Relationships between Shear Strength, Consolidation, Liquid Limit, and Plastic Limit for Remoulded Clays

Relations entre la résistance au cisaillement, la consolidation, la limite de liquidité et la limite de plasticité pour les argiles remaniées

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SUMMARY

The liquid limit of clays found in the U.A.R. has been studied. A wide range of clayey soils whose liquid limits varied from 190 to 32 was chosen. The shear strength at or very near the liquid limit was measured by a laboratory vane apparatus. These strengths enable the determination of the liquid limit from one test, that is, from one water content. The established relation between the undrained shear strength and corresponding consolidation serves to establish the correlation between the liquid limit and plastic limit. The latter can readily be obtained by knowing the liquid limit and the corresponding vane strength.

SOMMAIRE

On a étudié la limite de liquidité des argiles trouvées dans la R.A.U. Une grande variété de sols argileux a été choisie donnant des limites de liquidités de 190 à 32. La résistance à la limite de liquidité ou très pres d'elle est mesurée par un moulinet de laboratoire. Ces résistances servent à déterminer la limite de liquidité d'un seul essai correspondant à une teneur en eau. Les relations établies entre la résistance au cisaillement à teneur en eau constante et la consolidation correspondante servent à établir un rapport entre la limite de liquidité et la limite de plasticité. Cette dernière peut être obtenue rapidement en connaissant la limite de liquidité et la résistance au moulinet correspondante.

THE MEASUREMENT OF LOW SHEAR STRENGTH of saturated remoulded clays at water contents near or at the liquid limit can be done by means of a laboratory vane test. The size of the vane sample together with the size of the blades of the vane determine the proper evaluation of strength. For a 2 cm × 1 cm laboratory vane and a 3-cm thick sample, the diameter of the sample should not be less than 7.5 cm. Fig. 1.

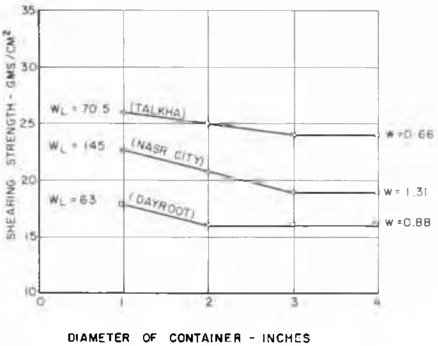


FIG. 1. Effect of the diameter of the container on the shearing strength of remoulded clays.

Twenty-nine soil samples from various localities in the U.A.R. have been studied (see Table I). These soils ranged from clayey silts (liquid limit, 32; plastic limit, 24) to clays.

TABLE I. LOCATIONS AND DESCRIPTIONS OF SAMPLES

No.	Locality	Description	Depth of sample in m
1	Shibin El-Kom	stiff brown clay	3.80
2	Shibin El-Kom	stiff darkish clay	7.20
3	Faraskor	medium darkish clay	2.40
4	Faraskor	soft dark clay	9.50
5	Cairo	stiff brown clay	8.60
6	Alexandria	soft dark clay	1.50
7	Qina	brown clay	—
8	Dayroot	soft dark clay	16.60
9	Dayroot	soft dark clay	14.60
10	Talkha	soft dark clay	8.70
11	Abu Zenema	silty clay	2.50
12	Abu Simbel	silty brown clay	4.00
13	Alexandria	very soft grey clay with broken shells	4.50
14	Zawyet Ghazal	medium to stiff brown clay	5.50
15	Zawyet Ghazal	stiff dark clay	7.60
16	Cairo west	stiff brown clay	5.30
17	Talkha	soft dark clay	8.70
18	Port Said	soft dark clay	24.00
19	Port Said	soft dark silty clay	—
20	Cairo south	stiff brown clay	4.50
21	Qalyuob	stiff brown clay	3.70
22	Qalyuob	medium to stiff dark clay	10.30
23	Qalyuob	medium to stiff dark clay	9.20
24	Tanta	brown clay	4.70
25	Nasr city-Cairo	brown clay	—
26	El Shallofa	grey laminated hard clay	—
27	Kom ombo	darkish silty clay	—
28	High dam	Aswan clayey silt	—
29	El Maasarah	hard brownish clay	—

For each soil the liquid limit was determined according to Casagrande's standard procedure together with the vane strength at the liquid limit and at water contents near to it.

TABLE II. SOME PHYSICAL PROPERTIES OF TWELVE U.A.R. CLAY SAMPLES

No.	Locality	Description	w_L	w_P	I_P	Clay fraction	τ_f at w_L grams/sq.cm.	Activity	C_c calculated from test
1	Cairo	dark clay	69	32.5	36.5	14	17.8	2.6	0.48
2	Tanta	brown clay	86	25	61	11	17.0	5.5	0.66
3	Cairo west	brown clay	72	27	45	17	17.5	2.65	0.54
4	Qalyuob	brown clay	67	25.8	41.2	5	17.5	8.2	0.57
5	Qalyuob	dark clay	70	25	45	8	17.8	5.6	0.49
6	Alexandria	dark clay	77	36.8	40.2	11	18	3.65	0.50
7	Talkha	dark clay	80	39.2	40.8	13	20	3.15	0.45
8	Abu Zenema	silty clay	33	20.5	12.5	5	28	2.5	0.16
9	El Shallofah	grey laminated hard clay	85	30	55	32	17	1.7	—
10	Kom ombo	darkish silty clay	61	23	38	10	19	3.8	—
11	High dam	Aswan clayey silt •	32	24	8	13	25	0.62	—
12	El Maasarah	hard brownish clay	190	38	152	80	13	1.9	—

For twelve samples the grain size distribution was determined and the activity (I_P/clay fraction) was calculated (see Table II).

If the water content *versus* the shear strength of the clay samples corresponding to the range of water contents of ($w_L \pm 0.15\ w_L$) are plotted on a double log scale, a group of straight lines, each representing one sample are obtained (Fig. 2). Points corresponding to the liquid limit of each soil can be joined by a straight line called the w_L line for convenience. This line shows clearly that although the strength at liquid limit is essentially small, a big relative difference is to be noticed (Fig. 3). The straight lines are nearly parallel for all samples (within the range of water contents adopted) and can be considered to have an average slope of $\beta = (\log \tau_f - \log \tau_{f1})/(\log w_1 - \log w) = 5.9$, where $w_1 = w\ (\tau_f/\tau_{f1})^{0.17}$.

Fig. 4 is used to determine the liquid limit in terms of the vane strength at water contents near to the liquid limit by one test for one water content as illustrated in Fig. 3. By knowing the shear strength τ_f of a remoulded sample and the water content corresponding to this strength which is represented by point (1) in Fig. 3, the liquid limit can be determined, which represents the water content at point (3) as illustrated by dashed path 1-2-3.

From the data by Skempton (1957) and others, it is possible to establish the relationship between the ratio of undrained strength to the corresponding overburden pressure C_u/P and the plasticity index (I_P) of the soil:

$$C_u/P = 0.11 + 0.0037\ (I_p) \qquad (1)$$

where (I_P) is expressed as a number rather than a ratio.

Again from consolidation test data on eight soils (Table

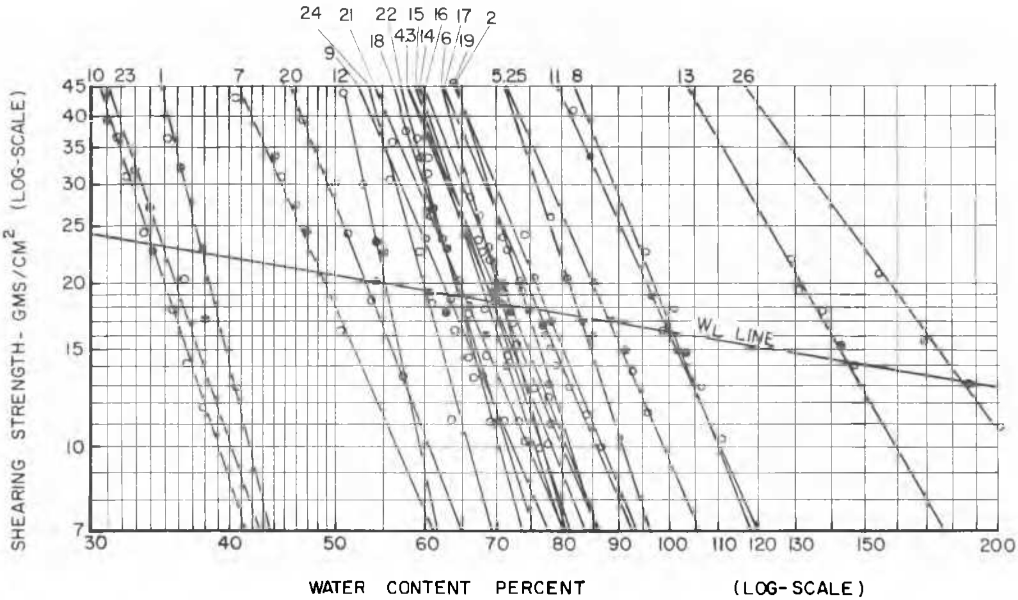


FIG. 2. Relation between moisture content and shearing strength.

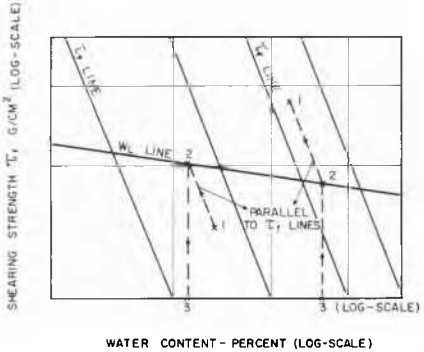


FIG. 3. Determination of liquid limit from vane shear strength at a moisture content near the liquid limit.

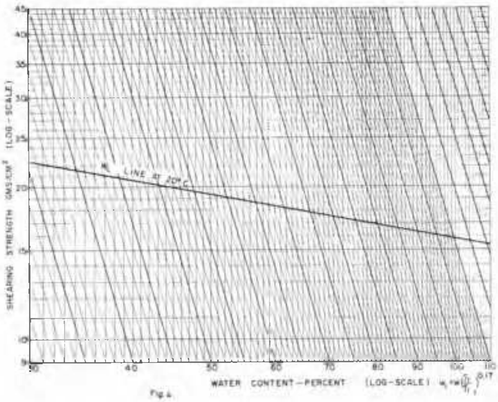
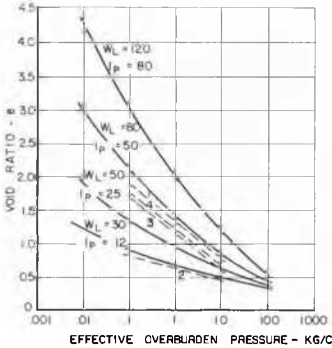


FIG. 4. Relationship between shearing strength, moisture content, and liquid limit.



① TO OBTAIN WATER CONTENT DIVIDE VOID RATIO BY SPECIFIC GRAVITY OF PARTICLES (= 2.7)

② FULL LINE CURVES AFTER (A.W. SKEMPTON - 1953)

③ FOR CLARITY CURVES 5, 6, 7 AND 8 ARE OMITTED

④ EGYPTIAN SOILS (BROKEN LINES)

	W_L	I_P
1	86	61
2	33	12.5
3	70	45
4	67	41.2

FIG. 5. Curves of the approximate relation between void ratio and overburden pressure for clay sediments as a function of the Atterberg limits.

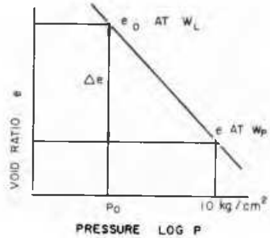


FIG. 6. Determination of plastic limit from void ratio and strength at liquid limit.

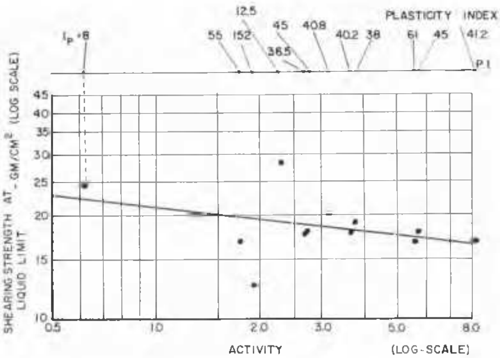


FIG. 7. Relationship between shearing strength and activity.

II) as well as from data by Skempton and from other data on remoulded clays, it is found that the void ratio e corresponding to the plastic limit is reached at pressures ranging between 9 and 11 kg/sq.cm. (Fig. 5). For convenience consider this pressure to be 10 kg/sq.cm. Hence from Fig. 6:

$$\Delta e = C_c\ (\log 10 - \log P_0)$$

$$\Delta e/S_s = (C_c/S_s)\ (1 - \log P_0)$$

but $$\Delta e/S_s = I_P$$

therefore $$I_P = (C_c/S_s)\ (1 - \log P_0) \qquad (2)$$

where $C_c = .007\ (w_L - 10)$ using $S_s = 2.7$.

In equation (2) the value of (I_P) is essentially inserted as a fraction. Equations (1) and (2) give the estimated consolidation pressures corresponding to the liquid limit and the plasticity index. For convenience the two equations can be solved by trial, making use of the relationship between activity and shear strength at liquid limit (Fig. 7) on which values of I_P are indicated. The irregular sequence of values of I_P in Fig. 7 is a result of the lack of correlation between

TABLE III. MEASURED VERSUS CALCULATED VALUES OF PLASTIC LIMIT

No.	Locality	Liquid limit	Plastic limit, standard test	Plastic limit (at P = 10 kg/sq. cm.)	Plastic limit calculated from eqn. (1) and (2)
1	Qalyuob	67	25.8	27	35.5
2	Cairo	69	32.5	28.5	36.5
3	Qalyuob	70	25	28.5	34
4	Alexandria	77	36.8	30	39.5
5	Tanta	86	25	30	42
6	Talkha	80	39.2	32.5	41
7	Cairo west	72	27	29	31.5
8	Abu Zenema	33	20.5	17	22.5

activity and I_P, or from the relationship $I_P = 0.73\ (w_L - 20)$.

Table III shows the actual values of plastic limit determined by standard tests and those calculated from equations (1) and (2) and also from curves at P = 10 kg/sq.cm.

CONCLUSION

The undrained shear strength of remoulded clay at a water content near to the liquid limit serves to determine the liquid limit value of the soil by means of only one test. The (e-log p) curves for various remoulded clays characteristically show that most of the clays tested, as well as other clays, reach their plastic limit when consolidated at a pressure near to 10 kg/sq.cm. This relationship made it possible to determine the plastic limit from the value of the liquid limit and the value of strength at the liquid limit. The "consolidation pressure" causing the clay to change from a colloidal sediment to the liquid limit state can readily be obtained and is not equal to zero.

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