Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

Hydraulic Conductivity of Compacted Fine Grained Soils and its Significance in Hydraulic Structures

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Abstract: The permeability behaviour of compacted fine-grained soils is of great practical importance. The permeability behaviour of compacted Kaolinitic soils and Montmoril- lonite soils have been carried out for the present experimental study, for the IS Light and Heavy compaction energy levels. One dimensional consolidation experiment has been carried out cor- responding to $0.95\rho_{dmax}$ on dry side of optimum, optimum and $0.95\rho_{dmax}$ wet of optimum moisture content, for the pressure ranging from 6.25 to 1600 kPa and the Consolidation parameters like C_v, m_v were compared for different energy levels and liquid limit. The soils compacted on dry side of optimum are exhibiting higher values of K than wet of optimum condition. Due to the influence of fabric on consolidation process, kaolinitic soils are having higher K than that of Montmorillonitic soils, irrespective of the clay mineralogical composition. IS Heavy compaction energy level gives lower value of K than Light compaction energy level. The magnitude of computed K from the conventional equation is always lesser than the experimental one and also it was influenced by the clay mineralogical composition, for both low and high liquid limit soils.

Keywords: Compacted; Clay mineralogical composition; Fine-grained soils, Permeability

1. Introduction

In most of the construction activities taking place across the globe, the superimposed loads, static or dynamic, finally get transferred to the geological formations beneath them, soil being one of the two widely encountered geological formations. The study of fine-grained soil is a fascinating subject and has attracted the attention of many researchers. Fine-grained soils predominantly comprise of sands, silts and clay size fractions. The fine fractions of soils are normally composed of clay minerals, which form the active components of fine-grained soils. While the Kaolinite is the least active clay mineral and Montmorillonite being is the most active clay mineral. The behavior of other clay minerals occupies the intermediate positions.

The present study aims at computing and analyzing hydraulic conductivity of fine-grained soils using the consolidation characteristics of compacted fine-grained soils with varying compaction energy levels, placement conditions and also to study the permeability behavior of Kaolinitic and Montmorillonitic soils with a particular reference to clay mineralogy of the soil.

1.2 Significance Of Hydraulic Conductivity In HydraulicStructures

The ever increasing constructional activities of hydraulic structures require good foundation soil for better performance of structures founded on such soils.In order to realize better performance of structures founded on compacted soils or engineered landfills, one has to have a clear understanding of the consolidation and permeability behavior of fine-grained compacted soils. Since, the fine-grained soils are composed of wide variety of clay minerals which are physico-chemical in nature and the engineering properties of compacted fine-grained soils depend upon the clay mineralogy of the soils.

Generally, for constructional of hydraulic structures clayey soils are not preferred because clay has a tendency to develop large shrinkage cracks upon drying. But geotechnical literature highlights the importance of compacted fine-grained soils in constructional activities due to small seepage losses when continuously wet and derive their strength from friction, cohesion and physico-chemical activity of clay mineral.

2.LITERATURE REVIEW

The recent study has indicated that Coefficient of consolidation (C_v) from the oedometer test together with a finite difference solution can be good predictor of field settlement rate. In this context, C_v obtained from the laboratory test continues to be in vogue.

The Terzaghi's consolidation theory is the foundation for the majority of graphical methods for getting C_v for laboratory time (t), compression (Δ), and data [Olson, 1986; Sridharan et al., 1987; Pandian et al., 1992; Sridharan and Prakash, 1993].

The fact that there are so many different procedures suggests that not all approaches may be appropriate in all situations. It might be challenging to determine which value of C_v represents a "fair" estimate of the soil because the value of C_v acquired using various approaches varies greatly.

It is possible to determine C_v from laboratory one-dimensional consolidation test data using a variety of methods such as the Logarithm of time fitting method (Cassagrande and Fadam, 1940), Square root of time fitting method (Taylor, 1942), Successive approximation method (Naylor and Doran, 1948) , Steepest slope method (Su, 1958), Scott's method (Scott,1961), Numerical method (Madhav, 1964), Inflection Point Method (Cour, 1971), Best fit method (Rao, 1975), Method by Sivaram and Swamee (1977), Velocity method (Parkin,1978,1984), Observational procedure (Asoaka, 1978), Method by Magnan and Deroy [as referred by Parkin and Lun (1980), Rectangular hyperbola method (Sridharan and Sreepada Rao,1981), Sridharan and Prakash, 1985; Sridharan et al, 1987), Log (d/t) v/s log t method (Pandian et al, 1992), d v/s t/d method (Sridharan and Prakash, 1993), Improved velocity method (Pandian et al, 1994), Log10

(H2/t) v/s U method (Sridharan et al, 1995), Two point method (Prasad and Rao, 1995), Early stage of log t plot method (Robinson and Allam, 1996), Improved t method (Tewatia and Venkatachalam, 1997) [37], Log d-log t method (Sridharan and Prakash, 1997) [14], Tewatia's method (Tewatia, 1998) [38], non-graphical matching method (Robinson and Allam, 1998) [15], One point method (Sridharan and Prakash, 1998) [39], Robinson's Method (Robinson, 1999) [40], Linear Segment of curve method (Feng and Lee, 2001), and Least squares method (Chan, 2003). On Terzaghi's one-dimensional consolidation theory, the majority of these techniques are based. The experimental Δ-t connection is employed in all of these methods to identify some distinctive elements of the theoretical U-T relationship, which can be used to locate on the primary and secondary compression regions on the experimental curve.

3.MATERIALS AND METHODOLOGY

3.1 Materials

The chosen soils under study have been classified using the IS soil classification system as outlined in IS: 1498-1970.
Table 3.1 presents the index properties of the soils, including the IS soil classification.

Table 3.1 Physical properties of soils studied

SL. NO	Soil	Specific gravity	Liquid limit W_L %	Plastic limit W_p %	Plasticity index I_p %	Shrinkage Limit W_s %	Shrinkage index I_s %	Grain size disribution %			IS classification
								Clay size	Silt size	Sand size	
1	Kollegala soil	2.74	55	26	29	15.9	10.1	37	34.5	28.5	CH
2	Kuderu soil	2.85	54	26	28	11.5	14.5	39	21	40	CH
3	Bannur soil	2.69	67	30	37	16.1	13.9	45	55	-	CH
4	CFTRI soil	2.72	68	33	35	13.9	19.1	51	49	-	MH
5	Chinaclay	2.67	68	30	38	24.8	5.2	63	37	-	CH

3.3 Methodology

For the current study, 1-D consolidated tests compacted for various placement conditions (i.e., dry side of optimum, OMC, wet side of optimum), liquid limit condition, and compaction energy levels were used to estimate consolidation parameters like co-efficient of consolidation (C_v), co-efficient of volume change (M_v), and swelling and non-swelling soils (Standard Proctor and Modified Proctor). For the seating pressure of 6.25 kPa under the forward loading condition, data on the flow velocity (V) and hydraulic gradient I of the falling head permeability test were also conducted.

3.3.1 Analysis by Consolidation Characteristics

For both the Standard Proctor and Modified Proctor methods, as well as for the liquid limit condition, the consolidation parameters of compacted fine-grained soils of the same low liquid limit group (i.e., K-soil and M-soil), and same high liquid limit group (i.e., K-M soil, M-soil, K-soil), were tabulated with respect to seating pressure of 6.25kPa-1600kPa with load increment ratio of one. The hydraulic conductivity of the soils under research was calculated using the standard consolidation equation for various placement settings, liquid limit conditions, and various compaction energy levels. From the obtained results the variations of consolidation characteristics like C_v , M_v and Hydraulic conductivity (K) plotted for different placement conditions, liquid limit condition, different compaction energy levels and clay mineralogy.

- Co-efficient of consolidation (C_v) with respect to applied pressure.
- Co-efficient of volume compressibility (M_v) with respect to applied pressure.
- C0-efficient of permeability (K) with respect to applied pressure.

3.3.2 Analysis By Permeability Characteristics

Under a seating pressure of 6.25 kPa loading condition, the falling head permeability test's flow velocity (V) and hydraulic gradient (i) were calculated for soils belonging to the same low liquid limit group (K-soil and M-soil) and same high liquid limit group (i.e., K-M soil, M-soil and K-soil). Slope, or hydraulic conductivity (K), was calculated using plots of flow velocity (V) vs hydraulic gradient (i) on both the linear and non-linear portions of the graphs. The obtained values of Hydraulic conductivity were plotted with respect to hydraulic gradient (i) by both normal and logarithmic scale. R^2 value and polynomial equations were computed for both Darcian and Non-Darcian behavior.

3.3.3 Pre-Consolidation Stress

Table 3.2 show the comparison of values of Pre-Consolidation stress from Log-Log method with the actual values

Soil	Type of soil	Redesignation of soil	Pre-consolidation stress (σp)	
			log-log method (kPa)	Actual (kPa)
S1	soils of same low liquid limit group(W_L=55%)	K-Soil	215	205
S2		M-Soil	150	150
S3	soils of same high liquid limit group (W_L=68%)	KM-soil	245	230
S4		M-Soil	130	130
S5		K-Soil	145	100

The soils selected based on liquid limit was divided into two groups G-1 (55%) and G-2 (68%).

4.Results and Discussions

4.1 variation of consolidation characteristics w.r.t pressure

Figures 1 through 3 represents Variation of C_v for different placement conditions with pressure for K-soil of Group-1.

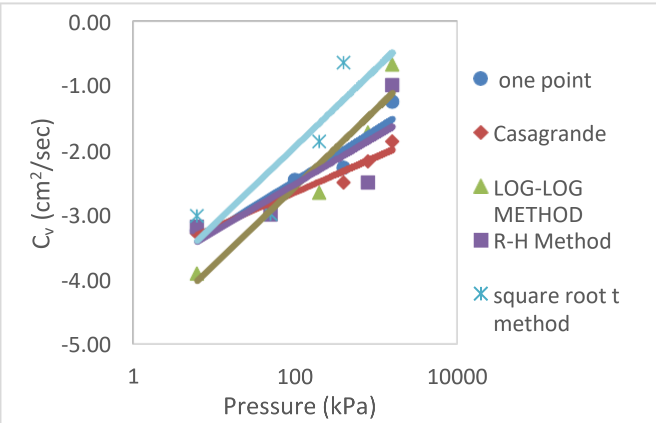


Fig.1 Variation of C_v at dry side of optimum with pressure for K-soil

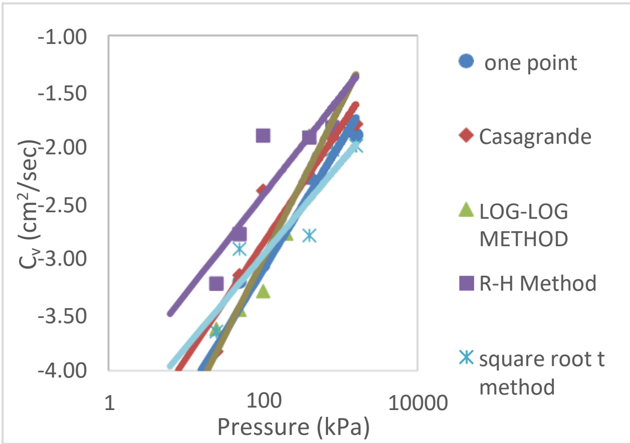


Fig.2 Variation of C_v at optimum with pressure for K-soil

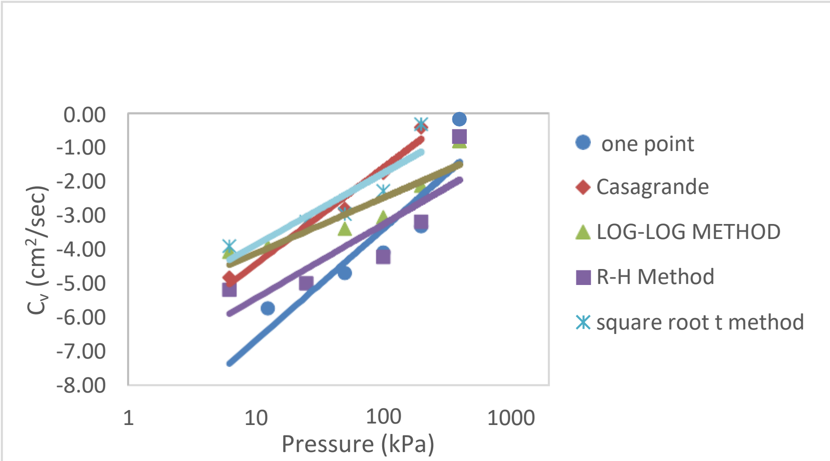


Fig.3 Variation of C_v at w_v et side of optimum with pressure for K-soil

From the Figure 1, decreasing trend in C value at dry side of optimum with respect to pressure was observed in all the methods.

From the Figure 2, it is observed that variations in C_v with increase in pressure are same for all the methods. The values of C_v in the initial seating pressure have decreasing trend, as the pressure increases increasing trend is observed upto pre-consolidation pressure.

From the Figure 3, it can be observed that at the pre-consolidation pressure, C_v attains minimum value in all the methods.

For all the placement conditions, the values of C_v of soil samples compacted dry side of optimum are more than the values of C_v of the soil samples compacted wet side of optimum.

Figures 4 through 6 represents Variation of C_v for different placement conditions with pressure for M-soil of Group-1.

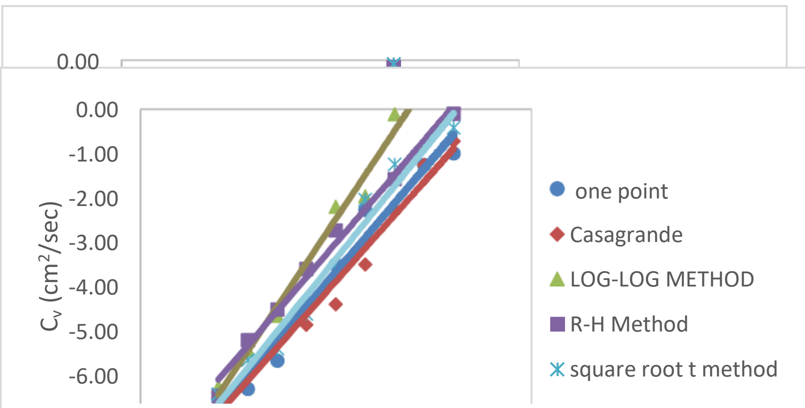
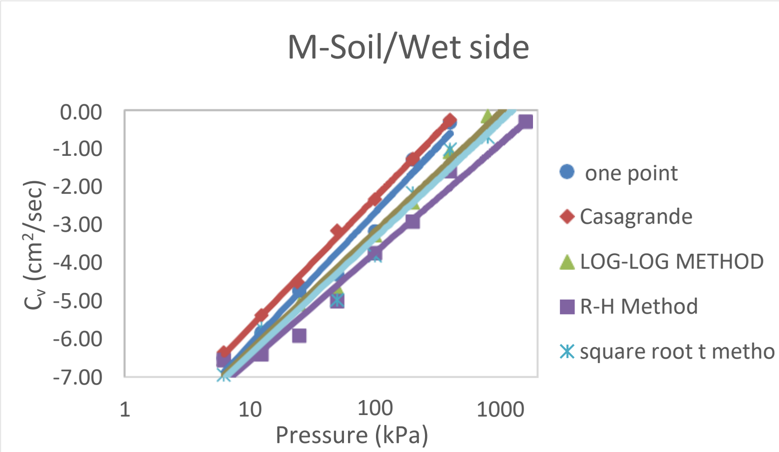


Fig.4 Variation of C_v at dry side of optimum with pressure for

Fig.5 Variation of C_v at optimum with pressure for M-soil

Fig.6 Variation of C_v



at wet side of optimum with pressure for M-soil

From the Figure 4, higher value of C_v (i.e.$3*10^{-3}$ cm^2/sec) was observed in Rectangular Hyperbola method. In one point method, casagrande method and logδ-logt method, C_v values reaches maximum at pre-consolidation pressure of 150kPa. Small variations in C_v value were observed in √t method which shows under estimated value i.e deviated from actual trend of C_v values.

From the Figure 5, decreasing trend in C_v value with pressure increment was observed in all the five methods.

From the Figure 6, higher value of C_v (i.e.$3.8*10^{-3}$ cm^2/sec) was observed in one point method. In rest four methods, trend of variations of C_v with increase in pressure are same.

From the Figures 4 through 6, it is observed that in dry side of optimum the C_v value increases beyond pre-consolidation pressure where in wet side of optimum, C_v value decreases at pre-consolidation pressure.

Comparison of C_v values of K-soil and M-soil of Group-1:

The K-soil has a higher co-efficient of consolidation than M-soil [i.e.$5*10^{-2}$ to $2.5*10^{-1}$ cm^2/sec for K-soil as against $5*10^{-4}$ to $3*10^{-3}$ cm^2/sec for M-soil] on dry side of optimum which is mostly due to the fact that the K-fabric soil's is more flocculent.

Figures 7 & 8 shows the variations of M_v for different placement condition with pressure for K-soil & M-soil.

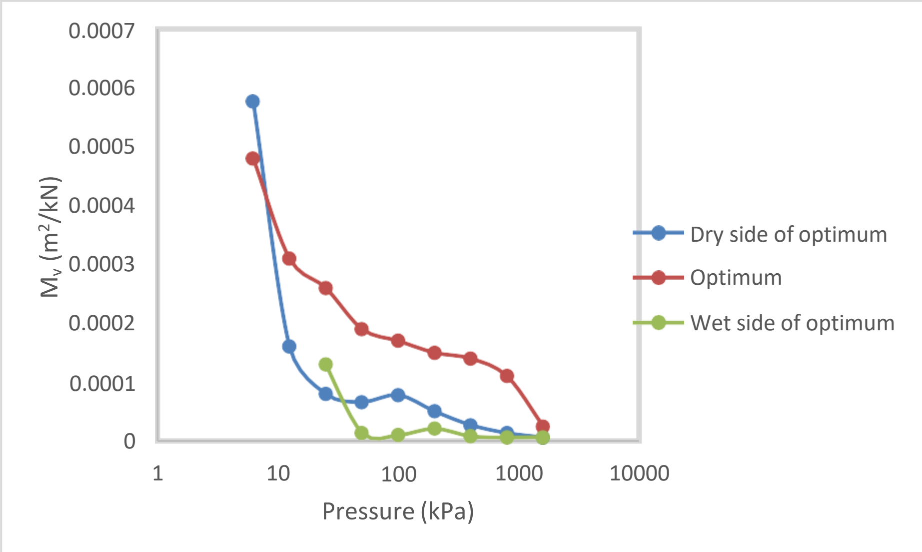


Fig.7 Variations of M_v for different placement condition with pressure for K-soil.

As demonstrated in Fig. 7, the greater M_v values were found on the optimum side when compared to the dry and wet sides of the optimum.

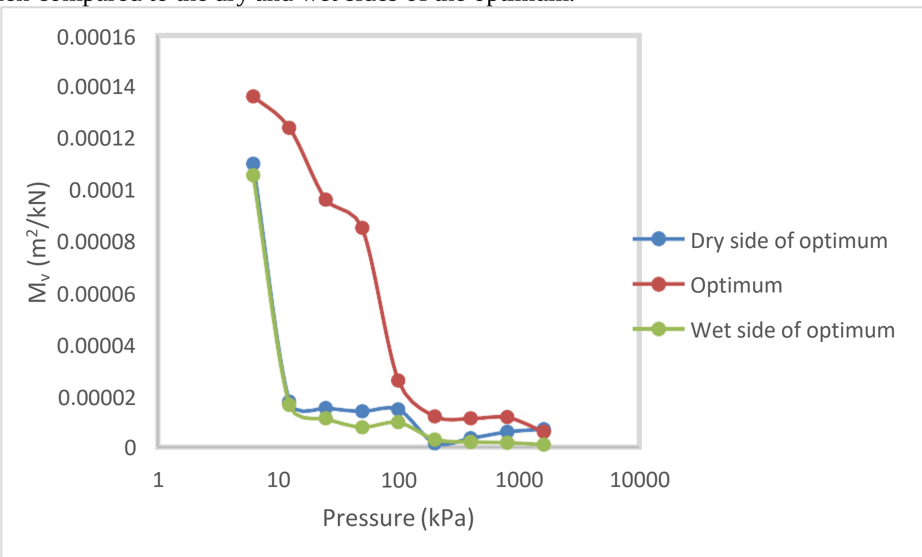


Fig. 8 Variations of M_v for different placement condition with pressure for M-soil.

As shown in Fig. 8, the higher M_v values were found on the optimum side compared to the dry and wet sides of the optimum.

Comparison of M_v values of K-soil and M-soil of Group-1:
K-soil of Group-1has higher Mv value [i.e. in range of 10^{-4}] when compared to M-soil of Group-1[i.e. in range of 10^{-5}]. It is due to fact that, the dominance of the double layer repulsion effect associated with M-soil.
Figures 9 through 11 represents Variation of 'K' for different placement conditions with pressure for K-soil of Group-1.

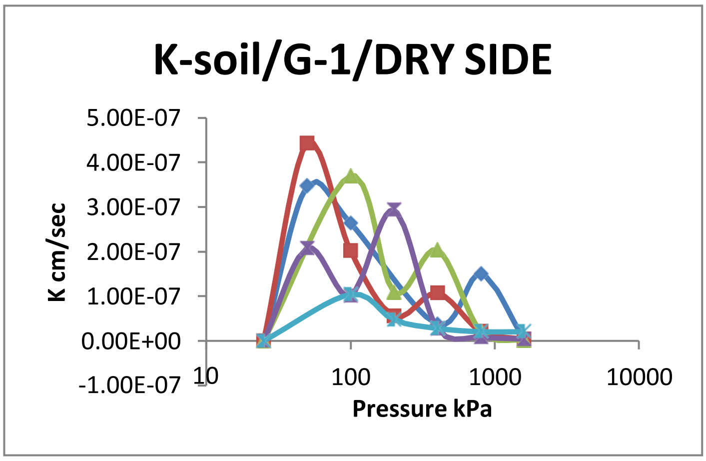


Fig.9 Variation of K at dry side of optimum with pressure for K-soil

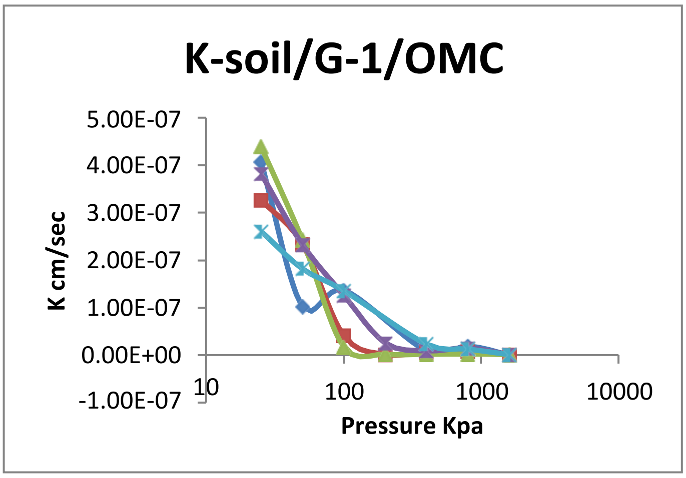


Fig.10 Variation of K at optimum moisture content with pressure for K-soil.

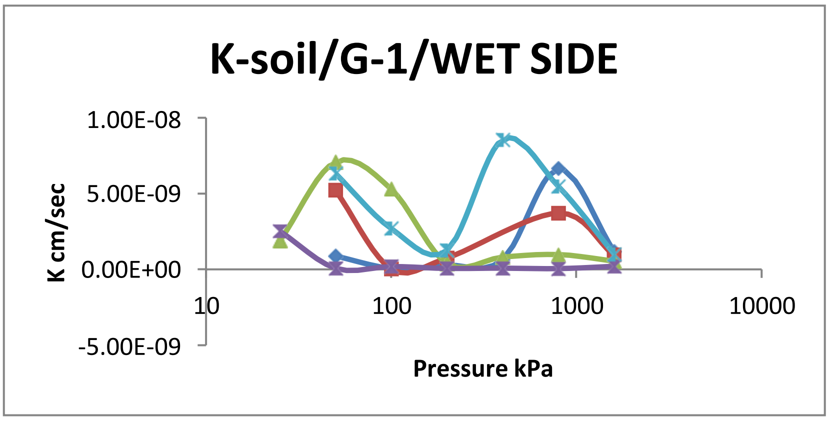


Fig.11 Variation of K at wet side of optimum with pressure for K-soil

Random values of K with increase in pressure were observed in all the methods except for √t method (Figure 9)
There is a decreasing trend in K values with increase in pressure was observed in all the methods. Minimum values of K were observed beyond pre-consolidation pressure of 205kPa. (Figure 10)

At pre-consolidation pressure minimum values of K were observed with increase in pressure. Beyond pre-consolidation pressure, increase- decrease trend in K values were observed. (Figure 11)

On dry side of optimum, higher values of K [i.e. $5*10^{-7}$ to $1*10^{-7}$ cm/sec] were observed than in wet side of optimum [i.e. $9*10^{-9}$ to $1*10^{-9}$ cm/sec]. It is due to high flocculent fabric was observed in dry side of optimum with relative comparison to dispersed structure of wet side of optimum.

Figures 12 through 14 represents Variation of 'K' for different placement conditions with pressure for M- soil of Group-1

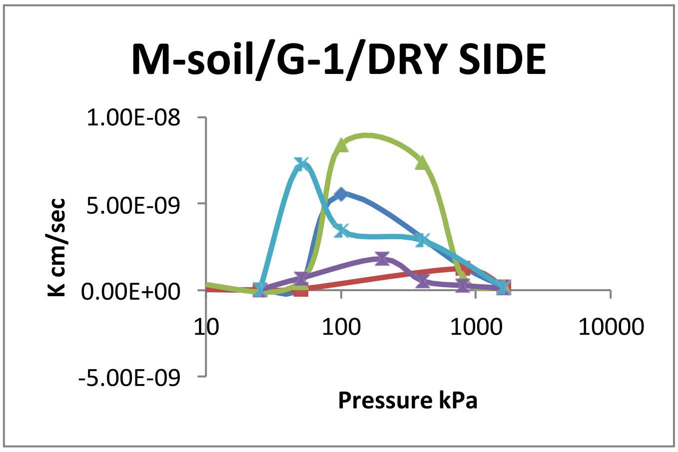


Fig.12 Variation of K at dry side of optimum with pressure for M-soil

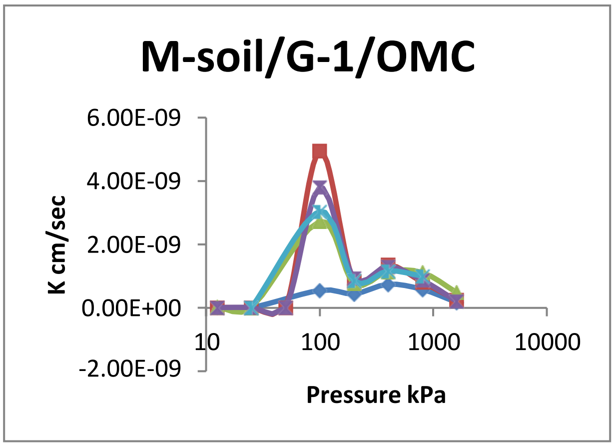


Fig.13 Variation of K at optimum moisture content with pressure for M-soil

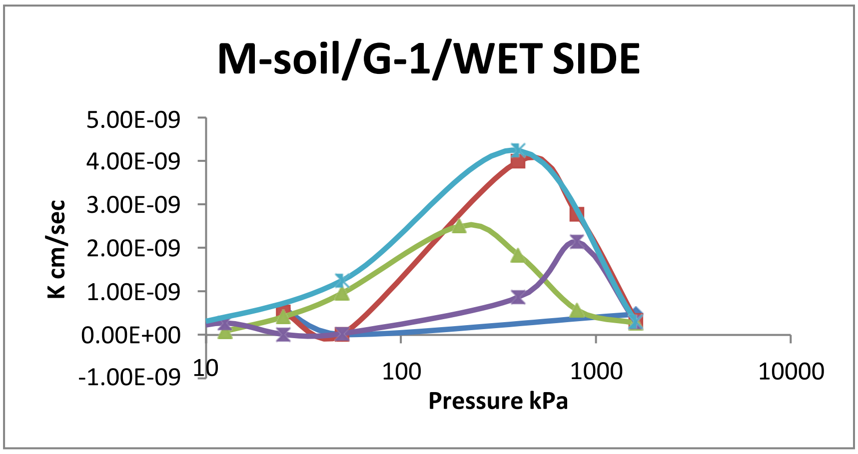


Fig.14 Variation of K at wet side of optimum with pressure for M-soil

From the Figures 12 and 14, similar variations in K value with increase pressure were observed. Only after pre-consolidation pressure, in most of the methods K attains the maximum value.

There is a decrease trend with increase in pressure were observed in all the five methods. At the pre-consolidation level, K values of all the methods attain minimum value [i.e. in range of $1*10^{-9}$ cm/sec]. (Figure 13)
The above discussion clearly indicates the effect of pre-consolidation stress i.e. stress history of soils.

5. CONCLUSIONS
Based detailed experimental study and discussions, the following conclusions are made.
CONSOLIDATION BEHAVIOR

- On an average, the soils compacted on dry side of optimum exhibit higher values of hydraulic conductivity than those compacted on wet side of optimum, irrespective of clay mineralogical composition of soils.
- Modified Proctor method gives lower value of hydraulic conductivity than Standard Proctor method.
- Pre-consolidation pressure exhibits a great influence on the values of co-efficient of consolidation (C_v), co-efficient of volume compressibility (M_v) and hydraulic conductivity (K) irrespective of placement condition and liquid limit condition.

PERMEABILITY BEHAVIOR

- For the soils of the present study the values of hydraulic conductivity obtained from permeability behavior are always greater than those calculated from conventional method using co-efficient of consolidation (C_v) and co-efficient of volume compressibility (M_v) values.
- The hydraulic conductivity of Kaolinitic soils is more than that of Montmorillonite soils even though the liquid limits of both the soils being the same, which is an indication of influence of fabric on the consolidation process.
- The clay mineralogical composition has a controlling influence on hydraulic conductivity of fine-grained soils for both low liquid limit condition and high liquid limit condition.
- The Non-Darcian flow through the soils appears to be valid for compacted fine-grained soils.

CONCLUDING REMARKS

On an average, the soils that are taken for present study have hydraulic conductivity range between 10^{-7} to 10^{-11} cm/sec, which is compatible with the standard hydraulic conductivity range between 10^{-6} to 10^{-11} cm/sec for safe design of hydraulic structures. Thus, compacted fine-grained soils can also use as a material for construction of hydraulic structures by providing suitable internal drainage system to dissipate excess pore pressure water.

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