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Some Observations of Coefficient of Permeability of Reconstituted Fined Grained Soils

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Abstract- Permeability data of reconstituted normally consolidated saturated soils were studied. As found in literature the values of coefficient of permeability of soils at their liquid limit water content are confined within a narrow range. It has been shown in the present work that values of coefficient of permeability of soils at their plastic limit water contents are also confined within a narrow range. Coefficient of permeability has been expressed as a function of liquidity index of the soils. A method of predicting the coefficient of permeability is also presented. Using two constants related to the liquid limit, the coefficient of permeability can be determined for any value of consolidation pressure.

I. INTRODUCTION

Permeability is a very important physical parameter of soil as some of the major problems of soil mechanics are connected with it. Following Terzaghi and Peck (1967) it may be stated that permeability of a soil along with its compressibility and shear strength characteristics constitutes 'foremost' properties in soil engineering. With its direct influence on seepage, shear strength and consolidation, permeability of soils has a decisive effect on the cost and difficulty of many construction operations. Of late soil permeability has assumed added importance with increasing emphasis given on combating environmental degradation through soil pollution. In this work some observations of permeability behaviour of reconstituted normally consolidated saturated soils are reported in relation to the consistency limits of the soils.

II. REVIEW OF LITERATURE

Griffiths and Joshi (1989) presented pore size distribution patterns for four soils at liquid limit water content, which show the same range of pore diameter, though the liquid limit values vary from 29% to 100%.

Pandian, Nagaraj and Sivakumar Babu (1993) stated that permeability is an indirect reflection of microstructure and more importantly indicates the flow-rate which depends upon the pore geometry. The authors stated that the observation of Griffiths and Joshi (1989) suggested that the flow rate at liquid limit state should be of the same range/order. To verify these observations the authors conducted permeability test at liquid limit state in a set up in which soils at liquid limit consistency were included and flow monitored. The findings obtained by the authors presented values of coefficient of permeability values at the liquid limit states which ranged from 1.65 $x10^{-7}$ cm/sec to 2.83 $x10^{-7}$ cm/sec for air dried and dried soils.

Nagaraj, Pandian and Narasimha Raju (1993, 1994) presented values of coefficient of permeability at the liquid limit states which ranged from 1.28 $x10^{-7}$ cm/sec to 3.4 $x10^{-7}$ cm/sec. The coefficient of permeability values were obtained from plots of velocity against hydraulic gradient for soils at liquid limit water content.

Nagaraj, Pandian and Narsimha Raju (1991) presented permeability coefficient at liquid limit for several clays which were also quoted by Mitchell (1992).

Hence it is observed that the values of permeability coefficient are of the same range/order at liquid limit. It is the object of the present study to see whether the same range/order of permeability occurs at plastic limit also and therefore whether a fixed magnitude of variation occurs in permeability between plastic limit and liquid limit.

Sivappullaiah et al. (2000) have correlated permeability of sand–bentonite mixtures from their void ratio (e) and liquid limit (w_L) given by equation (1):

$$\log_{10}k = (e - 0.0535w_L - 5:286)/(0.0063w_L + 0.2516) \qquad (1)$$

Nagaraj et al. (1993) also attempted to generalize the prediction of coefficient of permeability with the void ratio at liquid limit as shown by equation (2):

$$e/e_L = 2.28 + 0.233 \log_{10}k \qquad (2)$$

Sharma and Bora (2009) also obtained the relation between e/e_L and $\log_{10}k$ as follows

$$e/e_L = 3.606 + 0.392 \log_{10}k \qquad (3)$$

Another objective therefore is also to see the relation between permeability and easily determinable index properties of soil like liquid and plastic limit of soils and whether any correlation exists between permeability and liquid and plastic limit of soils.

III. METHODOLOGY

To determine permeability characteristics of soil, the conventional fixed ring consolidation cell is used. This method is appropriate for the determination of permeability of reconstituted normally consolidated soils. Slurry consolidation test were performed by reconstituting the soils at a water content slightly greater than their liquid limit water contents. The reconstituted soils were kept for a minimum period of 24 hours for uniform distribution of moisture. The reconstituted slurry was then transferred to oedometer rings. Consolidation test was carried out using a loading sequence of 0.05 kg/cm^2, 0.1 kg/cm^2, 0.2 kg/cm^2, 0.4 kg/cm^2, 0.8 kg/cm^2, 1.6 kg/cm^2, 3.2 kg/cm^2 and 6.4 kg/cm^2.

At each pressure, after equilibrium was achieved, falling head permeability tests were performed to determine the coefficient of permeability of the soil. A thin layer of kerosene over the water was placed so as to prevent evaporation of water. The coefficient of permeability was determined from the experimental data.

Thirteen fined grained inorganic soils having classification CL, CI and CH were used in the investigation. These thirteen soils were also used for the determination of coefficient of consolidation from index properties of soils (Sharma and Bora, 2009). Plastic limit of the soil was determined by the cone penetration method by taking the shear strength at plastic limit to be 100 times the shear strength at liquid limit (Sharma and Bora, 2003,2004). As mentioned in methodology, the consolidation test was done together with the results of the falling head permeability test performed at the end of each load increment. A plot of void ratio e versus $\log_{10}$ (k) is approximately a straight line both for coarse grained and fine grained soils (Taylor 1948, Lamb and Whitman 1973). This straight line relationship between e and $\log_{10}$ (k) for the soils is presented from Fig. 1 to Fig.5.

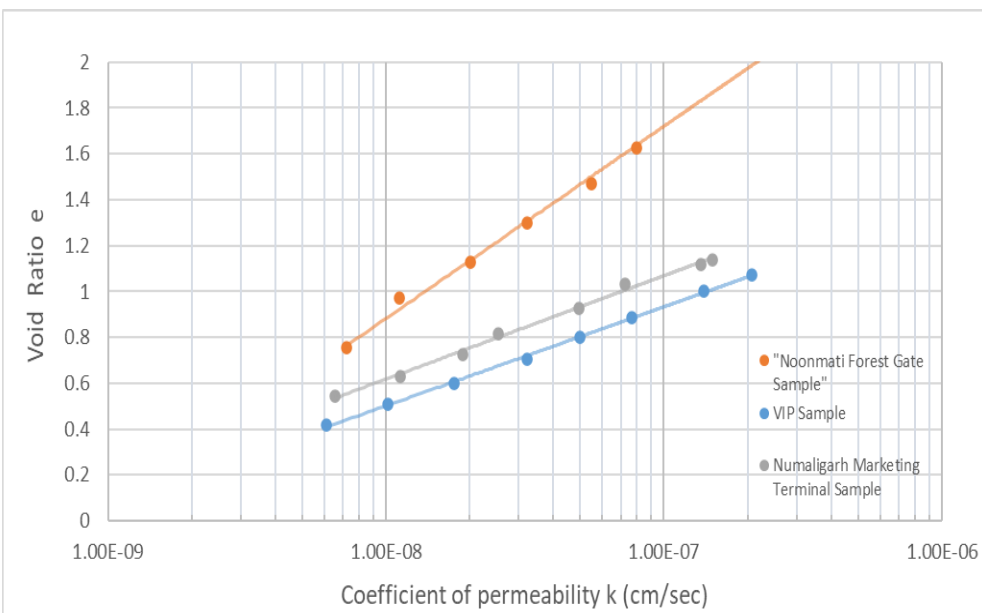

Figure. 1 e vs $\log_{10}$ k plot

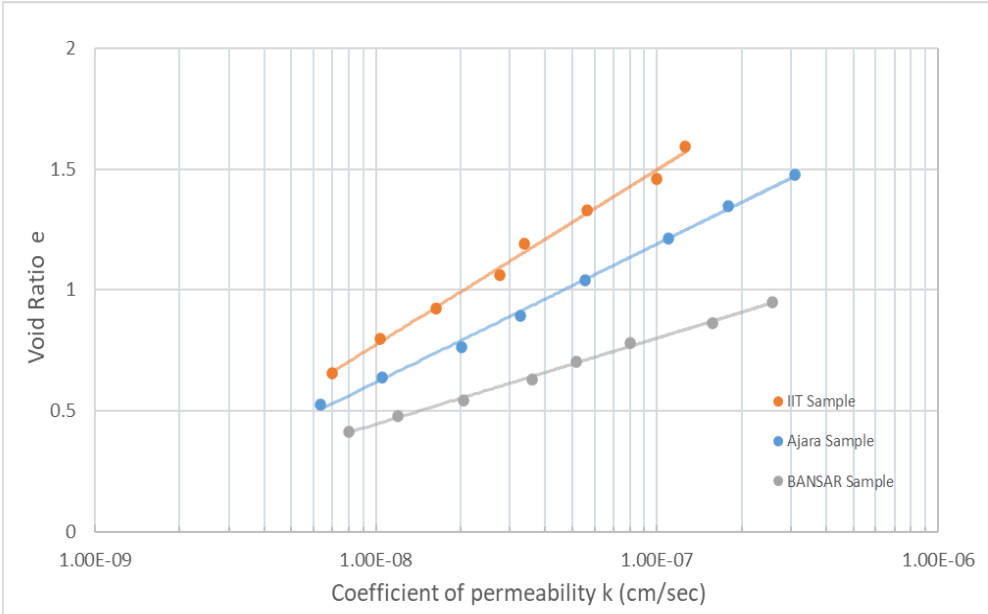

Figure.2 e vs $\log_{10}$ k plot

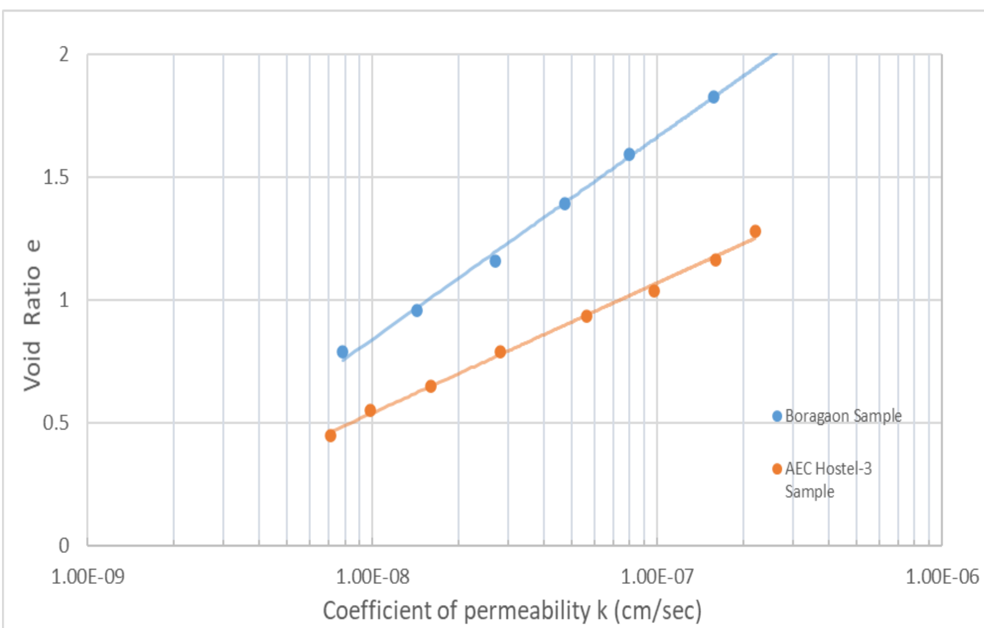

Figure.3 e vs $\log_{10}$ k plot

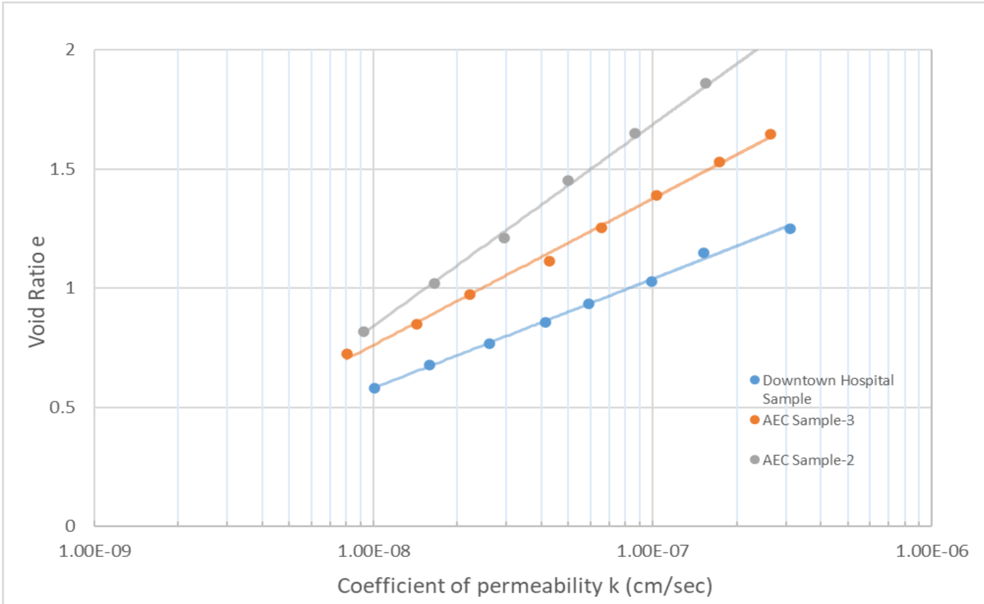

Figure. 4 e vs log k_{10} plot

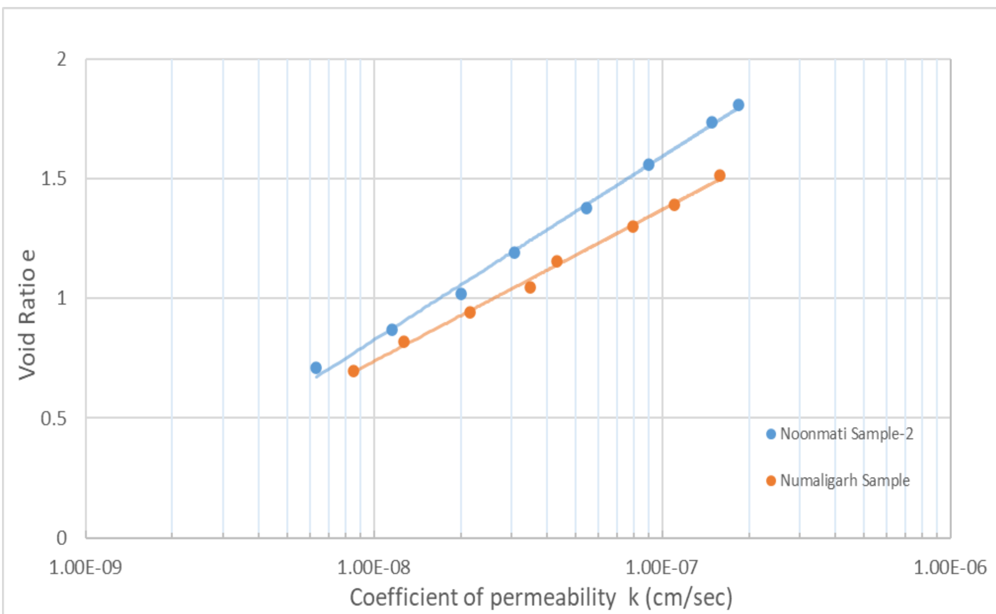

Figure. 5 e vs log k_{10} plot

Coefficients of permeability (k) values were obtained from the plots of e versus log k for the soil at the liquid limit void ratio (e_L) and hence at liquid limit water contents. Similarly, k values were obtained from the same plots at plastic limit void ratio (e_p) and hence at plastic limit water contents. The results are tabulated in Table 1. It is observed from the Table 1 that at liquid limit, the coefficient of permeability at liquid limit ranges from $1.28x10^{-7}$ cm/sec to $3.2x10^{-7}$ cm/sec. This range is consistent with the range given by Nagaraj et al (1991, 1993, and 1994) and quoted by Mitchell (1992). This lends evidence to the fact that at liquid limit water content coefficient of permeability varies within a narrow range.

Table 1: Physical properties and values of permeability at liquid limit and plastic limit of the soils

Sl. No.	**Liquid limit (w_L) (%)**	**Specific Gravity G_s**	**Void ratio at liquid limit e_L**	**Permeability at liquid limit (cm/sec)**	**Plastic limit w_p (%)**	**Void ratio at plastic limit e_p**	**Permeability at plastic limit (cm/sec)**
1	77	2.68	2.064	2.54E-07	28	0.750	7.11E-09
2	38.5	2.63	1.013	1.5E-07	17	0.447	7.37E-09
3	42	2.65	1.113	1.28E-07	20	0.530	5.64E-09
4	60	2.71	1.626	1.42E-07	24.2	0.656	6.9E-09
5	52.5	2.71	1.423	2.55E-07	21	0.569	7.91E-09
6	33.8	2.68	0.906	1.95E-07	16	0.429	8.89E-09
7	76	2.74	2.082	3.2E-07	29.5	0.808	8.7E-09
8	45.8	2.65	1.214	1.87E-07	16.2	0.429	6.62E-09
9	44	2.70	1.188	2.2E-07	16	0.432	1.43E-09
10	61	2.68	1.6348	2.6E-07	22.5	0.603	1.77E-09
11	78	2.71	2.114	3.1E-07	29.5	0.799	8.62E-09
12	69	2.72	1.877	2.16027E-07	24	0.653	4.41E-09
13	56	2.69	1.509	1.56E-07	24.2	0.652	6.99E-09

As already stated Griffith and Joshi (1989) showed that at liquid limit water content, soils have the same range of pore diameter. This observation suggested that the flow rate at liquid limit state should be of the same order. This property of soil has been attributed to the existence of the same pattern of microstructure at liquid limit state of soil (Nagaraj et al, 1994). In the present work coefficient of permeability was also determined at plastic limit which was found to vary from $5x10^{-9}$ cm/sec to $9.75x10^{-9}$ cm/sec (Table 1) giving a variation of 95 percent. In contrast, the variation in coefficient of permeability at liquid limit in the same Table was found to be 150 percent. This show that the variation in coefficients of permeability at plastic limit is even less than that at liquid limit implying thereby that if coefficient of permeability is of the same order at liquid limit so it is at plastic limit. In the present study it has been found that at plastic limit, coefficient of permeability which is of the same order (average values $7.25x10^{-9}$ cm/sec from Table 1) is about thirty times less than at liquid limit (average value $2.15x10^{-7}$ cm/sec from Table 1). Using the average values of soil permeability at liquid limit and plastic limit and using the log-linear relationship between void ratio (e) and coefficient of permeability (k) as witnessed in Figs. 1 to 5, a correlation has been developed as follows between permeability and liquidity index of soils.

e=eP+eL-ePlog 2.15×10-7-log 7.25×10-9 log k7.25×10-9

Or e-eP=eL-ePlog 2.15×10-7-log 7.25×10-9 log k7.25×10-9

e-ePeL-ePlog 30 =log k -log 7.25×10-9

log k =log 7.25×10-9 +e-ePeL-ePlog 30

log k =-8.139662+1.4771213×L.I. (1)

The above equation (1) shows that coefficient of permeability (*k*) is a log-linear function of the liquidity index of the soil. Since liquidity index itself is a normalising parameter, the above equation implies that *k* value at a particular liquidity index will be of the same order. This relationship between liquidity index and log of permeability is shown in Figure 6.

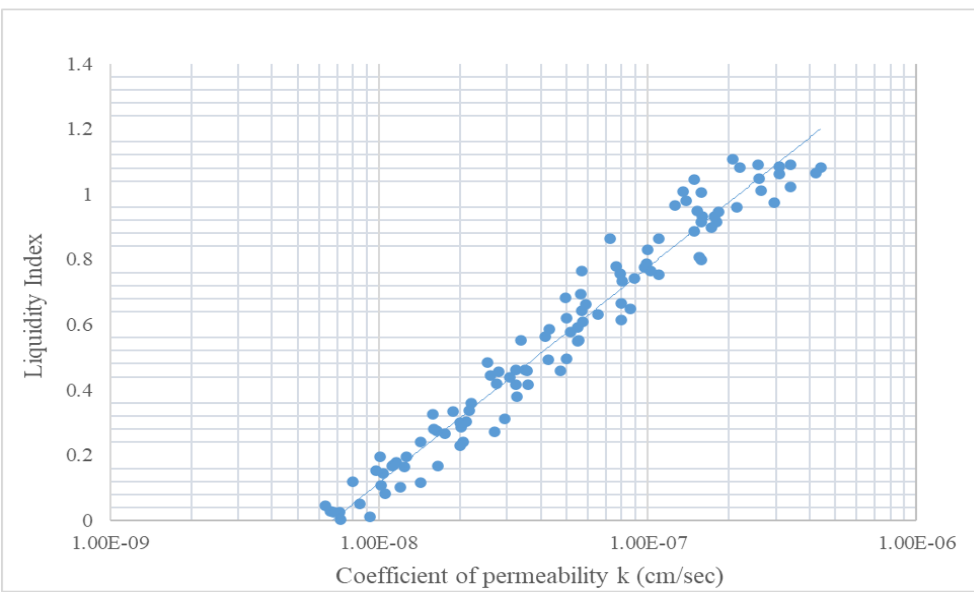

Figure.6 Relation between liquidity index and coefficient of permeability

It was noticed that irrespective of the different liquid limit of the soils a linear relationship between void ratio and log of permeability was obtained of the soil samples. The relationship between e and $\log_{10}k$ can be expressed by equation (2)

Void Ratio (e) = (m) * $\mathrm{Log}_{10}k$ + C

or Log k = [e – C] / m (2)

where m is the slope and C is the intercept of the equation respectively and e is the void ratio at which *k* is required. The slope and intercept were determined for all the soils and it was found that the slope and the intercept increases with the increase in liquid limits of the soils. It was also found that the slope and intercept were independently related to the liquid limits of the soils. These relationships are shown in Fig.7 and Fig.8.

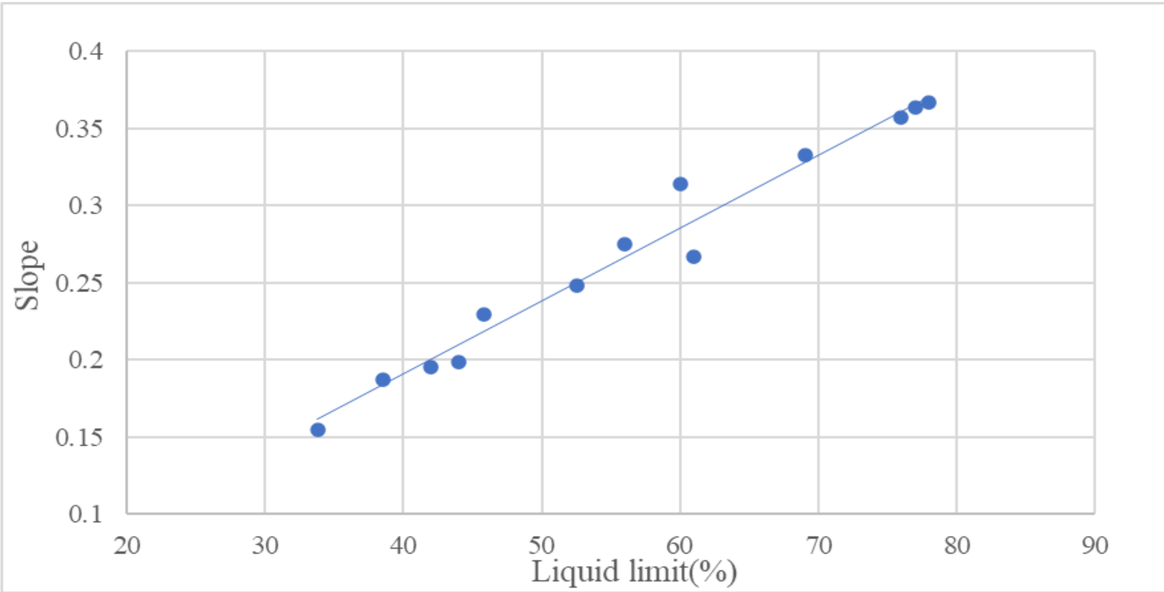

Figure.7 Relation between slope and liquid limit (slope from e vs $\log_{10}$k)

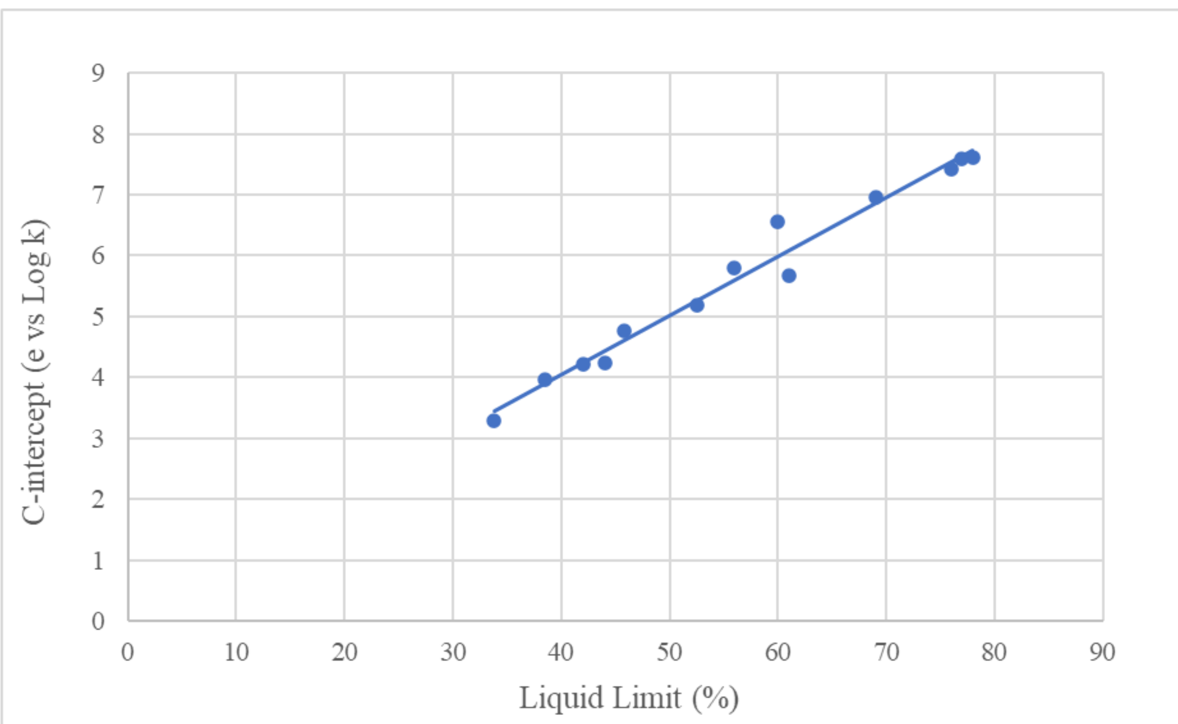

Figure.8 Relation between intercept and liquid limit.(intercept from e vs $\log_{10}$k)

From Fig. 7, m can be obtained as

$$m = 0.047 * LL + 0.001 \quad (3)$$

with a correlation coefficient R = 0.98 and from Fig.8, intercept C is obtained as

$$C = 0.0965 * LL + 0.1886 \quad (4)$$

with a coefficient of correlation R = 0.98.

Substituting the values of m from eq. (3) and C from eq. (4) in eq. (2), equation 5 is obtained.

$$\text{Log}_{10} k = [e - (0.0965 * LL + 0.1886)] / (0.047 * LL + 0.001) \quad (5)$$

where k is in cm/sec.

Knowing the liquid limit of the soil, at any void ratio, equation (5) can be used to predict the coefficient of permeability of the soil. Fig.9 and Fig.10 show the experimental and the predicted values based on equation (5). Similar observation were seen in all the soils.

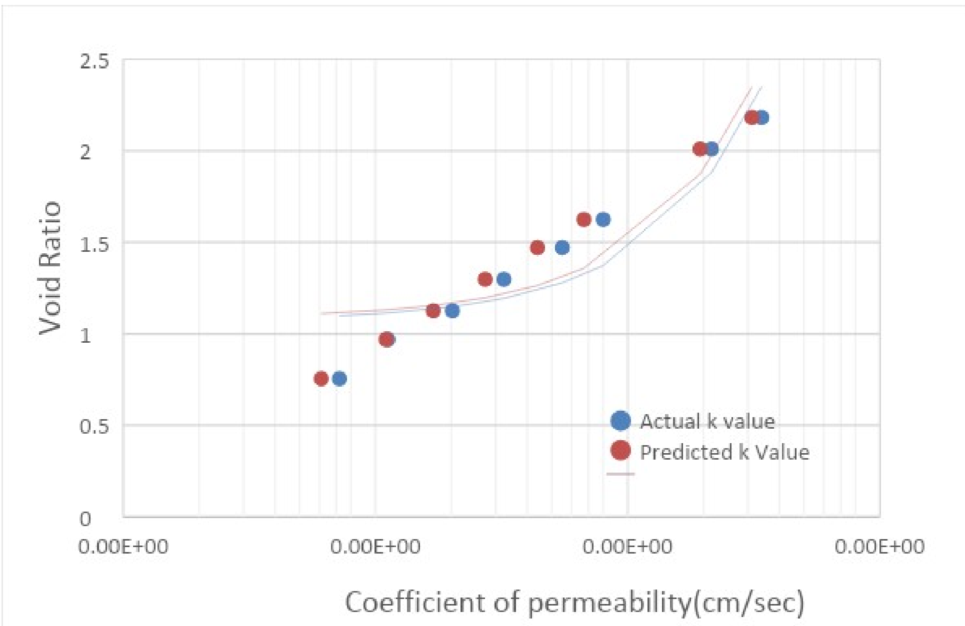

Figure.9 Experimental and the predicted curve for sample 1from equation 5.

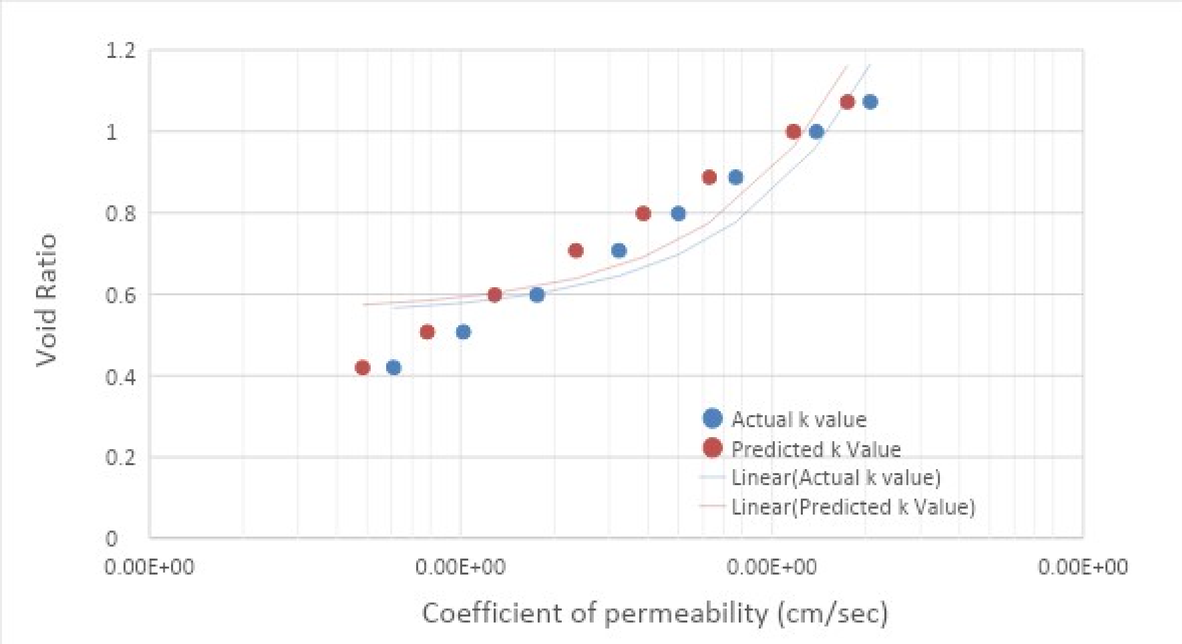

Figure.10 Experimental and the predicted curve for sample 2 from equation 5

Again the the relationship between e and $\log_{10}P$, where P is the consolidation pressure, for the reconstituted soils are shown in Fig 11 and Fig.12.
All the thirteen soils show similar trend. This straight line relationship can be expressed by equation (6)

$$\text{Void Ratio (e)} = -(m) * \text{Log}_{10}P + C \qquad (6)$$

where m is the slope and C is the intercept of the equation In this work also, the slope which is the compression index, correlates very well with the liquid limit of the soils as shown in Fig.13. The relationship between slope and liquid limit is shown in equation (7).

$$\text{Slope} = -0.0042*LL + 0.0387 \qquad (7)$$

With a correlation coefficient, R= 0.97.

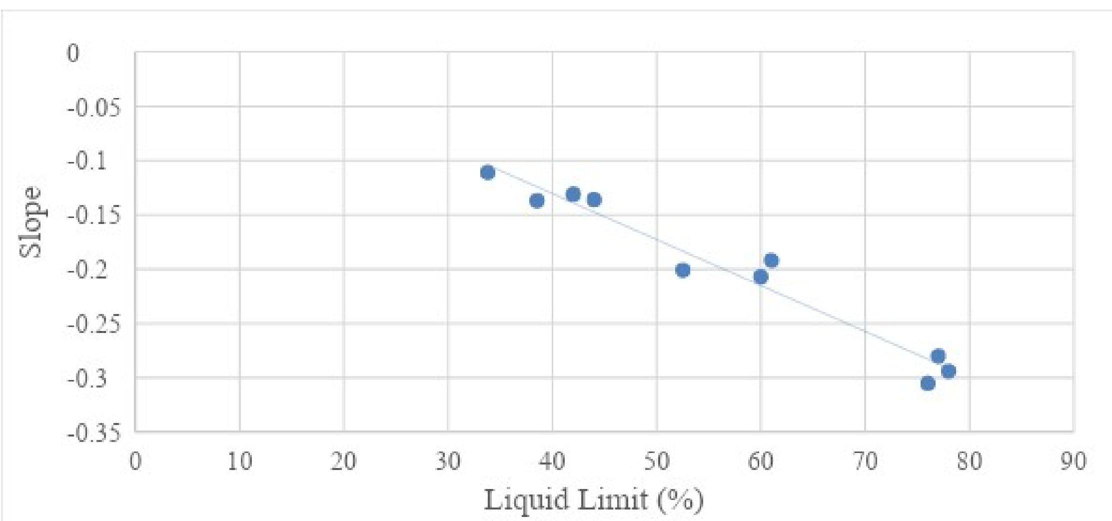

Figure. 13 Slope versus liquid limit (slope from e- $\log_{10}$ P)

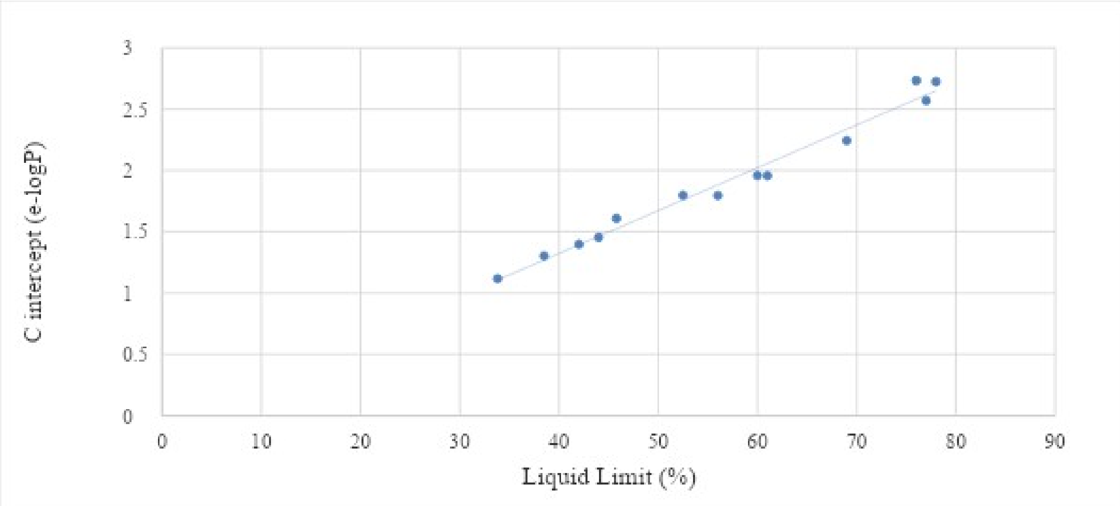

Figure.14. Intercept versus Liquid limit (intercept from e-log_{10}p)

Similarly the relation of the intercept C with the liquid limit of the soils is shown in Fig. 14. This relationship is shown in equation (8).

C = 0.0349* LL - 0.0747 (8)

Coefficient of correlation obtained is R = 0.99

Putting the values of eq.(7) and eq.(8) in eq.(6) equation (9) is obtained.

e = (-0.0042*LL + 0.0387) * Log P_{10} + (0.0349* LL - 0.0747) (9)

From equation (9), the value of void ratio (e) can be determined from liquid limit (LL) of the soil samples corresponding to different values of consolidation pressure (P). Again, equation (5) predicts the value of coefficient of permeability (k) from the corresponding void ratio (e) and liquid limit (LL) of the soil. Thus, by putting the value of void ratio (e) from equation (9) in equation (5), we get the predicted value of coefficient of permeability from only the liquid limit of the soils corresponding to different consolidation pressure. These predictions and its agreement with the experimental values are shown in Fig. 15 and Fig.16.

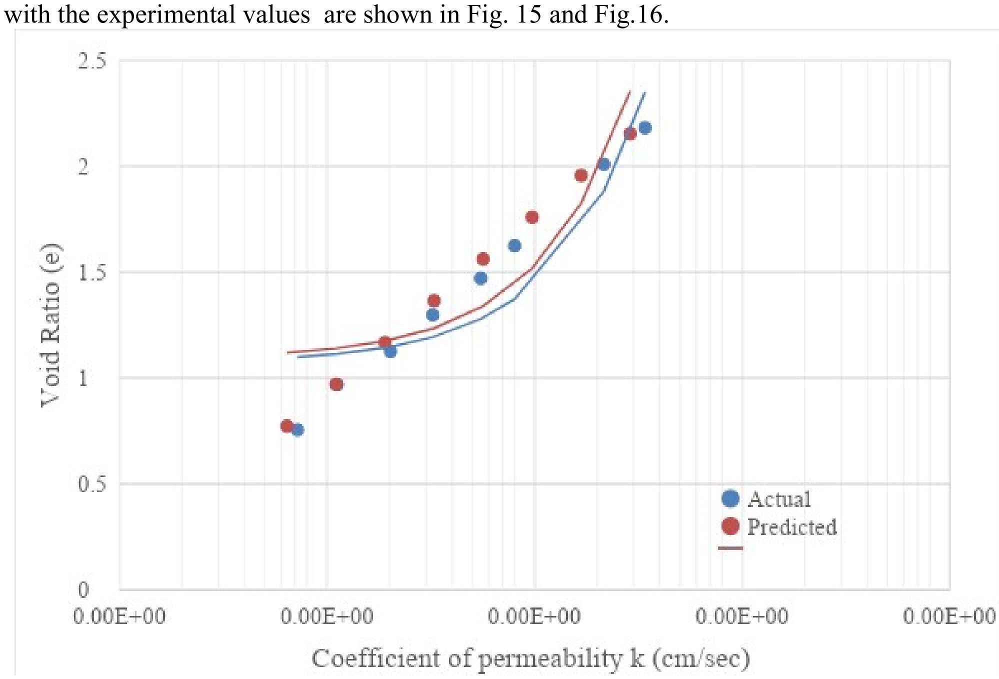

Figure.15 Experimental and the predicted curve for sample 1

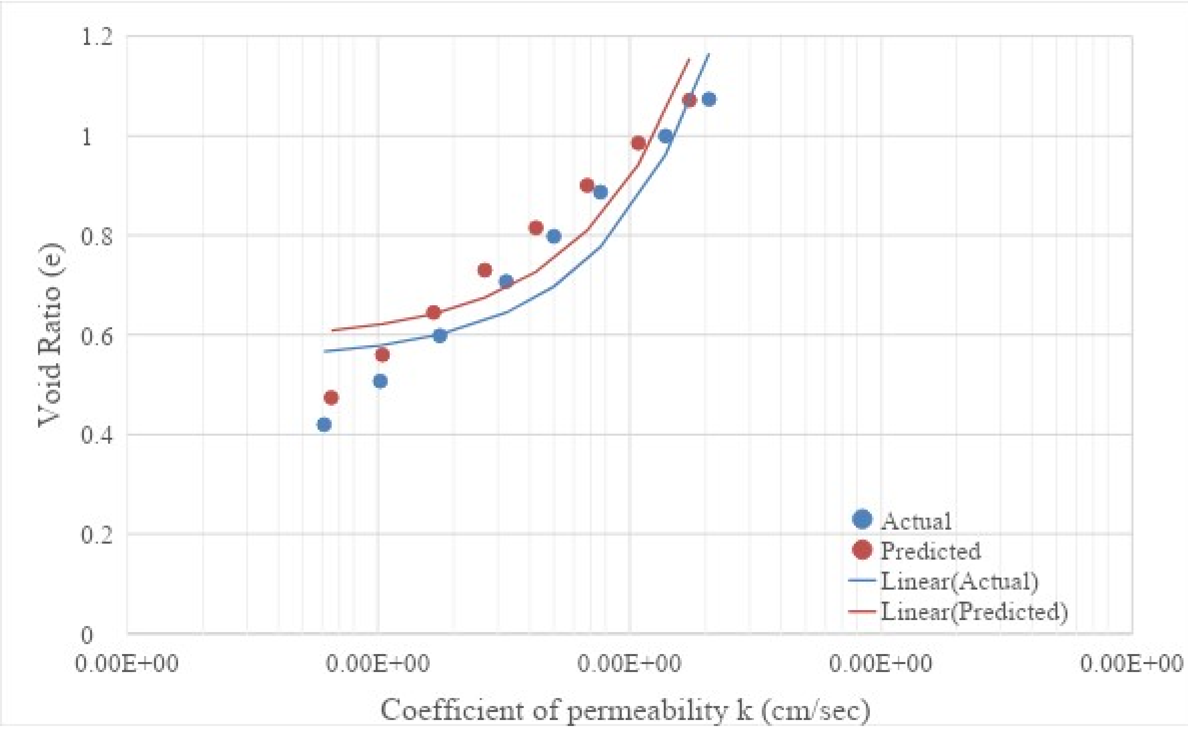

Figure.16 Experimental and the predicted curve for sample 2.

However it is to be noted that these assessments are valid only for slurry consolidated reconstituted soils and hence possessing similar microstructure. The permeability of compacted soils, subsequently saturated may not follow these relations because of their different microstructure

IV. CONCLUSIONS

The analysis presented here of permeability data of reconstituted normally consolidated saturated clays describe an approach in the investigation of permeability response of clays.The study shows that values of coefficient of permeability of soils at their liquid limit water content are confined within a narrow range of $1.28x10^{-7}$ cm/sec to around $3.2x10^{-7}$ cm/sec. Similarly values of coefficient of permeability of soils at their plastic limit water content are confined within a narrow range of $5x10^{-9}$ cm/sec to $9.75x10^{-9}$ cm/sec. Coefficient of permeability was found to be a function of liquidity index of the soils. Correlations were also developed between coefficient of permeability and liquid limit of the soils. For a soil of known liquid limit, the coefficient of permeability with consolidation pressure can be obtained from the above correlations. However it is to be noted that these assessments are valid only for slurry consolidated reconstituted soils and hence possessing similar microstructure. The permeability of compacted soils, subsequently saturated may not follow these relations because of their different microstructure.

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