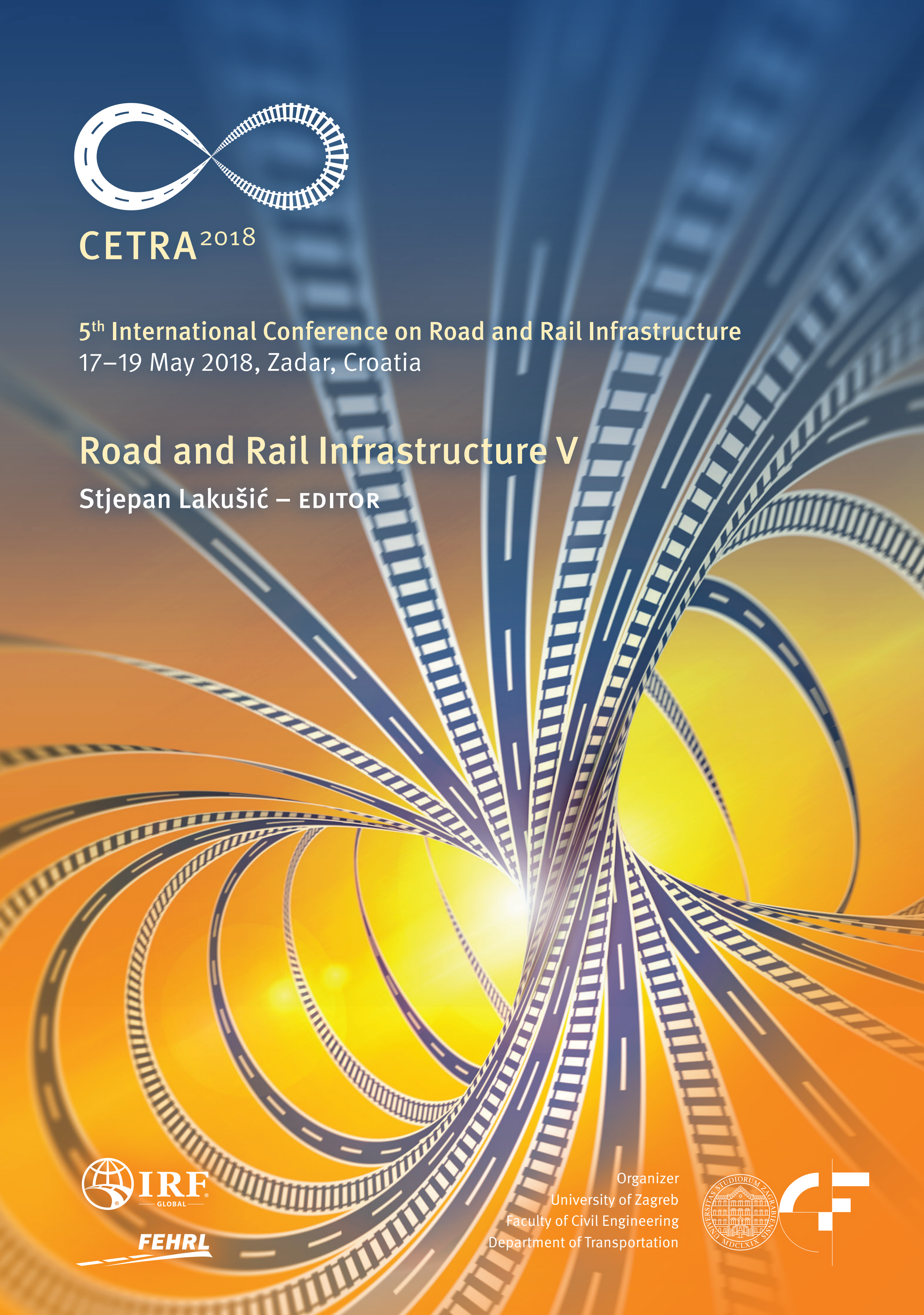

CETRA2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – **EDITOR**

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COMPRESSIBILITY CHARACTERISTICS OF SOFT CLAY USING LARGE SIZED MODEL CONSOLIDATION TEST THROUGH VERTICAL GEO-DRAIN

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Abstract

The present study is an attempt to determine consolidation characteristics of soft saturated kaolinite clay using large size consolidometer with aspect ratio 1.0:0.635. In the present investigation two drain material viz. sand and LLDPE granules are used as central drain with inward radial flow of ‘n’ value equal to 10. Further Barron’s equal strain (plain strain) theory is adopted to validate experimental results for vertical drain and is compared with virgin soil. Settlement computed from conventional consolidation test with aspect ratio (1:4/1:3) is compared with large size consolidometer with aspect ratio (1.0:0.635). Effect of large thickness of remoulded clay sample and pore water pressure mobility can be better understand through this study using vertical drains and its comparison with 1D vertical flow of conventional Oedometer. Pre and post vane shear strength are recorded and shear strength results are compared with virgin clay. Results indicate little variation in degree of consolidation computed from Barron’s theory and efficacy of sand drain is much higher than LLDPE granules.

Keywords: Consolidometer, geodrains, settlement, barron equal strain theory, sand drain, LLDPE drain, aspect ratio

1 Introduction

The aspect ratio (height: diameter) and size of the test specimens in geotechnical laboratory apparatus can significantly influence the measured compressibility and k values of peat and other soft soils. Side-wall friction, which develops along the inner wall surface of the confining cell and causes uneven compression over the specimen length, generally increases with increasing aspect ratio.

Laboratory testing with large-scale consolidation apparatus have proved useful in analysing the behaviour of vertical drains installed in soft clay. Bergado et al. (1991) used a transparent PVC cylinder (455 mm internal diameter, 920 mm height, and 10 mm wall thickness) was filled with soft remoulded Bangkok clay and a PVD (Ali drain – 4 mm × 60 mm) was installed using the 6 mm × 80 mm mandrel. Indraratna and Redana (1995) used a large-scale consolidometer (450 mm × 950 mm) to investigate the effect of smear due to the installation of prefabricated vertical drains and sand compaction piles. Sharma and Xiao (2000) also conducted a series of large-scale tests to study the behaviour around vertical drains installed in soft clay using remoulded kaolin clay.

Present investigation is undertaken to study the Compressibility characteristics of soft saturated kaolinite clay in large sized model consolidometer having aspect ratio 1.0:0.635(H: D) using vertical drain with n (r_e/r_w) value of 10. Two material viz. Sand and plastic granules were used as filler for vertical drain based on their permeability charactreristics.

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2 Experimental Investigation

2.1 Testing Program

Total four tests were performed namely:
1) Standard oedometer test (SOT);
2) Large size model Consolidation test without installing Vertical Drain (LCTWD);
3) Large size model Consolidation test with installing sand as vertical drain (LCTSD);
4) Large size model Consolidation test with installing LLDPE Granules as Vertical drain (LCTPG).

2.2 Testing Material

1) Soil-The soil sample is made of Kaolinite clay with mixed de-aired distilled water, twice the liquid limit to from slurry. The properties of soft kaolinite clay are shown in Table 1.
2) Sand-The vertical drain was filled with de-aired saturated sand. The properties of sand are shown in Table 2.
3) LLDPE Granules-The vertical drain was filled with LLDPE granules. The properties of LLDPE granules are shown in Table 2.

Table 1 Index properties of Kaolinite clay

Sr. No.	Descripation	Indian Standard	Symbol	Determination
1	Specific-Gravity	IS:2720-3	G	2.586
2	Liquid Limit	IS:2720-5	LL	73.5 %
3	Plastic Limit	IS:2720-5	PL	40.9 %
4	Shrinkage Limit	IS:2720-6	SL	36.116 %
5	Plasticity Index	IS:2720-5	PI	32.6 %
6	Soil type	IS:1498-1970	–	CH

Table 2 Index and Engineering properties of sand and LLDPE Granules

Sr. No.	Description	Indian Standard	Symbol	Sand	LLDPE Granules
1	Specific Gravity	IS:2720-3	G	2.66	1.37
2	Permeability	IS:2720-36	k	1.2274×10^{-2} cm/sec	1.6×10^{-2} cm/sec

2.3 Large scale Consolidation Test Setup

The test set-up includes a fabricated 10 mm thick mild steel circular tank and load frame with mechanical jack and proving ring is used to measure compressive load attached to a steel rod with circular steel plate for complete transfer of axial compressive load, Figure 1. The internal diameter of tank is 254 mm and height 450 mm. Four drain holes of diameter 25 mm were provided at the bottom of the tank to enable free drainage of the water from the bottom, if required, during the consolidation process. To measure the settlement of soil, one dial gauges having a sensitivity of 0.002 mm were used.

Figure 1 Consolidation Test Setup

2.4 Preparation of test sample and test procedure

The large scale consolidation tests were carried out on kaolinite clay with and without the vertical drain. Before commencing each test, a remoulded kaolin clay test sample at water content twice the liquid limit of soil was prepared by adding water to oven dry soil. The slurry was then transfer into cylindrical tank, before that the porous stone was inserted above the drainage hole and filter paper was kept at the bottom of tank. Cylindrical tank was then filled up with slurry till the predetermined height.Initially, Slurry was subjected to self-weight consolidation.The loads were applied in stages to avoid squeezing out of the slurry. A seating pressure of 0.1 kg/cm^2 was applied after which, vertical geo-drain was installed in specimen with help of mandrel of 25mm external diameter with n value 10. Gradual increment of loads was applied to produce stresses of 0.2, 0.4, 0.8, 1.6 and 3.2 kg/cm^2 of time interval of 3 days each. At end of consolidation test, vane shear tests were performed on the specimen.

3 Theoretical background

Barron (1948) presented the most comprehensive solution to the problem of radial consolidation by drain wells. For equal strain conditions horizontal sections remain horizontal throughout consolidation process. By considering the flow into and out of an infinitesimal cylindrical element the governing equation for consolidation by radial drainage (Barron, 1948) is given by:

$$\frac{\partial u}{\partial t}=c_h\left(\frac{\partial^2 u}{\partial^2 r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right) \tag{1}$$

The average degree of consolidation (Uh), in the soil body is given by:

$$Uh=1-\exp\left(\frac{-8T_h}{F(n)}\right) \tag{2}$$

The drain spacing factor, F(n) is given by:

$$F(n) = \frac{n^2}{n^2-1}\ln(n) - \frac{3n^2-1}{4n^2} \tag{3}$$

The time factor T_h is defined as: $$T_h = \frac{c_h \cdot t}{4r_e^2} \tag{4}$$

The coefficient of radial drainage consolidation (C_h) is represented by:

$$C_h = \frac{k_h(1+e)}{a_v \gamma_w} \tag{5}$$

Hyperbolic method is for estimating total primary settlement in case of vertical drain and constant surcharge. Plot the hyperbolic form of the test settlement data as t/δ vs t, where t is the time and δ is settlement from the start of constant load application. From Hyperbolic plot, identify the first linear segment immediately after initially concave downward segment of curve and measured its slope. Hyperbolic plots are linear between $U_{50\%}$ and $U_{90\%}$. For the lines radiating from the origin to $U_{50\%}$ point, the slope is (1/0.5 = 2.0), and to the $U_{90\%}$ point, the slope is (1/0.9 = 1.11).Thus, the ratio of the slopes of these radiating lines to the slope of the linear portion of the hyperbolic plots identifies the $U_{50\%}$ and $U_{90\%}$ for any settlement record using drains and surcharge.

4 Experimental results and discussion

Figure 2 depicts the degree of consolidation versus logarithm time factor recorded for large scale consolidation test with central vertical drains with 'n' value of 10. The theorectical curve given by Barron's for equal strain condition is almost similar to experimental result plot.

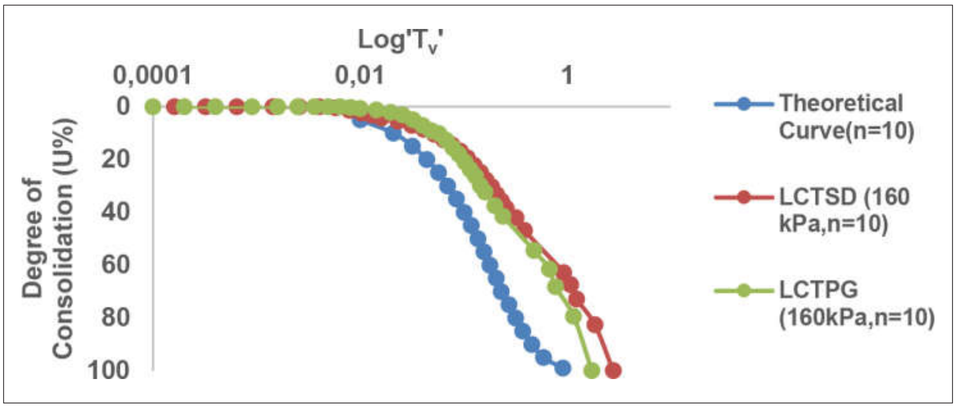

Figure 2 Degree of Consolidation versus Logarithemic Time factor (for n=10)

In absence of pore water pressure measurement facility in the large sized consolidometer, time required for value of 50 % degree of consolidation was calculated by using hyperbolic method. Figure 3 shows the degree of consolidation versus logarithm of time factor recorded for large scale and conventional scale specimen. The kaolin clay is highly compressible and the response was characterised in the form of traditional S-Shape, with primary consolidation substantially completed and secondary compression ongoing.

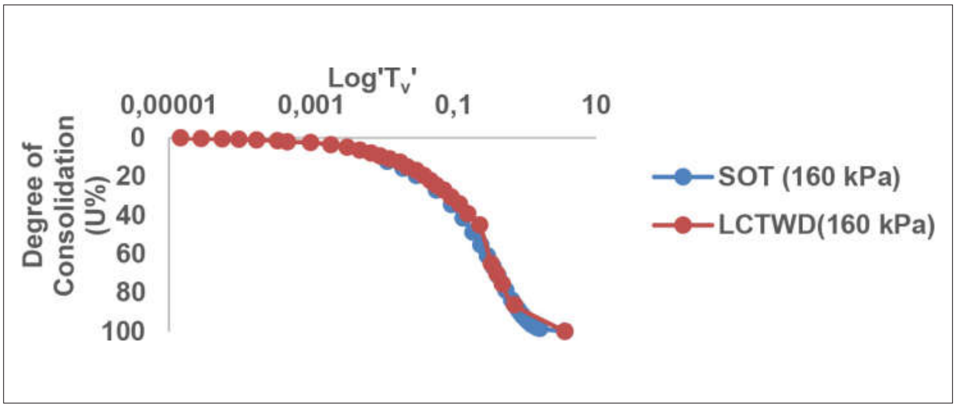

Figure 3 Degree of Consolidation versus Logarithemic Time factor

4.1 Effect of aspect ratio on Compressibility of large Specimen

Figure 4 represents the strained responses measured in Large scale Model Consolidation test (LCTWD) and the Conventional oedometer apparatus (SOT) were similar despite the singnificantly different specimen aspect ratios (1:0.635 and 1:3, respectively).The Large specimen and small specimen experienced practically identically strains of about 19.48 % and 28.96 % under 320 kPa. Due to greater effects of side wall friction and specimen boundary effects in large scale consolidation test experienced a smaller 19.48 % strain under same applied stress. The initial specimen compression recorded at start of different laod stages were negligible indicating,for practical purposes that the kaolin specimens had been in a fully saturated condition.

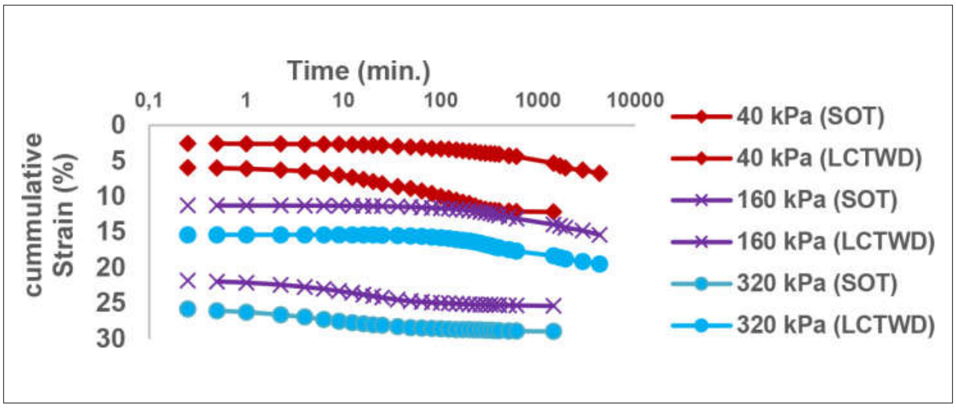

Figure 4 Cumulative strain versus Logarithm time

4.2 Comparison of Large specimen settlement

Figure 5 shows the plot between settlement and time period for virgin soil and various drain materials i.e. sand and LLDPE for ‘n’ value of 10. The use of sand as draining material is beneficial compared to LLDPE granules as the surface interaction between clay and drain plays an important role in deciding the rate of dissipation of excess pore water pressure since the clogging rate increase due to quick dissipation of excess pore water pressure. Due to uniform size and higher permeability of LLDPE granules, dissipation of excess pore water pressure is higher at initial stage but as load increases clogging of clay particles has been observed between adjacent LLDPE granules.

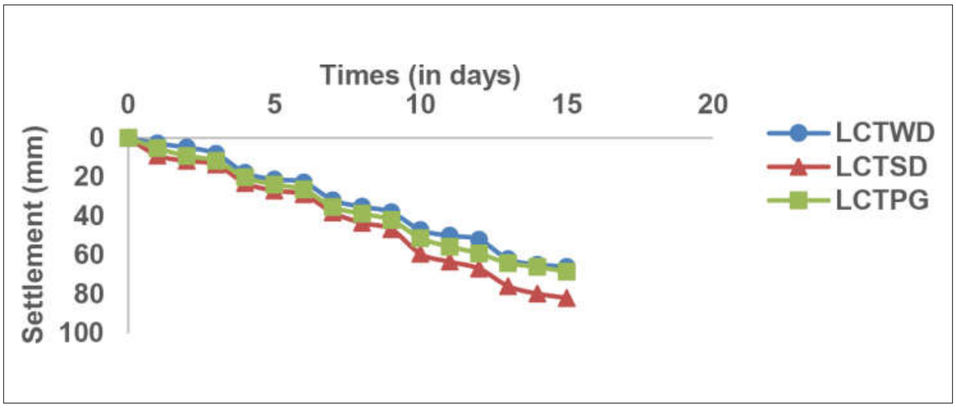

Figure 5 Settlement versus Time period in large sized Model Consolidation test

4.3 Comparison of consolidation parameter

From the Figure 6 it is very clear that the nature of C_{r50} increasing for 20,40,80,160 kPa and for 320 kPa value of C_{r50} decreasing. Value of Coefficient of Radial Consolidation finding using Barron's Equal Strain theory. Value of coefficient of consolidation (C_v) progressively increase with increase in applied pressure for both apect ratio specimen.
Figure 7 shows a Characteristics curve of normally consolidation soil for 'n' value equal to 10 and for with and without vertical Drain material.The value of compression index (C_c) is 0.48 for without vertical drain,0.595 for with vertical sand drain and 0.49 for with vertical LLDPE drain.for conventional oedometer test value of C_c is 0.62.

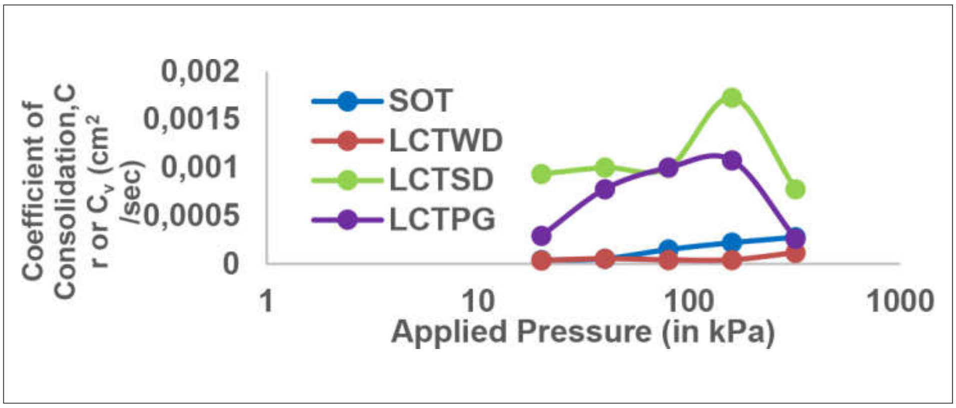

Figure 6 Coefficient of Consolidation (C_r or C_v) vs. Applied Pressure

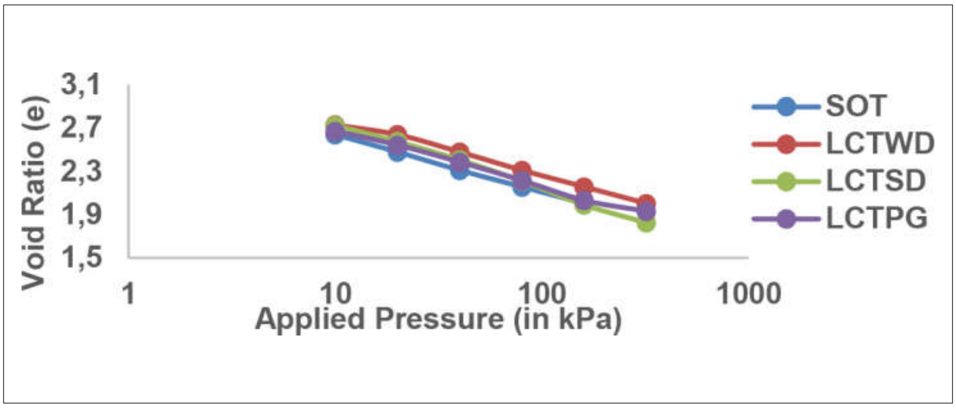

Figure 7 Void ratio (e) versus Applied Pressure

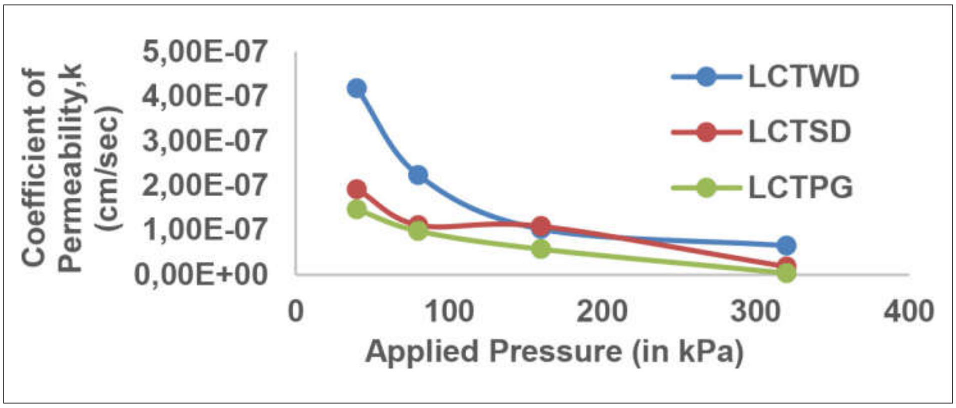

Figure 8 Coefficient of permeability versus Applied Pressure

Figure 8 shows that the permeability decrease with increase of pressure under lighter load and then it is more or less constant for higher intensity loading for vertical and radial drainage. Shear strength increase to some extent towards drain for any drain material.Soft clay consolidated by Sand drain gained a shear strength of 104 kPa compare to shear strength gained by LLDPE drain and with vertical drain as 74 kPa and 38 kPa respectively at end consolidation test.

5 Conclusion

Degree of Consolidation versus time factor plotted for ‘n’ value of 10 and for all pressures it is found that experimental plots are similar to theoretical plot given by Barron’s equal strain theory. Following conclusion can be drawn from this study:

- Barron’s equal strain theory can be used for large scale model consolidation test data for determination of various consolidation parameters.
- The considerable effect of aspect ratio is observed for large size consolidometer compare to smaller size. Applying plain strain condition the amount of vertical compressibility due to pore water expulsion in inward radial direction if integrated for full drain length shows higher compressibility with hydrodynamic lag. The volumetric pore water requires higher time to travel in vertical direction compared to horizontal direction.
- Due to greater effects of side wall friction and specimen boundary in large scale consolidation model experienced a smaller strain compared to conventional oedometer apparatus under same applied stress.
- Time Required for 50 % Consolidation in Large Sized Model Consolidation test using Sand Drain as Vertical drain is more effective than plastic granules. The vertical permeability though higher of LLDPE granules but due to low strain comptability, rearrangement of particles due to same size and high effect of viscous water, overall LLDPE drain shows lower effeiciency compared to sand drain of same size.
- Post vane shear strength results indiacte higher gain in shear strength for soil treated with sand drain compared to LLDPE drain.

The above study reveals that comprehensive mathematical modelling is needed to understand effect of aspect ratio along with fulll measurements of pore water pressure. The potential head developed by porewater may be more under steady state condition of flow but dissipation of this pore water is only possible at higher rate, if same amount of water is permeated withmore velocity. Further installation of drains of two different materails shows substantial agreement with above philosophy and sand drain shows better rate of compressibility as compared to LLDPE drain.

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