Stable Density

Densité stable

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Summary

(1) For canal embankments of about 20 ft. to 25 ft. high, we should not aim at dry bulk densities higher than 1.65 g/cm³.

(2) The greater the moisture of compaction, the lesser is the permeability.

(3) With the increase in moisture of compaction, there is a substantial saving in compactive effort.

Sommaire

Cette communication traite du compactage du sol considéré spécialement dans ses rapports avec l'hydrologie et les barrages.

1° Pour les remblais des canaux mesurant approximativement 20–25 pieds de haut nous ne devons pas viser à une densité apparente sèche supérieure à 1.65 g/cm³.

2° La teneur en eau du compactage est en proportion inverse de la perméabilité.

3° En augmentant la teneur en eau on réalise un substantiel travail de compactage.

Introduction

Compaction is the packing together of soil particles with the expulsion of air, which ultimately decreases the volume of air voids and increases the density of the soil.

The question naturally arises "What is the most stable density and moisture content at which the soils should be compacted?" The standards laid down for roads and runways cannot be applied for the canals. In the former case the question of bearing capacity is the predominant factor, while in the latter permeability matters the most.

Regarding density, history stands witness that earth-dams have been built at many places at not very high densities as are obtained by the present machinery, but they are serving quite successfully. There is always a limit to which a compactive effort can be increased with advantage. *Terzaghi* (1948) discusses that storage reservoirs have at places been compacted at dry densities lower than 95 lbs./cu.ft. and they are standing quite stably. Therefore our notion "Higher compaction means higher stability" needs modification. Soils compacted at very high densities need comparatively greater amount of over-load for keeping them in the stable position against the effect of swelling.

The second point which merits attention is the question of moisture of compaction. It was found out by *Cary* (1943) that an increase in the water content from 2 per cent below optimum to 2 per cent above decreased the co-efficient of permeability about 10,000. *Terzaghi* (1948) also states: "In Great Britain and the British Dominions, earth dams have been constructed with rather permeable outer parts and plastic cores of such consistency that the clay can be handled and packed into place with a spade."

In the light of the above references experiments were conducted with typical punjab soils containing clay content varying from 6.6% to 17.3% to investigate the stable density and to study the effect of moisture of compaction on the ultimate permeability of soils.

Experimental Work

The following experiments were carried out:—

(1) Effect of different cycles of wetting and drying on the density of loose and compacted soils.

(2) Effect of moisture during compaction upon the permeability of a soil compacted at different dry-bulk densities.

(3) Effect of moisture during compaction on the compactive effort needed for attaining a particular density.

Discussion of Results

The first experiment related to the *effect of varying cycles of wetting and drying on the density of loose and compacted soils,* was carried out with three types of soils having clay content varying from 6.6% to 17.3% clay.

The mechanical analysis of these soils is given in the table below:—

Table 1 Mechanical Analyses of the Soils

Soils	*Clay (<0.002 mm) in %*	*Silt (0.002–0.02 mm) in %*	*Sand (0.02–2.0 mm) in %*
Sandy loam	6.56	20.64	72.80
Sandy loam	12.32	33.28	54.40
Silty loam	17.28	52.64	30.08

The soils were compacted at 12% to 16% moisture content in blocks of 2 ft. × 2 ft. and in cylinders of 8-in. diameter. They were slowly wetted, taking full precaution that the original compaction was not disturbed with the pressure of water. Both the loose and compacted soils were then subjected to varying cycles of wetting and drying and the dry bulk density after each cycle of wetting and drying was observed. The results are embodied in Table 3 and diagrammatically represented in Fig. 1. The results showed clearly that the decompaction began to take place even after the first cycle of wetting and drying and the soils ultimately attained a stable density irrespective of the type of the soil or the original moisture or density of compaction. The loose soils became gradually compacted and the resulting dry bulk density was ranging between 1.5 to 1.6 g/cm³. But the silty loam type of soils exhibited some cracks after drying. This was due to the silty nature of soils. *Dhawan* (1950) had already investigated that for proper soil stabilization the soils should conform to the following specifications:—

Clay	8 to 15%
Silt	12 to 25%
Sand	60 to 80%

As the thickness of the soil compacted in blocks or cylinders was nearly 3 inches or 6 inches respectively, therefore a channel of the following dimensions was constructed in order to investigate the effect of thickness on decompaction. The channel was 30 ft. long and 2 ft. wide. Three compartments were made and the soils were compacted at about 12% moisture content and 1.5, 1.65 and 1.8 g/cm³ dry bulk density. The total depth compacted in each case was 18 inches. The channel was continuously run for 100 hours and then dried. This constituted one cycle of wetting and drying. The following table (2) gives the dry-bulk density of soils at various depths after each cycle of wetting and drying.

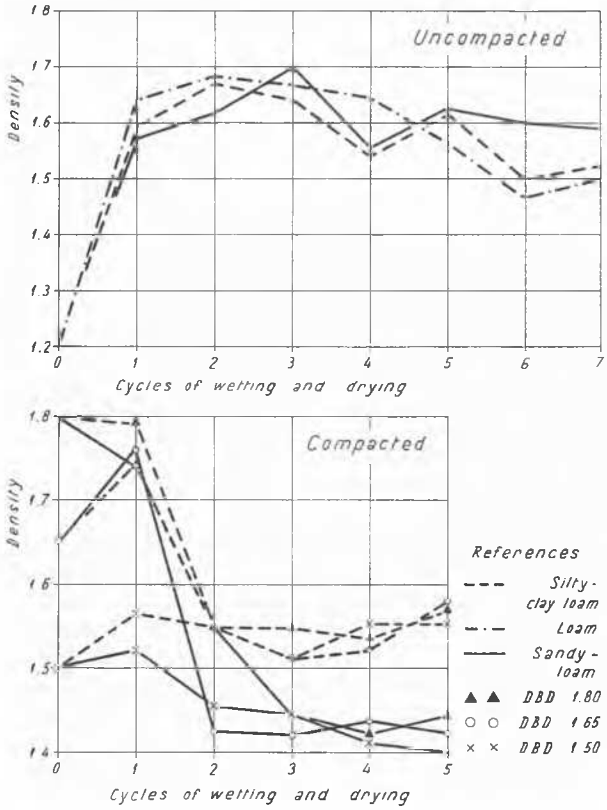

Fig. 1 Effect of Cycles of Wetting and Drying on Soils
Influence des cycles d'humidification et de dessication

From the Table 2 it was deduced that there was an inherent property in soil to develop particular density i.e. *Stable Density.*

The permanence of compaction of clay subjected to alternate wetting and drying was also studied by *H. C. Porter* (1942). His conclusions were that after several cycles of slow drying and wetting the soils returned to their original density. But he did not observe the expansion of clay on wetting.

When the moisture content is increased, the water lubricates the soil particles and the soil begins to loose its compactness with the swelling of clay. In addition the soil particles are set apart which, even on decrease in moisture content, reduces its density. This decrease in density can only be prevented if there is sufficient over-load to counter-act the above effect. It means, therefore, that before a particular soil is compacted at a parti-

Table 2 Dry-Bulk-Density (DBD) at Various Depths of Soils Compacted at Different Densities

Depth inches	*DBD in g/cm³ of Soils Compacted at*											
	1.52				*1.67*				*1.78*			
	DBD in g/cm³ after Different Cycles of Wetting and Drying											
	1	*2*	*3*	*4*	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*
0— 3	1.55	1.50	1.51	1.50	1.58	1.57	1.52	1.53	1.64	1.53	1.56	1.52
3— 6	1.51	1.47	1.51	1.51	1.51	1.58	1.48	1.52	1.68	1.66	1.67	1.59
6— 9	—	—	—	1.52	—	—	—	1.57	—	—	—	1.61
9—12	—	—	—	1.50	—	—	—	1.55	—	—	—	1.61
12—15	—	—	—	1.49	—	—	—	1.56	—	—	—	1.61
15—18	—	—	—	1.51	—	—	—	1.55	—	—	—	1.61

Table 3 Effect of Cycles of Wetting and Drying on Dry Bulk Density (DBD) of Compacted Soils

Soil	In g/cm³ at the Beginning	Moisture of Compaction %	DBD in g/cm³ after Different Cycles of Wetting and Drying									Average Value of DBD g/cm³
			1st	2nd	3rd	4th	5th	6th	7th	8th	9th	
Silty loam	1.6	12	1.45	1.52	1.51	1.49	1.54	1.47	1.34	1.54	1.49	1.46
	1.6	12	1.47	1.46	1.39	1.47	1.45	1.42	1.45	1.45	1.43	
	1.6	16	1.58	1.52	1.54	1.56	1.54	1.67	1.56	1.56	1.54	1.55
	1.6	16	1.56	1.49	—	1.46	1.49	1.45	1.47	1.56	1.55	
	1.7	12	1.65	1.56	1.53	1.66	1.68	1.675	1.68	1.52	1.55	1.57
	1.7	12	1.63	1.54	1.41	1.67	1.62	1.61	1.561	1.58	1.59	
	1.7	16	1.49	1.47	1.61	1.53	1.53	1.65	1.50	1.56	1.54	1.55
	1.7	16	1.63	1.57	1.45	1.58	1.44	1.49	1.52	1.53	1.56	
	1.8	12	1.49	1.663	1.52	1.65	1.48	1.56	1.63	1.53	1.56	1.58
	1.8	12	1.45	1.45	1.47	1.47	1.52	1.63	1.57	1.57	1.59	
	1.8	16	1.47	1.55	1.57	1.72	1.79	1.56	1.49	1.56	1.59	1.61
	1.8	16	1.41	1.61	1.68	1.53	1.68	1.64	1.52	1.65	1.63	
Sandy loam	1.6	12	1.45	1.45	1.51	1.44	1.549	1.547	1.59	1.54	1.54	1.53
	1.6	12	1.47	1.51	1.55	1.31	1.64	1.57	1.59	1.51	1.52	
	1.6	16	1.45	1.49	1.43	1.51	1.51	1.45	1.56	1.50	1.49	1.54
	1.6	16	1.41	1.45	1.45	1.57	1.58	1.54	1.50	1.58	1.59	
	1.7	12	1.48	1.58	1.65	1.53	1.56	1.58	1.53	1.63	1.59	1.59
	1.7	12	1.47	1.69	1.65	1.56	1.61	1.64	1.54	1.54	1.59	
	1.7	16	1.67	1.62	1.76	1.45	1.66	1.67	1.46	1.67	1.66	1.54
	1.7	16	1.44	1.47	1.49	1.49	1.67	1.56	1.53	1.54	1.41	
	1.8	12	1.55	1.67	1.66	1.58	1.55	1.63	1.57	1.56	1.55	1.58
	1.8	12	1.53	1.64	1.67	1.66	1.67	1.63	1.53	1.59	1.61	
	1.8	16	—	1.41	1.60	1.53	1.62	1.53	1.54	1.62	1.41	1.52
	1.8	16	1.55	1.64	1.53	1.60	1.63	1.59	1.59	1.52	1.63	

cular density, a correc idea of soil crust is necessary to maintain its original density, otherwise unstable conditions might occur due to fluctuations in moisture content.

Preliminary experiments carried out with clayey, silty, and sandy loam soils in consolidation apparatus showed that over saturated soil when placed under a direct load of ½ to 1 ton/sq.ft. attained a particular density. Clayey and sandy loam soils attained a higher density than silty loam soils. The silty loam soils needed one ton per sq.ft. load or a soil crust of about twenty feet depth to bring the density to about 1.69 g/cm².

From the above observations it was also confirmed that while compacting such type of soils in embankments of twenty feet or less we should not aim at densities higher than 1.65 g/cm³. In such cases higher density would not bring any extra advantage. The lower depths will gradually become more compacted with age due to the over load even in case of sandy loam or clayey soils.

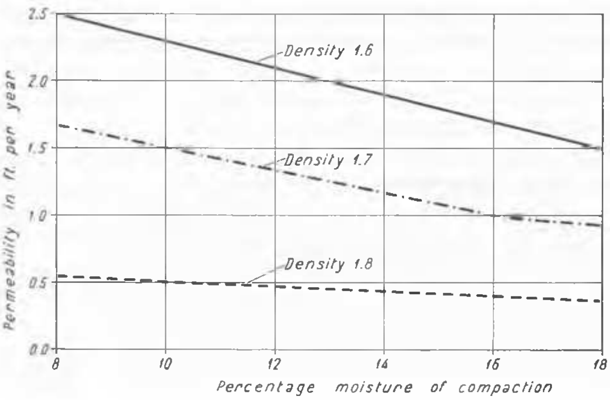

Fig. 2 Relation—at Varying Density—between the Moisture of Compaction and Permeability
Relation – à différentes densités – entre la teneur en eau et la perméabilité

Fig. 3 Assembly of Percolation Cylinders
Dispositif de cylindres de filtration

Experiments were next conducted with a soil containing 17.3% clay to investigate the *effect of moisture of compaction on the permeability of a soil.* The soils were compacted in a compaction apparatus of 2.5-inch diameter, and 1-inch thickness of the compacted soil was trimmed off and its permeability determined in constant head permeameter at a gradient of 1 : 24. Fig. 2 shows that the effect of moisture of compaction on the permeability of soil and Fig. 3 exhibits the arrangement of percolation cylinders.

It is inferred from the above experiments that the permeability decreases with the increase in the moisture of compaction.

These results confirmed the findings of *Cary* (1943) qualitatively.

It is a matter of common observation that clay puddle is practically impervious. The addition of water to a dry soil reduces the capillary force and this serves the following functions:—

(*a*) The friction force between the soil grains reduces.

(*b*) The particles are therefore set apart slightly.

The combined effect of the above two factors reduces the frictional force between the grains and the soil becomes more plastic, which ultimately increases the permeability. When the soil has already attained sufficient moisture content and has swelled, an extra amount of water will not disturb its equilibrium. Water enters through the free surface and flows into the interior but the amount of resistance offered to the flow of water depends upon both the moisture content and the state of compaction of the soil. Therefore the relative amounts of permeability will be governed by the degree and moisture content of compaction.

The effect of initial moisture in the soil profiles on the infiltration capacity has already been investigated by many scientists. *Diseker* and *Yoder* (1936) found that saturating the soil with water greatly increased the run off and diminished the permeability. On the other hand compaction decreases the non-capillary porosity which controls the permeability of soil (*Baver*, 1948).

Compacting a soil mass at a higher moisture content than the optimum brings in the question of pore-pressures. These pore-pressures are hydro-static and are created by any one of the following factors:—

(*a*) Consolidation in the soil mass.

(*b*) Percolating Water.

(*c*) Mechanical compaction.

The amount of pore-pressure which will result from any of the above factors is a function of the permeability of the particular soil in question. Therefore we have to be very judicious in selecting such types of soils which do not produce harmful pore-pressures. It has been noticed that Punjab soils having clay content between 8 to 15%, silt 12 to 25%, sand 60 to 80% are sufficiently stable and free from the above effects.

Fig. 4 shows the *effect of moisture on the compactive effort* needed to atttain a particular density. There is a substantial saving in the compactive effort with the increase in moisture content. It brings the double advantage of compacting soil at a higher moisture content than the optimum. Firstly the permeability of the soils decreases and secondly we have to put in less effort to attain a particular density.

From the above discussion it is concluded that at the present time, the relation of the moisture content, the degree of compaction, the probable effects of consolidation and the physicochemical properties of the soils are still very imperfectly understood. Taking all the above factors into consideration it shows that there is an optimum compactive effort for a particular type of soil and embankment, which will be stable under adverse conditions of moisture. The specifications for compaction of a 200-foot high embankment cannot be similar to that of a 20-foot high embankment. A compromise is needed in this direction and the modern trend towards the use of heavy rollers for obtaining very high densities for all kinds of projects need proper judgment and care.

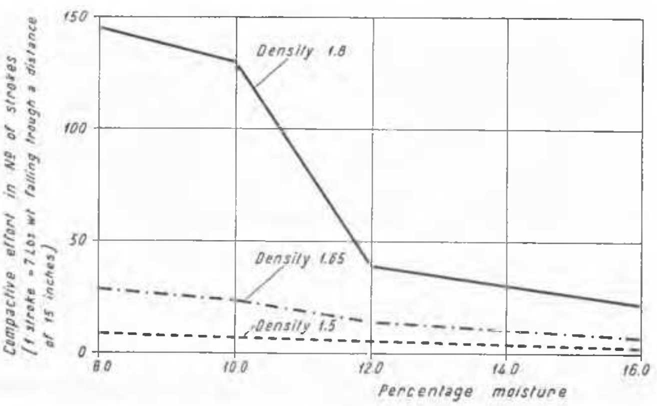

Fig. 4 Relation between the Moisture of Compaction and Compactive Effort
Relation – à différentes densités – entre la teneur en eau et le travail de compactage

Acknowledgment

The authors take this opportunity of expressing their thanks to *R. B. Shri C. L. Handa*, I.S.E. Ex Director, Irrigation Research Institute, Punjab (I) for his keen interest in the investigation of the problem. Our thanks are also due to Dr. *H. L. Uppal* M.Sc., Ph.D., Director, Irrigation Research Institute, for his helpful suggestions.

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