft high, densities higher than 1·65 g/cm^3 are desirable and that high moisture contents are associated with low permeabilities. They also concluded that a small increase in moisture of compaction there was a saving in compactive effort.

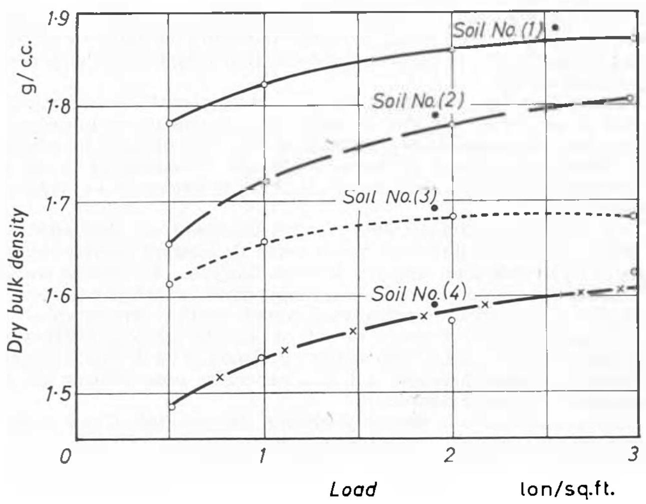

Fig. 1 Stable density at different loads
Densité stable pour des charges differentée

From the above discussion it is inferred that Proctor's density does not supply the specific information of correct density and moisture at which the soils should be compacted for stability and economy. Therefore, in order to obtain a clear conception of the 'stable density', it was considered desirable to investigate in detail the relation between density, moisture and degree of compaction of varying types of soils.

Experimental

The following experiments were carried out: (1) determinations of stable densities of soils for varying loads; (2) determination of moisture content at which a soil can be compacted to the desired stable density with the least compactive effort.

Discussion of Results

Determinations of stable densities of soils for varying loads—It is well known that the extent to which the dry density can be increased by compaction depends on the amount of water present in the soil at the time of compaction. For a soil of known compaction there will be an optimum moisture content for maximum density (PROCTOR, 1933).

The specifications for the compaction of a 200 ft. high embankment cannot be similar to that of a 25 ft. high embankment. The ultimate density of a soil, therefore, depends upon the total amount of over-burden to which it is to be subjected. In the light of these facts an attempt was made to determine the 'stable density' of a soil under different loads. These conditions were simulated in the standard consolidation apparatus.

Four types of soils, having the mechanical composition given in Table 2, were selected for this study.

Table 2
Mechanical analysis of soils
Analyse mecanique des sols

S. No.	*Clay 'particles' below* 0·002 mm	*Silt particles greater than* 0·002 mm *but less than* 0·02 mm %	*Sand particles greater than* 0·02 mm *but less than* 2·0 mm %
(1)	18·4	17·6	64·0
(2)	21·28	30·88	47·84
(3)	24·4	43·52	32·08
(4)	43·92	33·28	22·8

The dry bulk density of these soils was determined under saturated conditions in a consolidation apparatus for loads varying from ½ ton/sq. ft. to 3 ton/sq. ft. The final readings were taken when the dial-gauge of the consolidation apparatus did not exhibit any further reduction.

Fig. 1 and Table 3 show the relation between the dry bulk density and the effective overburden. Table 4 compares the percentage of the maximum density obtained for different types of soils under varying loads in the consolidation apparatus.

Table 4 shows clearly that while 95·44 per cent of the maximum density was attained under a load of ½ ton in the case of soil No. (1), only 89·86 per cent of the maximum density was attained in the case of soil No. (4), even under a load of 3 tons. Soil No. (2) behaved like soil No. (1); while soil No. (3) did not reach the peak density under a load of 3 tons.

In nature soils of diverse physicochemical characteristics are encountered which are bound to exhibit different engineering properties. If these soils are compacted at the maximum density obtained by Proctor's method, unstable conditions may be produced when the over-burden is insufficient to produce Proctor's density. Moreover excess compactive energy would be needed for attaining Proctor's maximum density than is

Table 3

S No.	*Soil sample No.*	*Clay*	*Silt*	*Sand*	*Percentage O.M.*	*Maximum density*	*Stable density at different loads* ½ ton *Moisture*	½ ton *Density*	1 ton *Moisture*	1 ton *Density*	2 ton *Moisture*	2 ton *Density*	3 ton *Moisture*	3 ton *Density*
(1)	(1)	18·4	17·6	64·0	12·0	1·865	15·4	1·78	14·3	1·82	14·7	1·86	14·0	1·87
(2)	(2)	21·28	30·88	47·84	14·6	1·765	19·3	1·65	18·0	1·72	12·5	1·775	13·8	1·805
(3)	(3)	24·4	43·52	32·08	18·4	1·72	21·7	1·615	20·4	1·65	19·6	1·68	19·7	1·68
(4)	(4)	43·92	33·28	22·8	15·6	1·805	25·6	1·485	21·3	1·533	23·9	1·572	22·9	1·622

Table 4

Comparison of the percentage of maximum density obtained for different types of soils in the consolidation apparatus

Comparaison du pourcentage de densité maximum obtenu pour différents types de sols dans l'appareil de consolidation

S. No.	*Load percentage of maximum density under*			
	½ ton	1 ton	2 tons	3 tons
(1)	95·44	97·58	99·19	100·00
(2)	93·48	97·73	100·00	100·00
(3)	93·89	95·93	97·67	97·67
(4)	82·27	84·98	87·09	89·86

actually required under the specified load, which can be easily reproduced in the consolidation apparatus. Thus the proper density at which the soil should be compacted can be determined by imposing the maximum pressure under which that soil is to

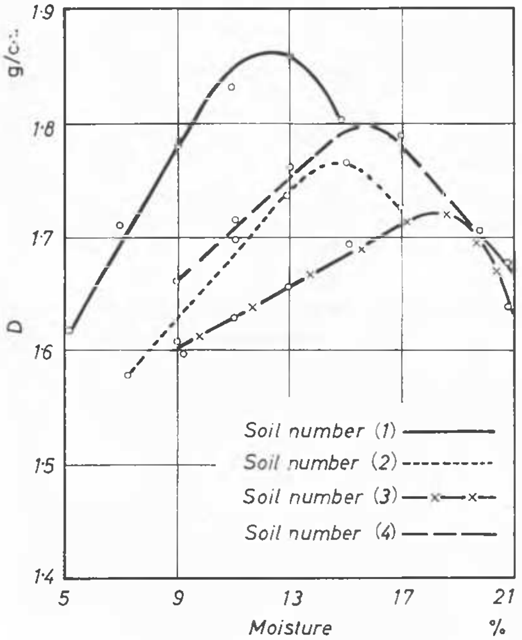

Fig. 2 Maximum density at optimum moisture of different soils
Densité maximum pour teneur en eau optimum de différents sols

be subjected. It is therefore concluded from the above discussion that Proctor's density only supplies us with a particular soil constant and that it would not be advisable to specify one value of soil density for different types of constructions.

Determination of the moisture content at which a soil should be compacted to the desired 'stable density' with the least compactive effort—Knowing the 'stable density', determined from the consolidation apparatus by imposing a load equivalent to the height of an embankment or the probable pressure to which it is to be subjected, the next point to be investigated is the moisture content at which the soil can be conveniently compacted with the least compactive energy. Proctor's representation of moisture and density relationships are usually presented in a plot of dry density *versus* water content percentage. Moisture density relationships for four soil samples obtained with the standard compaction apparatus are embodied in Fig. 2. With a knowledge of only the moisture-density relationship, as investigated by Proctor's technique, neither the correct density for a particular structure nor the moisture content with which soils should be compacted with the minimum amount of compactive effort to a desired density is known. The determination of the relationship between the moisture of compaction and the effort required for compacting a soil to different densities is of great practical importance. To accomplish this

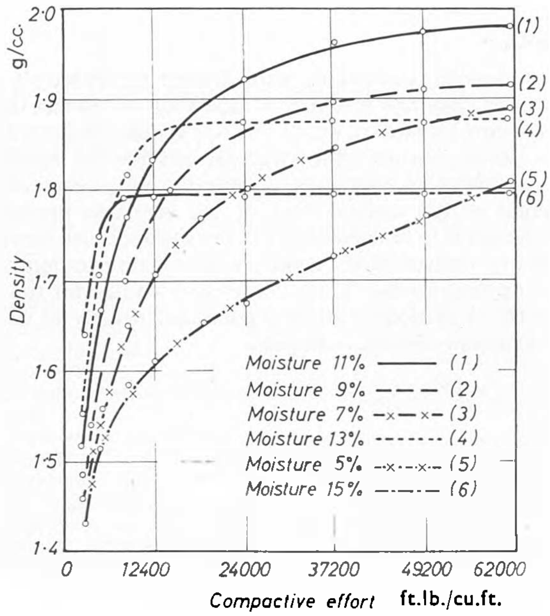

Fig. 3 Relation between compactive effort and density at varying moisture percentages. Soil No. 1
Relation entre l'effort de compaction et la densité pour des pourcentages différents de teneur en eau. Sol No. 1

purpose the first step was to ascertain, with the help of the standard compaction apparatus, the densities attained by soils (Nos. 1–4) with different compactive efforts at varying moisture contents. Fig. 3 shows typical graphs of the relationship between compactive effort and density at varying moisture

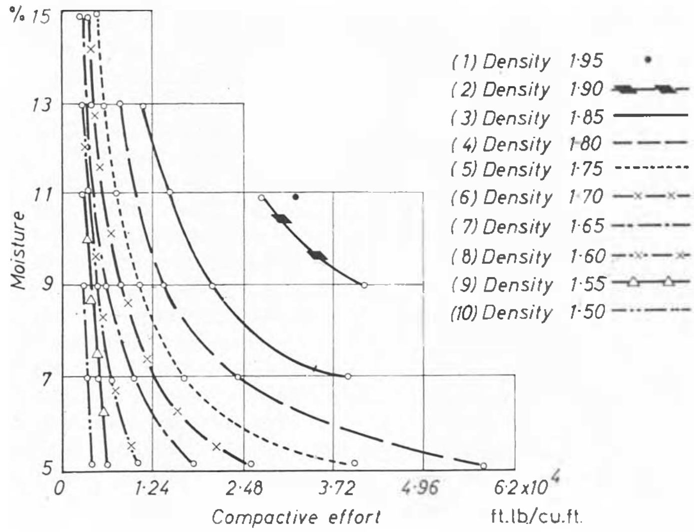

Fig. 4 The relation between moisture of compaction and compactive effort of soil. Soil No. 1
Relation entre la teneur en eau de compaction et l'effort de compaction du sol. Sol No. 1

contents for soil No. (1). From these graphs the efforts needed to compact a soil to different densities and moisture contents were determined. The relation between the moisture of compaction and the compactive effort required to produce particular dry-bulk densities is represented graphically for soil No. (1) in

Fig. 4. These relationships afforded information of far greater practical importance than Proctor's moisture density curves. From the graphs (Figs. 1 to 4) the 'stable density' for a particular construction, and the compactive energy required for obtaining that density may be obtained.

Conclusions

The following conclusions were drawn: (1) Proctor's compaction test does not give a true indication of correct density and moisture content at which the soil should be compacted; (2) the 'stable density' of a particular soil may be determined in the consolidation apparatus by imposing a load equivalent to the height of the embankment or the probable pressure to which the soil is to be subjected; (3) density-moisture curves are obtained by measuring the density and moisture content under various applied loads. These curves give a value for the compactive effort needed to attain a particular density in relation to the moisture content to be used.

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