Consolidation and Strength Characteristics of Indian Black Cotton Soils

Consolidation et Caractéristiques de résistance des 'Black Cotton Soils' de l'Inde

by D. MOHAN, Assistant Director (Soil Engineering), Central Building Research Institute, Roorkee (U.P.), India

Summary

About 20 samples of black cotton soil from different parts of India, covering practically the entire area where such soils predominate, were tested in the laboratory with a view to ascertaining if their strength and consolidation characteristics could be correlated with simpler properties which do not involve elaborate testing.

Remoulded samples were tested for unconfined compressive strength at decreasing moisture contents. A straight line relationship is noticeable between liquidity index and log shear strength.

Free swell of the soil particles was observed by measuring the change in volume of 10 c.c. of dry soil passing 36 B.S. sieve. Although a definite relationship is not visible between the free swell on the one hand and volume expansion and swelling pressure on the other, yet a trend is noticeable which may be sufficient for the preliminary design.

The soil samples were subjected to gradual consolidation in a consolidometer after remoulding them near the liquid limit. The compression index has been observed to bear a relation to the liquid limit similar to the one observed by Skempton.

Swelling pressure and volume expansion were also measured at different moisture contents and dry densities, but no definite correlation could be established.

Sommaire

Une vingtaine de sols du type 'black cotton soil' provenant de différentes régions de l'Inde ont été étudiés en laboratoire afin de voir si on pouvait établir une relation entre les caracteristiques de résistance et pré-consolidation et les propriétés plus simples ne nécessitant pas d'essais compliqués.

Des échantillons remaniés ont été soumis à l'essai de compression libre pour des teneurs en eau décroissantes. On constate une relation linéaire entre l'indice de liquidité et le log de résistance à la compression.

On observa le gonflement libre des grains de sol en mesurant le changement de volume de 10 c.c. de sol sec, passant le tamis normal B.S. 36. Quoiqu'il n'y ait pas, à première vue, une relation bien définie entre le gonflement libre d'une part et l'augmentation de volume et la pression de gonflement de l'autre, il y a cependant des tendances marquées qui pourraient suffire pour les calculs préliminaires d'un projet.

Après remaniement, vers la limite de liquidité, les échantillons de sol furent soumis à une consolidation progressive dans le consolidomètre. On a constaté que l'indice de compressibilité montre une certaine relation avec la limite de liquidité; cette relation est très semblable à celle constatée par Skempton.

On a mesuré également la pression de gonflement et l'augmentation de volume pour des teneurs en eau et des densités sèches différentes, mais on n'a pas pu obtenir de relation définie.

Introduction

Black cotton soils, also known as 'Regurs', have a predominance of montmorillonite clay mineral. They are equivalent to the Russian 'Chernozems' and black earths of Australia, and are found as a result of decomposition of the parental rock which is mostly trap. When they exist at a site with the parent rock underneath their depth is shallow, averaging about 3 ft., but in low lying and flat areas where they develop over alluvium, after being transported by the wind and the rain, they go deep and usually average about 6 ft. and upwards of 15 ft. in depth. These black soils have not only the properties of a medium to heavy clay but also the corresponding secondary properties such as high water holding capacity, stickiness when wet and a high shrinkage and swelling capacity. During the dry seasons of the year they crack considerably, fissures 4 to 8 in. wide and over 3 ft. deep being common, and the soil develops distinctly columnar structure which persists throughout the year in deeper layers. These soils though very useful for growing cotton are a great problem to the foundation engineer.

Samples of black cotton soil obtained from different places in India are shown in Fig. 1; they cover practically all the States where black soil exists. The depths from which samples were obtained varied from 2 to 8 ft.

Table 1

S. No.	*Location*		*Liquid limit*	*Plastic limit*	*Plasticity index*	*Shrinkage limit*
	Town	*State*				
1	*Nagpur*	*Madhya Pradesh*	69	32	37	13
2	*Hoshangabad*	*Madhya Pradesh*	50	28	22	11
3	*Akola*	*Madhya Pradesh*	83	36	47	11
4	*Shujalpur*	*Madhya Bharat*	56	25	31	11
5	*Indore*	*Madhya Bharat*	56	29	27	11
6	*Shajapur*	*Madhya Bharat*	56	27	29	11
7	*Dhar*	*Madhya Bharat*	63	32	31	12
8	*Barwaha*	*Madhya Bharat*	57	33	24	12
9	*Barwani*	*Madhya Bharat*	68	31	37	11
10	*Baramati*	*Bombay*	76	33	43	13
11	*Phadegaon*	*Bombay*	79	38	41	12
12	*Kopergaon*	*Bombay*	64	34	30	14
13	*Parbhani*	*Hyderabad*	97	34	65	13
14	*Nanded*	*Hyderabad*	75	36	39	13
15	*Badnapur*	*Hyderabad*	81	40	41	12
16	*Bhopal*	*Bhopal*	46	24	22	11
17	*Madras*	*Madras*	70	21	49	11
18	*Dinapur*	*Bihar*	56	26	30	13
19	*Jhansi*	*Uttar Pradesh*	48	16	32	11
20	*Lonavala*	*Bombay*	88	34	54	—

Liquid, Plastic and Shrinkage Limits

The liquid, plastic and shrinkage limits were found in the usual manner and are shown in Table 1.

The liquid limit ranges from 46 to 97 and the plasticity index from 22 to 49. The shrinkage varies between the narrow limits of 11 and 14. A curve has been plotted between liquid limit and plasticity index (Fig. 2). Numerals on the curve refer to the serial number of soil in Table 1. The larger concentration of points is along a straight line represented by the equation $LL = 1{\cdot}3PI + 21$. The line almost coincides with Casagrande's 'Line A'.

Particle Size Analysis

The soil contained kankar (limestone mixed with clay) in sizes up to ¾ in. and a considerable amount of trap rock particles. Particle size analysis of the soil was carried out by the pipette method after removal of the organic matter; it is shown in

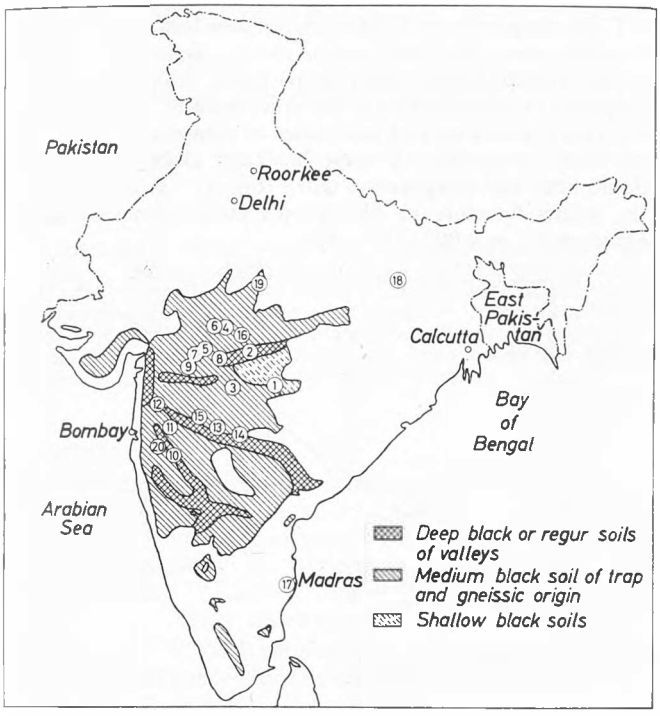

Fig. 1 Soil map of India showing location of black soils
Carte des sols de l'Inde, montrant l'emplacement des 'black soils'

Table 2. The various limiting sizes are according to the International Society of Soil Science Classification.

Table 2

S. No.	Location	Gravel > 2 mm	Coarse sand 2–0·2 mm	Fine sand 0·2–0·02 mm	Silt 0·02–0·002 mm	Clay < 0·002 mm
1	*Nagpur*	8	6	17	15	54
2	*Hoshangabad*	3	6	10	36	45
3	*Akola*	10	7	2	22	59
4	*Shuljalpur*	8	3	19	19	51
5	*Indore*	8	1	17	18	56
6	*Shajapur*	5	6	24	19	46
7	*Dhar*	1	6	29	15	49
8	*Barwaha*	1	3	14	33	49
9	*Barwani*	0	5	19	26	50
10	*Baramati*	2	6	13	19	60
11	*Phadegaon*	2	2	7	27	62
12	*Kopergaon*	0	0	6	39	55
13	*Parbhani*	1	0	6	19	74
14	*Nanded*	2	6	15	25	52
15	*Badnapur*	5	2	13	23	57
16	*Bhopal*	3	6	28	21	42
17	*Madras*	2	5	24	24	45
18	*Dinapur*	0	1	9	35	55
19	*Jhansi*	6	1	25	22	52
20	*Lonavala*	0	6	10	20	70

The soil lies in the clay range and the clay content varies from 42 to 74 per cent. A curve has been plotted between liquid limit and clay content (Fig. 2). The concentration of points is again along a straight line which may be represented by the equation $LL = 1{\cdot}91 \times$ clay content—34·5.

Organic Content and Specific Gravity

The organic content was determined by the dichromate oxidation method; it varies from 0·4 to 2·4 per cent. The specific gravity ranges between 2·66 and 2·73.

Unconfined Compressive Strength

The soil was compacted at the plastic limit in a Proctor's mould by a Proctor's rammer. Cylindrical test specimens,

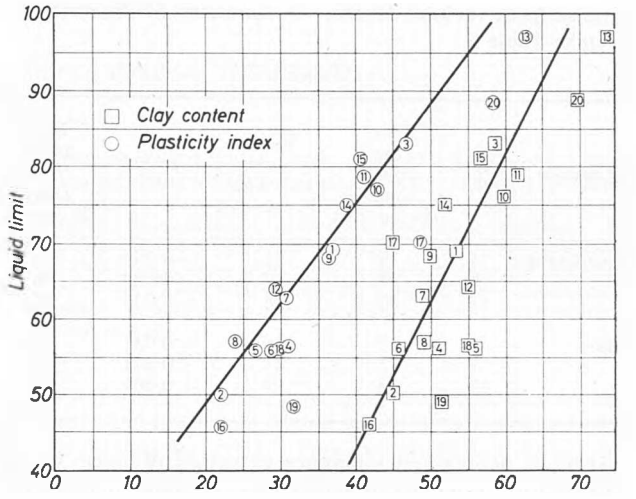

Fig. 2 Liquid limit *versus* clay content and plasticity index
Limite de liquidité en fonction de la teneur en argile et de l'indice de plasticité

diameter 2 in. and height 3 in., were obtained from the compacted soil mass in the mould by pushing in a sampling tube. These were subjected to gradual air drying and the compressive strength was determined at four different moisture contents in decreasing order in a testing machine worked at a uniform rate of loading.

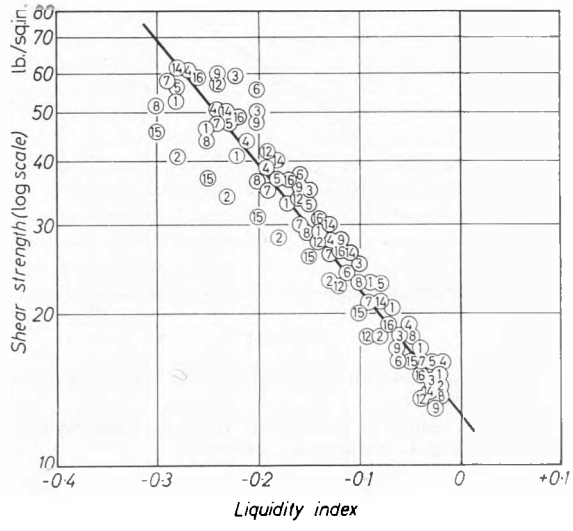

Fig. 3 Shear strength *versus* liquidity index
Résistance au cisaillement en fonction de l'indice de liquidité

The compressive strength which is twice the shear strength in this case increases with the decrease in moisture content. A curve has been plotted between the liquidity index $(W - PL)/(LL - PL)$ and logarithm of the shear strength (Fig. 3). The curve has been plotted only up to a liquidity index range of − 0·3 which gives the minimum moisture content at which black cotton soil usually exists at a depth of 4 ft. The liquidity

index in all cases has a negative value as the moisture content is below the plastic limit.

The concentration of points is along a straight line and at the plastic limit the strength of the soil is very low.

There is no appreciable difference in strength between an undisturbed and remoulded sample of black cotton soil, as its sensitivity is nearly unity. A check of the curve (Fig. 3) was carried out by taking a portable unconfined compression test apparatus to the site and testing undisturbed and remoulded samples from various depths. A summary of observations is given in Table 3.

Table 3

Location	*Depth (ft.)*	*Shear strength undisturbed* (lb./sq. in.)	*Shear strength remoulded* (lb./sq. in.)	*Liquidity index*	*Shear strength from curves* (lb./sq. in.)
Powerkhera	4	19	21	− 0·036	16
	8	21	17	− 0·034	16
	12	20	18	− 0·034	16
Indore	4	17	16	− 0·031	15
	8	22	23	− 0·071	19
	12	29	29	− 0·091	21

There is no marked difference in values of shear strength between those obtained by actual tests and those obtained from curves.

Free Swell

A free swell test was carried out by slowly pouring 10 c.c. of dry soil passing No. 36 B.S. sieve into a 100 c.c. graduated flask

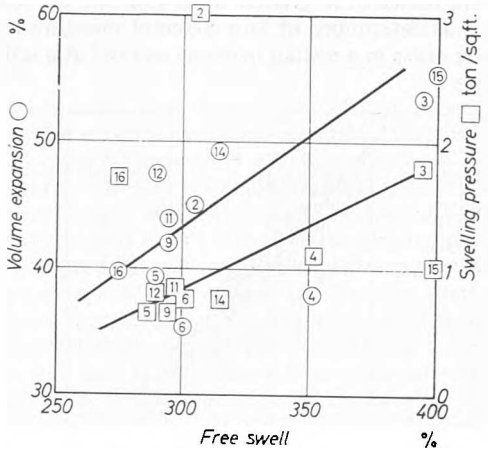

Fig. 4 Relationship of free swell with volume expansion and swelling pressure
Relation entre le gonflement libre et l'augmentation de volume et la pression de gonflement

filled with water and noting the increased volume of the soil at the bottom after it comes to rest. The free swell value is given by the percentage increase in volume.

Curves between free swell on the one hand and volume expansion and swelling pressure on the other have been drawn (Fig. 4). Although straight lines have been drawn in both cases along the larger concentration of the points yet no definite correlation can be established at this stage. A trend is, however, visible which may do for the preliminary design.

Compression Index

Eight samples from different places were tested in a fixed ring consolidometer for compression index. Specimens were put in the consolidometer rings at the liquid limit and gradually subjected to consolidation in the usual manner. Pressure–void ratio curves were plotted and values of compression index read off from the curves. A curve has been plotted between the liquid limit and compression index (Fig. 5). It is noticed that the points lie close to Skempton's curve expressed by the equation $C'_c = 0{\cdot}007\ (LL - 10)$.

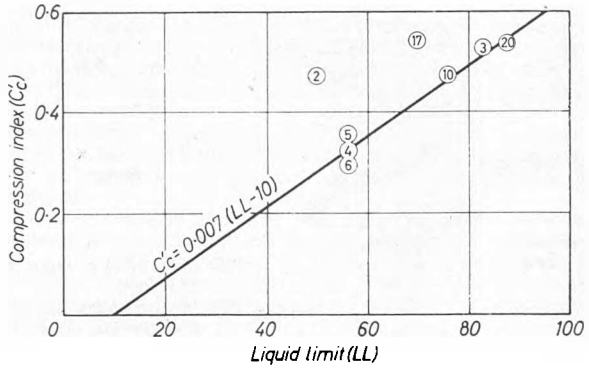

Fig. 5 Compression index *versus* liquid limit
Indice de compressibilité en fonction de l'limite de liquidité

Swelling Pressure and Volume Expansion

An attempt was also made to see if there is a correlation between the moisture content, dry density, swelling pressure and volume expansion. For this purpose eight specimens were moulded in a consolidometer ring near the plastic limit. Four of them were tested for swelling pressure and four for volume expansion at varying moisture contents and densities. There was a wide scatter in the points and no definite trend could be established.

Conclusions

From the limited number of tests carried out on remoulded samples of black cotton soil a trend towards a straight line relationship is noticeable between the liquid limit and log shear strength; also the compression index bears a close relation to the liquid limit as observed by Skempton. The results, however, need further confirmation by testing large numbers of samples, both undisturbed and remoulded. A definite relationship between the liquidity index and the shear strength which in turn is directly related to the bearing capacity will greatly aid the design of foundations on black cotton soil.

This work was carried out as part of the normal programme at the Central Building Research Institute and the results are published by permission of the Director.

The author is grateful to his assistants, Messrs G. S. Jain, R. K. Goel and R. N. Bhargava, who carried out the soil testing and compilation of the results.