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Physical Properties of Soils from the Ganges Valley*

L. C. JAIN & N. K. PATWARDHAN
Central Building Research Institute, Roorkee

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The physical properties of alluvial soils selected from different brick fields in the Gangetic plains have been determined with a view to correlating Atterberg's limits with the other important characteristic properties of the soils. Such a correlation is of value in evaluating the performance of the soil when used as a raw material for making bricks, tiles, etc., or as a building material. The value of tan *B* in the formula for determining the liquid limit of the alluvial soil by one-point method was found to be 0·085. The formula correlating the liquid limit (*LL*) and plastic index (*PI*) is given by $PI = 0{\cdot}72\,(LL-15)$.

The effect of mechanical composition on Atterberg's limits has also been studied. In the case of alluvial soils investigated by the authors, the formula suggested by Dos Santos does not correlate the liquid limit with the new soil constant developed by him. The expression, $LL = 0{\cdot}67 - 0{\cdot}303t - 0{\cdot}309t^2$, arrived at gives a better correlation between Atterberg's limits and mechanical composition.

TERZAGHI and Peck[1] have suggested the correlation of Atterberg's limits with other properties of soils as one of the most promising fields of research in soil physics. These properties are also of great help in predicting the behaviour of soils when used as a building material or as a raw material for making bricks, tiles, etc. In this paper an attempt at such correlation has been made for a number of alluvial soils occurring in the Gangetic plains and a new soil constant based on lines similar to the one arrived at by Dos Santos[2] has been evaluated. Also, a better correlation between Atterberg's limits and mechanical composition for these soils has been arrived at.

Nature of soils of the Gangetic plains

The upper Gangetic plains are situated at a height of 800-1000 ft above the sea level, and gradually sloping towards east during the course of the Ganges, till it meets the Bay of Bengal. It is generally observed that the alluvium, which is a water-borne material, in the upper plains is coarser than that in the lower plains near the delta region. This is as would be expected, on account of the easterly slope of the plains over a distance of 1000 miles. This is confirmed by the data presented in Table 1 which indicates that the coarser fraction of the brick earth tends to decrease as we go down the course of the Ganges. The presence of the finer material affects the other properties such as plasticity and dry strength and would ultimately be responsible for the differences in the properties exhibited by soils in the different parts of the valley. It is also observed that the percentage of $CaCO_3$ is higher in the lower reaches of the plains whereas the total soluble salt content is low throughout the course.

Experimental details

Thirty-two samples of soils were collected from different brick fields situated in the Gangetic plains. The sampling covered the whole course of the Ganges from Hardwar to Calcutta, and care was taken to see that the upper, middle and lower regions were represented evenly.

Samples of soils passing the 2 mm. sieve were used in these studies. Mechanical analysis was carried out by the international method, and Atterberg's limits were determined according to standard ASTM methods. Flow index was calculated by subtracting the moisture content at 100 blows from the moisture content at 10 blows. Optimum moisture and density were determined in a modified Proctor's cylinder, allowing a 5·5 lb. hammer to fall through a height of 10 in. Volumetric shrinkage was determined on rectangular samples of soil briquettes of 3 × 2 × 1½ in. size which were moulded at the sticky point moisture.

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TABLE 1 — MECHANICAL ANALYSIS OF SOILS

(Calculated on carbonate and moisture-free basis)

Sl No.	Location		Retained on 200 mesh sieve	Between —0·076 and 0·02 mm.	Between 0·02 and 0·002 mm.	Between 0·006 and 0·002 mm.	Between 0·002 and 0·001 mm.	Below 0·001 mm.
1	Bijnor	(A)	13·9	35·9	2·3	14·5	6·4	27·0
2	do	(B)	9·5	20·4	35·6	4·2	6·3	24·0
3	Moradabad	(A)	27·6	34·0	15·7	6·8	1·9	14·0
4	do	(B)	5·5	18·4	20·7	12·6	10·1	32·7
5	do	(C)	24·3	30·6	16·8	8·2	2·5	17·6
6	do	(D)	54·7	27·1	5·3	3·3	1·9	7·7
7	do	(E)	18·3	39·4	12·7	8·3	2·9	18·4
8	Bareilly	(A)	26·6	28·7	12·6	8·5	4·4	19·2
9	do	(B)	16·1	35·9	16·6	9·1	6·5	15·8
10	Aligarh	(A)	50·4	25·0	1·0	9·7	2·6	11·3
11	do	(B)	21·9	46·3	11·5	6·1	3·4	10·8
12	do	(C)	23·3	49·1	8·7	6·0	1·8	11·1
13	do	(D)	8·6	44·3	14·0	6·0	9·1	18·0
14	Shahjahanpur		5·0	59·2	15·2	6·6	0·2	13·8
15	Hardoi		5·1	52·1	15·8	6·4	3·1	17·5
16	Allahabad		10·0	48·1	13·1	8·1	0·8	19·9
17	Banaras	(A)	1·1	41·2	24·9	10·8	2·7	19·3
18	do	(B)	1·3	34·0	23·4	8·9	4·9	27·5
19	Chapra	(A)	0·6	24·8	24·1	21·3	3·4	25·8
20	do	(B)	56·4	6·4	12·0	5·9	2·5	16·8
21	do	(C)	4·3	48·1	19·2	7·0	4·3	17·1
22	Patna	(A)	12·8	33·0	22·3	6·8	3·3	21·8
23	do	(B)	13·6	38·6	16·1	9·0	2·1	20·6
24	Bhagalpur		1·6	53·1	16·6	6·4	1·8	20·5
25	Monghyr		3·8	29·7	24·5	11·8	2·7	27·5
26	Murshidabad (Lalbagh section)		1·8	20·2	31·6	11·0	2·4	33·0
27	Murshidabad (Kandi section)		8·3	45·5	19·8	6·1	3·5	16·8
28	Burdwan		26·8	40·1	12·0	3·3	3·9	13·9
29	Hooghly		3·0	17·5	23·8	18·3	3·8	33·6
30	Calcutta	(A)	0·6	26·8	27·0	10·4	6·1	29·1
31	do	(B)	0·4	25·7	31·1	7·9	6·1	28·8
32	do	(C)	0·5	27·3	29·5	9·3	6·1	27·3

These briquettes were also used for finding out the dry strength of soil blocks.

Results and discussion

One-point method for determining the liquid limit — In liquid limit determination, when water content and number of blows are plotted on semilogarithmic plot, flow lines of higher liquid limit have a steeper slope than the flow lines of lower liquid limit. However, the logarithmic plot tends to make them equal. Cassagrande has suggested that flow lines obtained by plotting the liquid limit determinations on logarithmic scale might give a constant slope for soils of the same geolog ical origin, so that the procedure for determining the liquid limit might be simplified. The feasibility of using the simplified procedure was first tested in the Waterways Experimental Station, Vicksburg, Mississippi[3]. A large number of liquid limit tests on soils of different geological origin were performed. These observations indicated that the slope of the flow curve, when plotted on logarithmic plot, is independent of the soil type and geological classification. The following formula was suggested by them for obtaining the liquid limit by one-point method:

$$LL = W_N \frac{(N)^{\tan B}}{25} \quad \ldots\ldots\ldots (1)$$

The value of tan B worked out to be 0·121. W_N represents the moisture at N number of blows. They further suggested that if the liquid limit is used for quantitative correlation with other tests, the number of blows may be kept between 20 and 31, but for classification purposes the number of blows may be kept between 15 and 41. This formula was tested in the Hirakud Research Station[4]. The average value of the slope of flow line (tan B) was found to be 0·114. The results obtained in the present work were statistically examined and the mean value of tan B was found to be 0·085. Maximum and minimum value of tan B were 0·13 and 0·056 respectively. The standard deviation was 0·016 and coefficient of variation was 18·8. Thus the formula for the alluvial soils examined worked out to be

$$LL = W_N \frac{(N)^{0.085}}{25} \quad \ldots\ldots\ldots (2)$$

Relation between liquid limit and plasticity index — The relation between the liquid limit and plasticity index (*PI*) for a large number of British soils grouped together according to their geological classification was derived by Clare[5]. The equation corresponding to the relationship for soils of recent and pleistocene geological formation as worked out by him is:

$$PI = 0{\cdot}74(LL-17) \quad \ldots\ldots\ldots \quad (3)$$

The results obtained in this laboratory are plotted in Fig. 1, and the equation worked out for the soils of the Ganges valley, which are of the same geological age, as discussed before, is given by

$$PI = 0{\cdot}72(LL-15) \quad \ldots\ldots\ldots \quad (4)$$

For soils containing more than 1 per cent $CaCO_3$, the equation

$$PI = 0{\cdot}7(LL-19) \quad \ldots\ldots\ldots \quad (5)$$

gives a better relation than equation (4).

The values obtained experimentally and those calculated by the above formula are given in Table 2 and Table 3 respectively. The mean deviation, standard deviation and coefficient of variation between the experimental values and values calculated from equation (4) are respectively —0·21, 1·40 and 11·42, and between the experimental and calculated values from equation (5) are +0·30, 1·50 and 8·77.

It may also be pointed out that a similar relationship has been worked out at the Uttar Pradesh Public Works Department Research Institute[6], Lucknow. The equation obtained at the Institute for alluvial soils of Uttar Pradesh is $PI = 0{\cdot}8(LL-15)$.

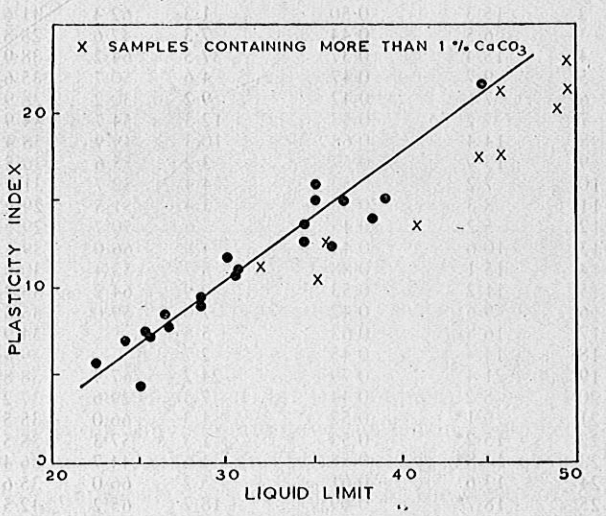

FIG. 1 — PLOT OF LIQUID LIMIT VERSUS PLASTICITY INDEX

TABLE 2 — PHYSICAL PROPERTIES OF SOILS

SL No.	LIQUID LIMIT	PLASTIC INDEX	FLOW INDEX	STICKY POINT	VOL. SHRINKAGE %	SHRINKAGE LIMIT	SHRINKAGE RATIO	TOTAL SOLUBLE SALTS %	$CaCO_3$ %
1	44·6	21·6	10·2	27·9	29·7	12·4	1·91	0·110	0·13
2	39·0	15·2	5·9	30·6	21·5	18·6	1·79	0·230	0·20
3	24·0	7·0	5·1	18·9	11·2	13·1	1·90	0·100	0·36
4	36·5	15·8	5·0	27·8	28·4	13·1	1·93	0·120	0·56
5	28·5	9·5	5·0	23·7	16·6	15·1	1·91	0·060	0·24
6	24·9	4·1	5·2	22·7	—	—	—	0·110	0·10
7	25·5	7·2	5·3	22·2	14·8	14·5	1·90	0·050	0·34
8	35·0	16·0	8·0	23·5	19·3	13·6	1·96	0·070	0·13
9	34·3	12·7	6·2	26·2	15·5	17·8	1·86	0·080	0·58
10	25·3	7·3	5·4	20·2	12·6	13·6	1·90	0·063	0·34
11	26·6	7·8	6·1	22·5	16·5	13·9	1·84	0·050	0·09
12	22·4	5·8	7·3	19·8	12·8	13·2	1·93	0·051	0·04
13	29·9	11·9	4·5	25·0	20·1	14·5	1·92	0·050	0·79
14	36·0	12·4	6·4	27·0	13·5	19·4	1·76	0·400	0·19
15	30·6	11·1	7·8	24·6	16·7	15·5	1·84	0·080	0·15
16	28·4	8·8	5·8	22·1	17·7	12·9	1·92	0·060	0·13
17	38·3	13·9	6·9	31·1	25·0	17·0	1·77	0·040	0·17
18	34·9	14·5	7·8	26·3	27·8	11·9	1·93	0·040	0·13
19	49·5	23·0	10·3	31·3	25·2	17·2	1·78	0·110	1·05
20	26·4	8·5	6·6	21·8	10·2	16·4	1·85	0·080	0·60
21	32·0	11·1	5·7	24·7	18·4	14·8	1·85	0·160	2·13
22	40·7	13·4	8·0	30·7	21·6	18·4	1·80	0·100	1·98
23	35·8	12·6	7·3	28·2	23·3	15·3	1·81	0·110	3·64
24	34·4	13·7	7·0	23·7	19·9	13·4	1·92	0·040	0·22
25	45·6	21·4	8·5	30·2	30·2	13·7	1·82	0·130	6·08
26	49·1	20·3	9·6	36·5	35·8	17·0	1·84	0·080	3·32
27	35·2	10·5	7·8	27·3	15·2	18·9	1·80	0·090	6·35
28	30·4	10·8	6·8	23·7	14·1	16·0	1·82	0·070	0·06
29	56·2	28·5	9·0	37·5	42·2	14·8	1·86	0·100	3·54
30	49·8	21·0	9·2	36·3	26·3	21·0	1·72	0·140	4·31
31	44·6	17·6	7·2	35·7	28·4	19·4	1·74	0·150	4·21
32	45·5	17·7	8·4	36·2	31·0	18·6	1·77	0·120	4·10

TABLE 3 — PLASTIC INDEX, LIQUID LIMIT AND OTHER PROPERTIES OF SOILS

SL No.	*PI* calculated by eqn (4)	Colloidal activity [*PI*/clay (<0·002 mm.)]	C_3 $\frac{U+11+C_3}{2.8}$	Liquid limit by Dos Santos formula	Liquid limit by New formula
1	21·3	0·65	−16·0	58·1	45·6
2	15·3	0·50	−1·3	62·4	41·6
3	6·5	0·44	−7·3	47·6	28·8
4	15·4	0·37	−37·5	64·2	38·9
5	9·7	0·47	−4·6	50·7	35·6
6	7·1	0·42	−9·2	30·2	28·9
7	7·2	0·33	−12·3	54·7	34·9
8	14·4	0·68	−10·3	49·9	38·4
9	13·9	0·57	−3·2	55·6	36·5
10	7·2	0·52	−4·4	32·7	31·9
11	8·3	0·55	−3·4	51·5	29·9
12	5·2	0·45	−7·6	50·7	29·2
13	10·6	0·44	−4·8	66·0	39·4
14	15·1	0·88	+8·7	53·4	30·0
15	11·2	0·53	−0·9	64·2	35·2
16	9·6	0·42	−7·0	59·0	35·6
17	16·8	0·63	+5·8	—	34·9
18	14·4	0·45	−2·7	—	39·8
19	21·4	0·79	+24·2	67·9	38·8
20	8·2	0·44	−7·3	29·6	37·2
21	9·1*	0·52	−1·3	66·0	35·5
22	15·2*	0·53	+1·3	57·3	38·5
23	11·8*	0·55	+1·6	44·7	36·4
24	13·6	0·61	+5·2	66·0	35·6
25	18·7*	0·69	+18·7	65·2	42·5
26	21·0*	0·59	+10·5	—	44·0
27	11·3*	0·51	−1·8	62·4	35·2
28	10·8	0·60	+1·4	49·1	35·0
29	26·0*	0·76	−31·4	66·0	49·9
30	21·6*	0·60	−12·6	67·9	44·3
31	17·9*	0·50	+3·4	67·9	44·1
32	18·5*	0·53	−5·2	67·9	43·2

*Calculated according to equation (5).

It is difficult to say whether these differences obtained as a result of the application of the two formulae are significant, bearing in mind the possible experimental error in a simple test of this type, and considerable scattering points. Further work on these lines is necessary in order to establish a general formula for the alluvial soils.

Liquid limit and compaction characteristics — Although the results plotted in Figs. 2 and 3 show no clear-cut relation between the liquid limit and maximum dry density and optimum moisture content, they do indicate a definite tendency for the dry density to decrease and optimum moisture to increase with increase in the liquid limit.

Mechanical composition and Atterberg's limit — Clay fraction has a great influence on the engineering properties of cohesive soils. In many cases the behaviour may be explained by the existence of a thin film of absorbed water on the surface of the clay particles. The properties of these absorbed films depend upon the nature of exchangeable bases and the type of clay minerals.

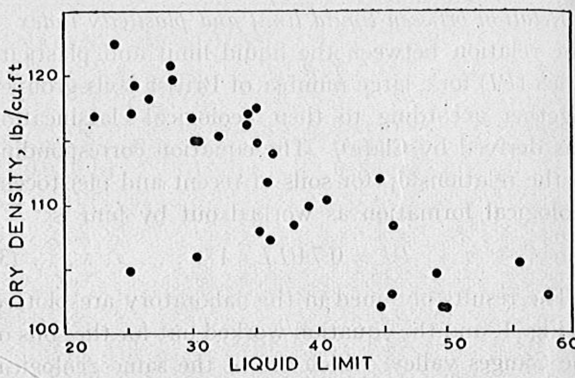

FIG. 2 — PLOT OF LIQUID LIMIT VERSUS DRY DENSITY

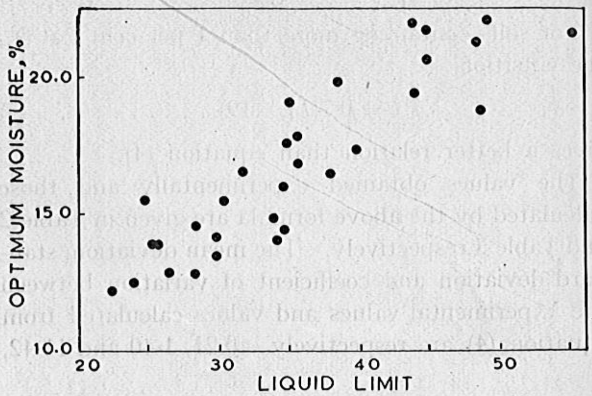

FIG. 3 — PLOT OF LIQUID LIMIT VERSUS OPTIMUM MOISTURE

Cooling and Skempton[7] have correlated the Atterberg limit with clay content. Clare has also plotted the relation between liquid limit, plastic limit and the clay content. A relation, on similar lines, for alluvial soils studied by the authors is shown in Figs. 4-6.

Skempton[8] has discussed three types of clays, viz. inactive, normal, and active, based on the relation between liquid limit and clay content. He found that the clays can be differentiated better on the basis of the relation between plasticity index and clay content[9]. The ratio *PI*/clay content has been defined as the activity of the clay. This activity is the least for kaolinite and maximum for montmorillonite, that of illite falling in between the two. The activity for quartz is zero while that of calcite and mica is less than that of kaolinite. Clays with activity less than 0·75 were defined as ' inactive ' and that between 0·75 and 1·25 were called ' normal '. ' Active ' clays have an activity above 1·25. The activity could thus be related to the mineralogical composition and to the geological history of clays and soils. According to Skempton, clays formed by normal weathering and deposited in fresh water seem to fall into a group with the activities between 0·5 to 0·75. Soils with activity less than 0·5 are late glacial clays derived largely from erosion of non-argillaceous rocks by ice

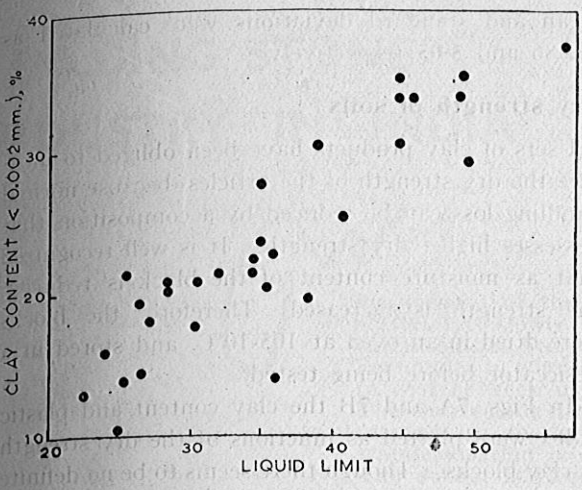

FIG. 4 — PLOT OF LIQUID LIMIT VERSUS CLAY CONTENT

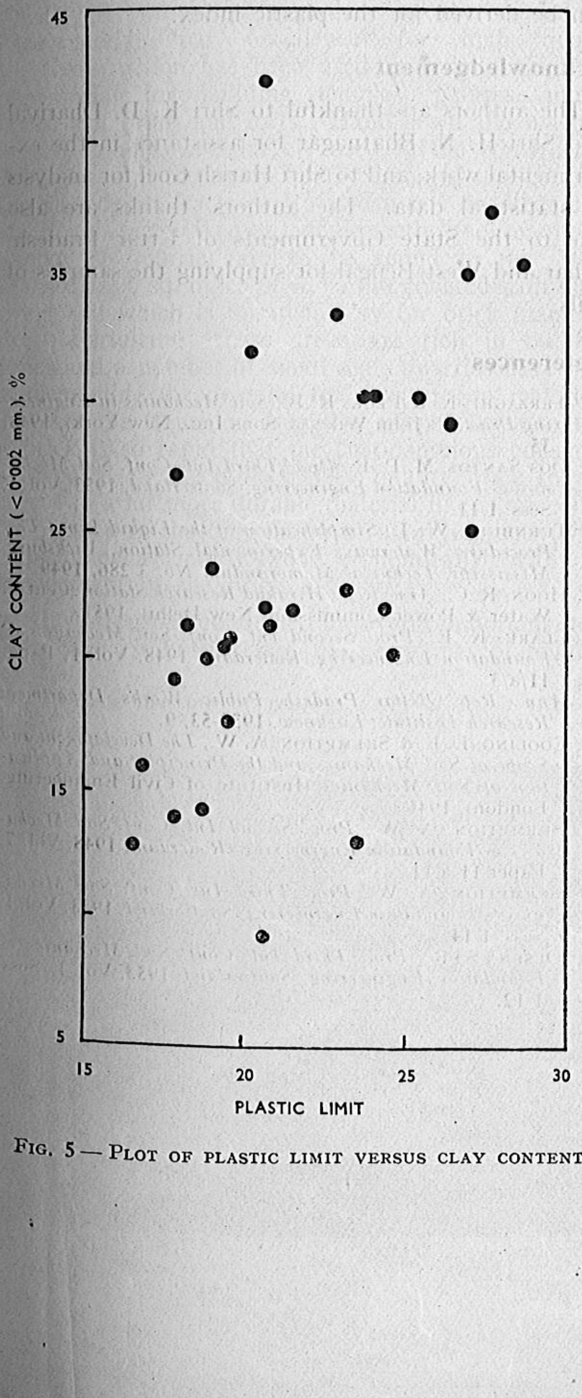

FIG. 5 — PLOT OF PLASTIC LIMIT VERSUS CLAY CONTENT

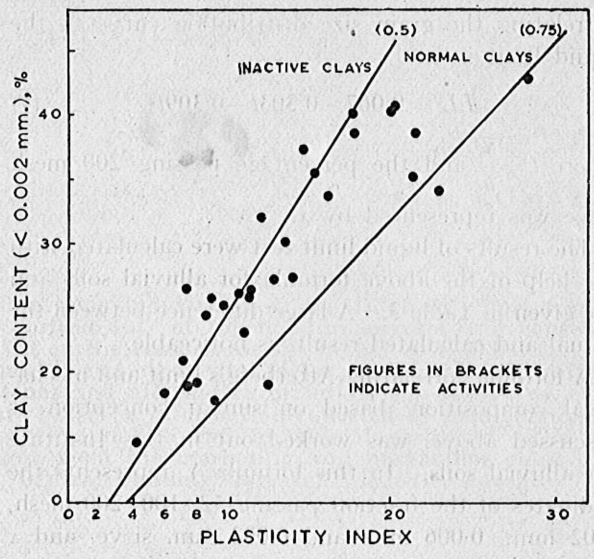

FIG. 6 — PLOT OF PLASTICITY INDEX VERSUS CLAY CONTENT

sheets and deposited in ice-dammed lakes. The activity of alluvial clays investigated in the present work was calculated and with the exception of only two samples all the soils fall within the group of inactive clays. Activity of some clays lies between 0·5 to 0·75 and of others below 0·5.

Olsen[10] has given statistics of the relation between Atterberg's limits and clay content of Norwegian soils containing above 20 per cent of particles in clay fraction. The graphic representation of plastic index as a function of material of particle size less than 2 microns best differentiates the Norwegian clays and correlation is represented by the following equation:

$$PI = \frac{U + 11 + C_3}{2{\cdot}8} \quad \ldots\ldots\ldots \ (6)$$

where U is the percentage of particles less than 2 microns. In ordinary clays the value of C_3 varies between 0 and ± 7. Clays in which C_3 is greater than 7 are either humus-rich or interglacial or sticky clays. Clays in which C_3 is less than -7 are more or less of a type poor in clay mineral. The values of C_3 as calculated by us for alluvial clays of the Gangetic plain are given in Table 3.

Dos Santos[2] worked out a new soil constant. This constant, a, is related to grain size distribution curve through the expression

$$a = \frac{\Sigma Y}{100N}$$

where Ys are the ordinates of grain size distribution curve corresponding to the percentage passing 7, 14, 25, 52, 100 and 200 mesh sieves. N is the number of ordinates which, in this formula, is 6. The formula correlating the grain size distribution curve to the liquid limit is

$$LL = 0{\cdot}067 - 0{\cdot}303t - 0{\cdot}309t^2 \quad \ldots\ldots \quad (7)$$

where $t = \frac{x}{a}$ and the percentage passing 200 mesh sieve was represented by x.

The results of liquid limit test were calculated with the help of the above formula for alluvial soils and are given in Table 3. A large difference between the actual and calculated results is noticeable.

A formula correlating Atterberg's limit and mechanical composition, based on similar conception as discussed above, was worked out in this Institute for alluvial soils. In this formula Y represents the ordinates of the fraction passing 52, 100, 200 mesh, 0·02 mm., 0·006 mm. and 0·002 mm. sieve, and x represents the percentage fraction of the soil below 0·002 mm. and the formula which correlates the liquid limit-grain size curve is given by the equation:

$$LL = 17{\cdot}61 + 0{\cdot}5006t + 0{\cdot}0015t^2 \quad \ldots\ldots \quad (8)$$

where $t = \frac{x}{a} \times 100$ and $a = \frac{\Sigma Y}{N}$

The values of liquid limit calculated by the above formula are given in Table 3. It may be pointed out that out of the total liquid limit determinations made, 88 per cent showed a difference of less than 10 per cent from the values by the actual test, compared to 87 per cent obtained by Dos Santos[2]. The mean and standard deviations were calculated as −1·86 and 5·05 respectively.

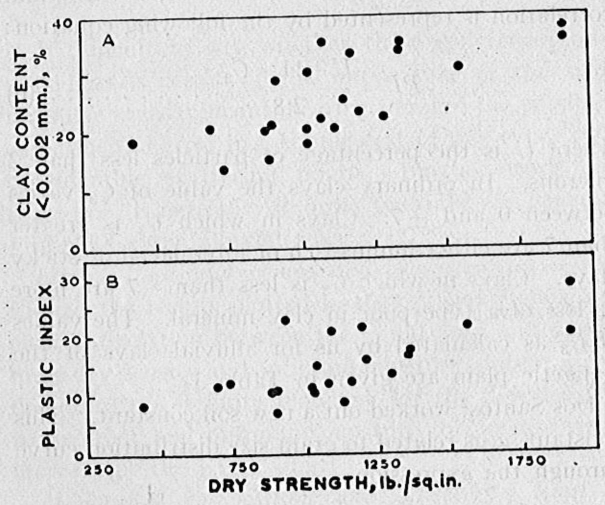

Fig. 7 — Trend of variation of dry strength with A, clay content (<0·002 mm.) and B, plastic index

Dry strength of soils

Users of clay products have been obliged to measure the dry strength of the articles, because normal handling loss can be reduced by a composition that possesses higher dry strength. It is well recognized that as moisture content of the block is reduced, the strength is increased. Therefore, the blocks were dried in an oven at 105-10°C. and stored in a desiccator before being tested.

In Figs. 7A and 7B the clay content and plastic index were plotted as functions of the dry strength of clay blocks. Though there seems to be no definite correlation between clay content and dry strength it seems that the greater the clay content, the greater is the dry strength of a soil. A similar conclusion can be derived for the plastic index.

Acknowledgement

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