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INFLUENCE OF BAMBOO REINFORCEMENT ON COMPRESSIBILITY CHARACTERISTICS OF SOFT CLAY USING MODEL CONSOLIDATION TEST

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Abstract

The objective of this research work is to study the influence of filter paper wrapped perforated bamboos with various geometrical patterns (spacings) and configurations to estimate the compressibility characteristics of remolded kaolinitic clay mass using large scale model consolidation test set-up. Series of model consolidation tests were framed to determine load-settlement parameters with and without bamboo reinforcement. The various geometrical installation patterns adopted viz. circular, rectangular and cross (plus shape) with constant slenderness (l/d) equal to 10 for all model tests. To achieve this objective special model tanks with twin T-shape loading arm were fabricated of size 50 cm in diameter and 50 cm in height which can withstand compressive force up to 10T. Findings of this experimental work shows that bamboo reduced the settlement of soft clay and increase the consolidation process.

Key words: Bamboo, Soft soil, Consolidation Settlement, Timber pile, Ground Improvement

1. Introduction

Soft soil occurs in many parts of the world. Their specific properties such as large void ratio, high water content, high compressibility, low shear strength, low permeability and special structural features require significant attention for analysis and design of geotechnical structure founded on them. It is a great challenge to undertake large scale construction of high-speed transportation systems, high rise building and underground works for many urban areas located on such soils. Soft ground improvement by reducing water content of soft soil through consolidation process is one of the many methods. To accelerate the consolidation process of soft soil PVD, sand drains, reinforcement etc. are used. Less research work has done using bamboo as a reinforcement due to less codal guidelines and less availability of theoretical background for consolidation of soft soil with reinforcement.

Suyuti et.al (2018) conducted full scale model CBR test on soft soils using bamboo pile and it was noted that CBR value increases with bamboo reinforcement. The average value of field CBR test on very soft soil reinforced by bamboo pile was obtained 4.86%, which nearest to minimum standard of CBR required in Indonesian guidelines. Maulana et.al (2018) used Bamboo pile in their study and conducted model test by laying Bamboo pile of 2 cm diameter and length of 20 cm. Results show that spacing between bamboo piles is less effective at ratio s/d=10 but in ratio s/d=5 it can show a significant effect on the settlement. Hegde A. et.al (2014) analysed laboratory investigation on soft clay reinforced with bamboo and geosynthetics. Conclusion of this study shows that use of bamboo cell and bamboo grid was found 1.3 times higher than geocell and geogrid in soft clay bed and also reduction in settlement was observed. Asaduzzaman Md et.al (2014) performed model test using bamboo reinforcement of 12 inch length and 0.5 inch diameter at different depths. Three square footing of different sizes were used. Bearing capacity of soil increased 1.77 times in single layer bamboo reinforcement soil and 2.02 times in multiple layered bamboo reinforced soil. Waruwu Aazokhi et.al (2017) conducted small scale laboratory test. Settlement was measured by applying embankment on bamboo grid reinforced peat soil and unreinforced peat soil. This study proved that Bamboo Grid reinforcement was effective to reduce settlement of peat soil. 2-3 numbers of bamboo grid layers are considered.

Sandyutama Y. et.al (2015) analysed the effect of hybrid pile in soft soil. They conducted full scale trial embankment by installing hybrid pile (combination between timber pile and PVD) and measured vertical displacement, lateral displacement and pore water pressure. They observed that hyhrid pile effectively reduce the settlement on 6-8 m length and accelerate rate of consolidation. Wu Limin et.al (2018) studied effective use of drained timber pile through laboratory test. They have performed four types of soil-column consolidation tests for soft soil with and without drained- timber pile. They conclude that drained timber pile with two layers of Geotextile provide dominant contribution to total consolidation degree. Dipika Devi et.al (2016) studied that use of bamboo fiber improve the shear strength parameters of soil. They used two different length of bamboo fiber. They added the fiber in variate percentage quantity. The increase in length of fiber improve the shear strength of soil. Marto et.al (2011) analysed model study using bamboo as reinforcement in soft clay. They has done three types of study to measure settlement as well as lateral movement. There were (1) Embankment on Bamboo-Geotextile composite reinforced (2) Embankment on high strength Geotextile reinforced (3) Un-reinforced embankment. Conclusion of this study that performance of the embankment on Bamboo Geotextile composite reinforced was better compared with embankment on high strength Geotextile reinforced and un-reinforced embankment. Soundara B et.al (2017) has studied the effect of bamboo-grid Jute textile composite on soft soil. Two fold of bamboo- grid Jute textile composite increases the strength of the soft soil.

Radhakrishnan, G et.al (2010) studied marine clays are problematic so to analyse the stability of an embankment laboratory consolidation test with sand drain and without sand drain was done. Results of this research show that installation of sand drain in soft clay accelerate process of consolidation and improve the shear strength of soft soil. Kirmani S.M.H. (2004-2005) discussed the application theory, technique and monitoring process of drains, design procedure and types of drains in their research. From their research we can conclude that from trail test of sand drain we get 90% required degree of consolidation efficiency within the imposed time. Hausel, W.S. (2004) explained in detail checking up on vertical drains and shared experience with vertical drains. Also include the consolidation due to horizontal flow and cost data on vertical sand drains. Hansbo (2004) made study on consolidation of clay with special reference to influence of vertical sand drains and gave important theory for consolidation and results with conclusion that sand drain accelerate the rate of consolidation. Gosh S. et.al (2008) studied that use of small diameter timber piles showed effective benefits for pile lengths greater than the width of footing. A semi empirical method to calculate settlement also mentioned in their research. Results shows that at particular area ratio the bearing capacity of soil increases with length of timber pile. Timber pile also reduce the settlement. Giannakogiorgos A. Th. et.al (2015) analysed numerical model to find the system performance. They compare it with other layouts without timber piles and the gravel raft. They conclude that treated ground would tend to act as a stiffer raft and reduce the impact of liquefaction from soil below the treated area. Purwondho Rudy et.al (2018) used vertical jute fiber drain and preload the soil with sand to speed up the consolidation process. Conclusion of research that the expanding nature of jute burlap allows it to operate as a filter without clogging and it is biodegradable, making it ecologically beneficial. Khatib Anwar et.al (2005) performed plate load test on soft clay reinforced with bamboo-geotextile composite. Bamboo were arranged in square and parallel pattern. Results shows that bamboo-geotextile composite reinforced model show higher bearing capacity than unreinforced soil. Alhaji Mohammed Mustapha (2008) had performed laboratory trial test using soil specimen in cylindrical form and bamboo specimens in circular plates. They conclude that dry density of model soil specimen decreases with increase number of bamboo specimen and UCS and modulus of rigidity increase with increase number of bamboo specimen. Arnold Verruijt (2009) provides different theory of consolidation for theoretical background. From these theories calculations are done for deformation.

From the above literature review, the notable research work done by various group of researchers, it is concluded/observed that soft soil compressibility characteristics are affected by many parameters which includes reinforcement material, type of loading, soil type, anisotropy of soil, drainage characteristics etc. The above research work done by various research workers have mainly concentrated on settlement issues or increasing shear strength using one single material, mostly geosynthetics in form of PVDs or sand drains or geodrains or stone columns or either they have completely replaced the improvement of soft soil by using conventional pile foundation or deep ground improvement techniques. They lack in giving most economical viable solution in terms of multi-functionality viz, drainage, settlement, stiffness of soil and increase in shear parameters of bamboo infused treated soil. The present research study is an attempt to overcome above deficiencies by projecting a large size model consolidation tank to determine compressibility characteristics of soft kaolinitic clay mass reinforced with perforated bamboo drains/piles of various geometrical spacings with constant l/d ratio. The objective is to determine consolidation parameters of soft saturated class mass using with and without bamboo reinforcements. The perforated bamboo pile wrapped with Whatman filter paper and filled with sand as drain material is used in this study to accelerate pore pressure dissipation, settlement and increase stiffness of soil at the end of consolidation. To achieve above objective a series of large-scale model consolidation test with one way drainage (top) is planned using circular, square and plus geometrical patterns of bamboo reinforcement having l/d equal to 10 are performed at Geotechnical Engg Laboratory, L.D. College of Engineering, India. Special T shaped loading pad is developed indigenously to apply compressive load of equal magnitude on two model tank simultaneously as per series of applied pressures of conventional consolidation test.

2. Methodology

2.1 Materials

Kaolinite Clay: Powder form

Table 2.1.1 Index properties of Kaolinite clay

G	L.L.	P.L.	S.L.	Clay, Silt	Soil type
2.59	69.22 %	41.31 %	22.44 %	92%, 8%	CH

Bamboo reinforcement: Vertical hollow pipe type

Table 2.1.2 Properties of bamboo reinforcement

Diameter	Length	Tensile strength	Compressive strength	Young's modulus	Density
3 cm	30 cm	1223.66 kg/cm^2	560.84 kg/cm^2	$1.43x10^6$ kg/cm^2	0.0007 kg/cm^3

Fig.1 Kaolinite clay

Fig. 2 Bamboo with holes and wrapped filter paper

2.2 Setup for Model Consolidation Test

Set up for the model consolidation tests on Kaolin clay was made by fabricating two model tank of size 50 cm in diameter and 50 cm in height with T section loading arm. The compressive load is applied by means of mechanical jack of capacity 10 ton. This mechanical jack is fixed at the inner side of the top section channel at equal distance from both extreme ends of loading frame.

Fig. 3 Model Test set-up

Proving ring is attached to a steel rod so that there is complete transfer of axial compressive load at the center of column. T shaped loading pad was attached with proving ring for proper load distribution. T shaped loading pad was resting on soil sample to transfer the compressive load.

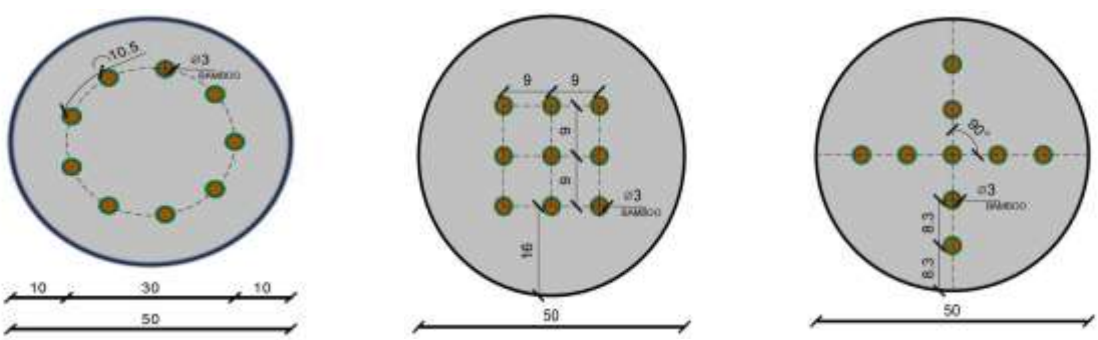
2.3 Sample Preparation

To guarantee full saturation of the sample the clay was mixed to form a slurry with twice the liquid limit (140% of its weight) with de-aired distilled water in a rotary laboratory mixer for a period of 2 h to a uniform consistency.

Fig.4 Soil Sample

The viscosity was suitably low to allow the removal of entrapped air when a vacuum was applied to the surface of the slurry in the consolidation cell. The slurry was filled into the tank up to predetermine height. Care should take that no air voids remain presence in slurry.

Fig. 5 Bamboo installation geometrical patterns viz. circular, square and plus shape.



Circular Pattern (MC2_CB)

Square Pattern (MC3_SB)

Plus Pattern (MC4_PB)

Fig. 5 Different patterns of bamboo reinforcement

2.4 Test Procedure

For the large-scale model consolidation test, test procedure followed as per IS 2720 (part 15). To measure the settlement of soil, dial gauges having a sensitivity of 0.01 mm and capacity of 50 mm used. The compressive loading was applied using proving ring arrangement of 10-ton capacity through indigenously developed. T shaped loading pad for distribution of uniform pressure equal to 20,40,80 and 160 kPa on dual model tanks simultaneously.

Fig. 6 Hard strata (at bottom)

Fig. 7 Drainage layer of sand (at top)

On the completion of the consolidation test the soil sample is collected from various location of the tank for final water content determination. Further laboratory post vane shear test is performed on a consolidated soil mass at various depth of clay mass to determine gain shear strength under the influence of each geometrical pattern.

3. Results, Analysis and Discussion

From the measurements of consolidation data, the results and plots of various series of large-scale consolidation tests for various geometrical patterns is discussed below. The test results are compared with virgin clay mass without reinforcement. The consolidation parameters were determine using Terzaghi's one dimensional consolidation theory.

1. Virgin clay- without bamboo (MC1_WB)

Fig. 8 and 9 shows results analysis of virgin clay.

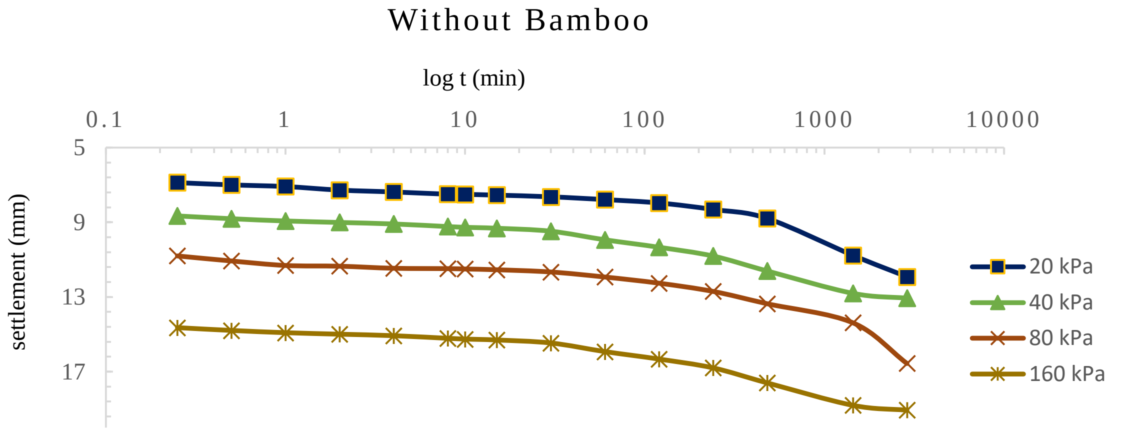


Fig.8 Plot of s vs log t for MC1_WB

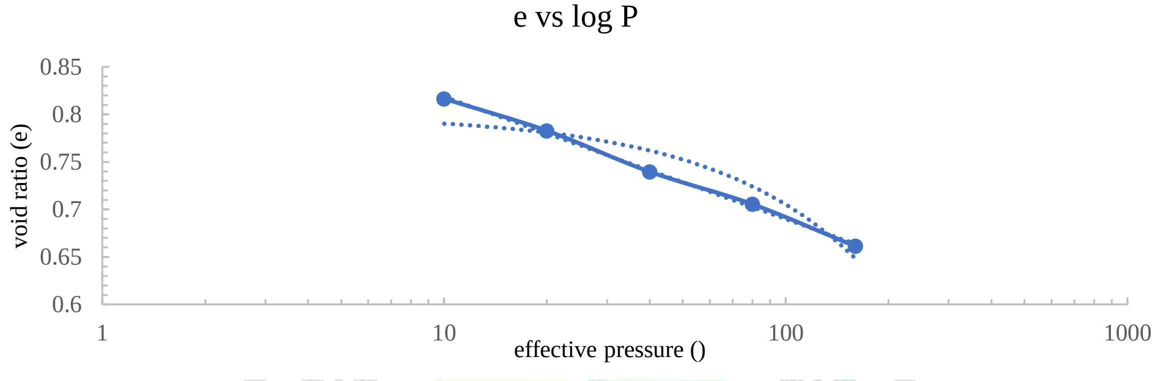


Fig.9 e vs log P for MC1_WB

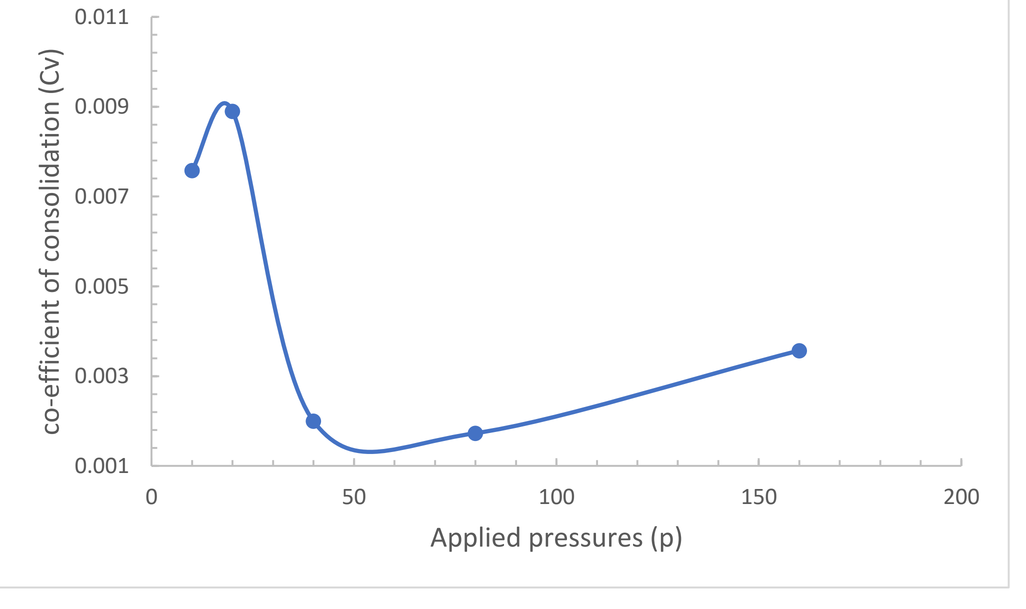


Fig. 10 Coefficient of consolidation (cv) vs. applied pressure (σ')

Fig.8 shows that settlement is more in virgin clay compared to use of bamboo reinforcement. Void ratio computed at every increment of pressure is plotted against effective log pressure from which compression index is calculated. Fig.9 shows the curve of relationship between void ratio and applied pressure. From plot it can be concluded that void ratio of MC1_WB is higher than MC2_CB, MC3_SB and MC4_PB. The time required for 50% consolidation for virgin soil using model consolidation test without bamboo at applied pressures 20 kPa, 40 kPa, 80 kPa, 160 kPa and 320 kPa are 520 min, 450 min, 1720 min, 2310 min and 1120 min respectively. Figure 10 shows the plot of coefficient of consolidation vs. applied pressure for model consolidation test without bamboo. For analysis time required for 50% (T50) consolidation is taken for all applied pressures. The average value of coefficient of consolidation are 7.58×10^{-3} cm^2/sec for 10 kPa, 8.90 $\times 10^{-3}cm^2$/sec for 20 kPa, $2.0 \times 10^{-3}cm^2$/sec for 40 kPa,$1.73 \times 10^{-3}cm^2$/sec for 80 kPa, and $3.57 \times 10^{-3}cm^2$/sec for 160 kPa. For Applied pressure 10kPa and 20kPa, value of coefficient of consolidation increases and for 40 kPa, 80 kPa and 160 kPa the value of coefficient of consolidation decreases.

2. Circular Pattern of bamboo (MC2_CB)

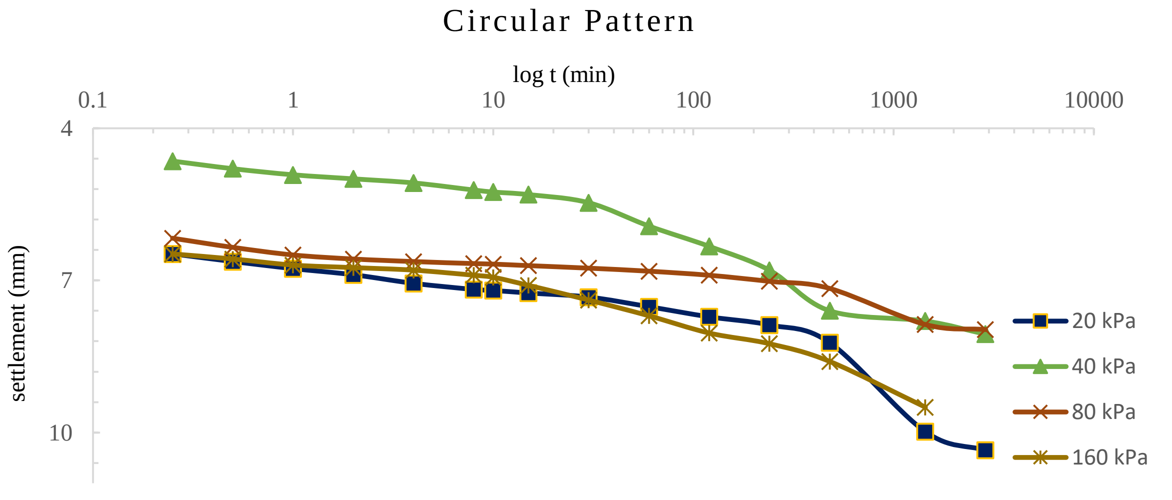


Fig.11 s vs log t for MC2_CB

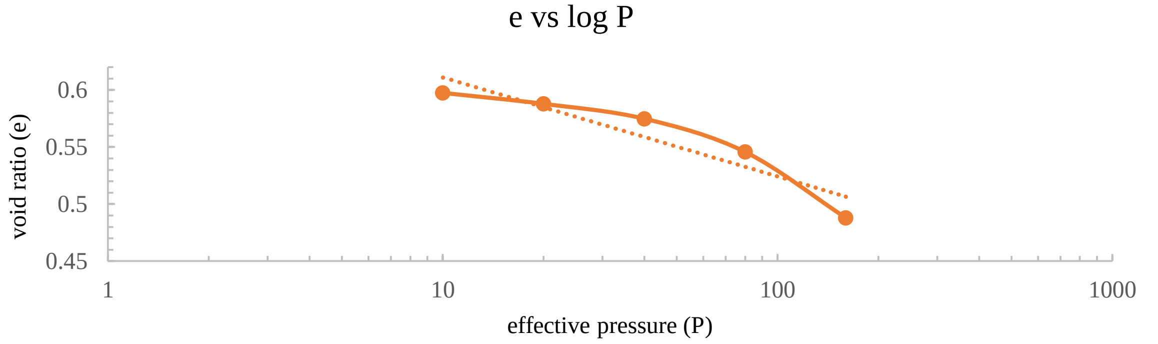


Fig.12 e vs log P for MC2_CB

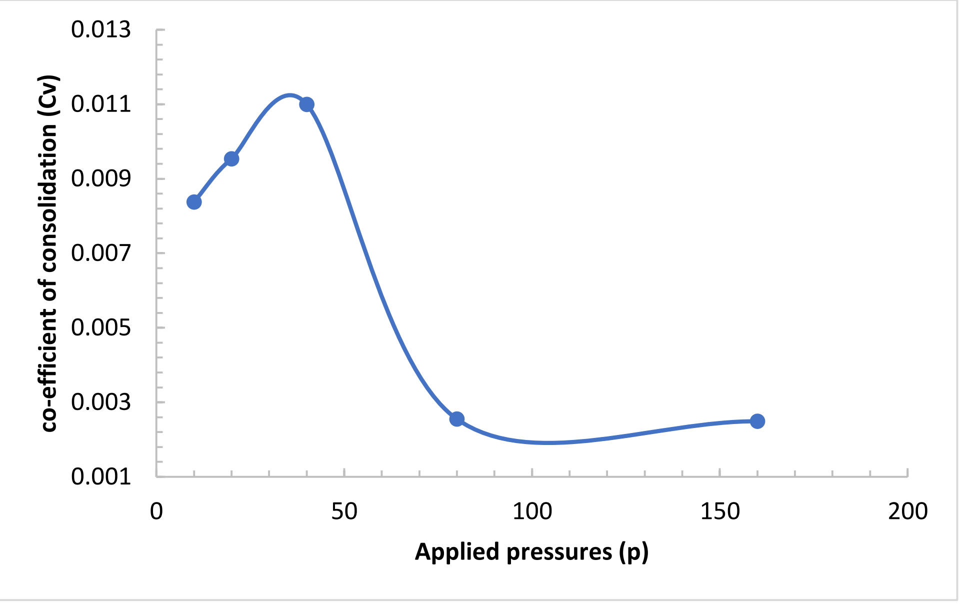


Fig.13 Coefficient of consolidation (cv) vs. applied pressure (σ')

Fig.11 shows relationship between settlement vs time for all applied pressure. From the plot we can conclude that settlement of soft clay decreases compared to without bamboo consolidation test. Total settlement for this test is 45.01 mm which shows that bamboo works effectively as a drainage purpose. Fig.12 shows the plot of void ratio vs applied pressure. Void ratio is more in virgin soil but with the use of bamboo void ratio decreases. In MC2_CB void ratio decreases more than MC4_PB as zone of influence of bamboo is more in MC2_CB. So, value of Cc is less than MC4_PB. The time required for 50% consolidation for virgin soil using model consolidation test without bamboo at applied pressures 10 kPa, 20 kPa, 40 kPa, 80 kPa and 160 kPa are 478 min, 420 min, 1570 min and 1610 min respectively. Figure 13 shows the plot of coefficient of consolidation vs. applied pressure for model consolidation test without bamboo. For analysis time required for 50% (T_{50}) consolidation is taken for all applied pressures. The average value of coefficient of consolidation are 8.38 × 10^{-3}cm^2/sec for 10 kPa,9.54 × 10^{-3}cm^2/sec for 20 kPa,1.10 × 10^{-3}cm^2/sec for 40 kPa,2.55 × 10^{-3}cm^2/sec for 80 kPa, and 2.49 × 10^{-3}cm^2/sec for 160 kPa. For Applied pressure 10kPa and 20kPa, value of coefficient of consolidation increases and for 40 kPa, 80 kPa and 160 kPa the value of coefficient of consolidation decreases.

3. Square Pattern of bamboo (MC3_SB)

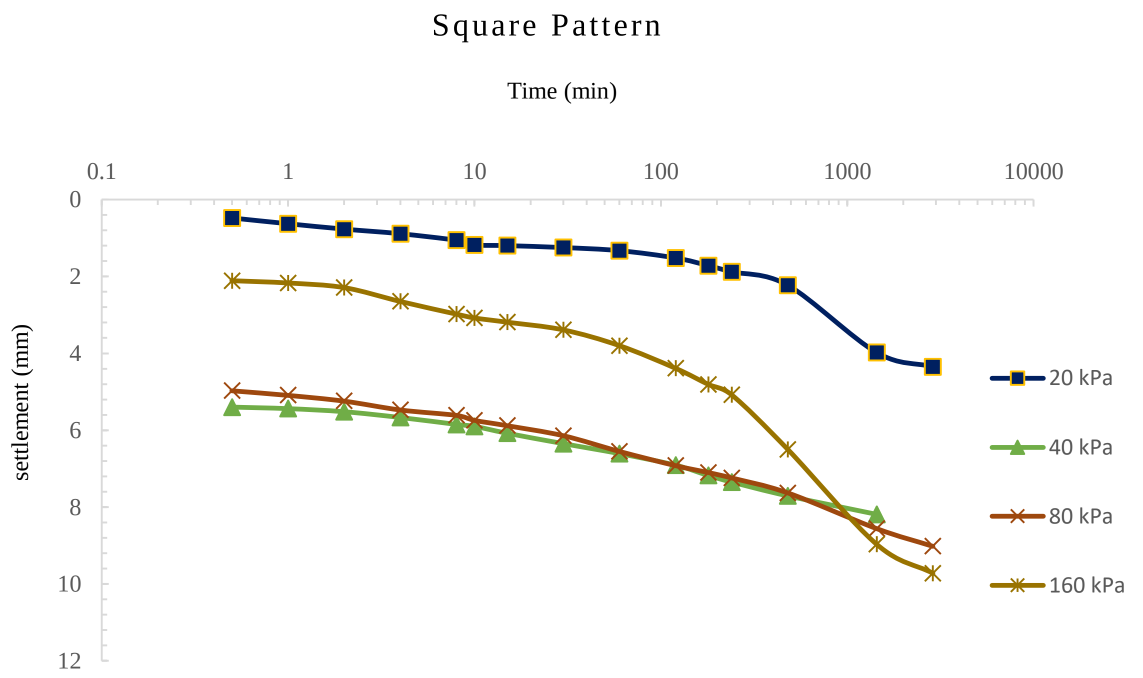


Fig.14 s vs log t for MC3_SB

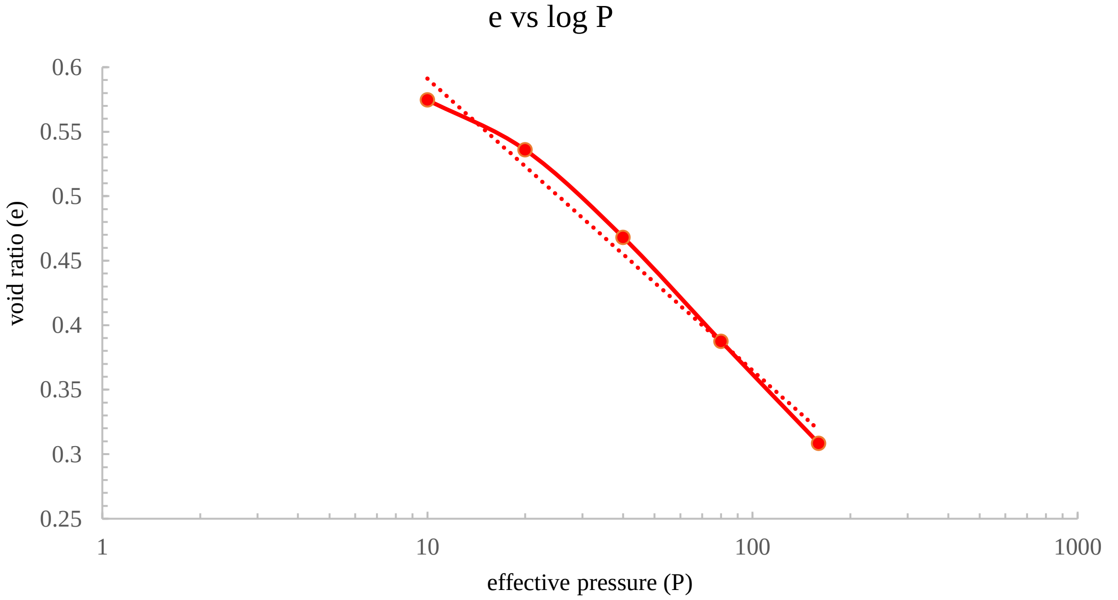


Fig.15 e vs log P for MC3_SB

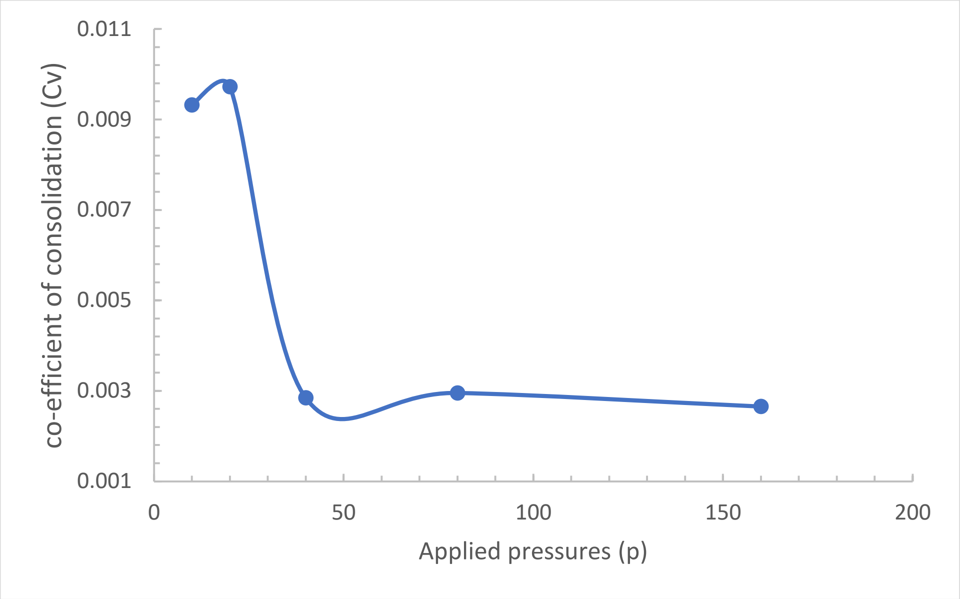


Fig. 16 Coefficient of consolidation (c_v) vs. applied pressure (σ’)

As shown in fig.14 settlement of soft clay decreases with use of bamboo. Square pattern of bamboo covered more influence zone of bamboo so total settlement of MC3_SB is 40.04 mm which lowest than other three tests.in this pattern bamboo works effectively as a drainage medium and increases the rate of consolidation.Fig.15 shows relationship between void ratio and applied pressure for MC3_SB. For all applied pressure maximum decrease in voids is occur in square pattern. Value of compression index for MC3_SB is lowest than other three tests. The time required for 50% consolidation for virgin soil using model consolidation test without bamboo at applied pressures 10 kPa,20 kPa, 40 kPa, 80 kPa and 160 kPa are 430min, 412min, 1412 min, 1360 min and 1510 min respectively. Figure 16 shows the plot of coefficient of consolidation vs. applied pressure for model consolidation test without bamboo. For analysis time required for 50% (T50) consolidation is taken for all applied pressures. The average value of coefficient of consolidation are $9.32 \times 10^{-3} cm^2/sec$ for 10 kPa,$9.72 \times 10^{-3} cm^2/sec$ for 20 kPa,$2.84 \times 10^{-3} cm^2/sec$ for 40 kPa,$2.95 \times 10^{-3} cm^2/sec$ for 80 kPa, and $2.65 \times 10^{-3} cm^2/sec$ for 160 kPa. For Applied pressure 10kPa and 20kPa, value of coefficient of consolidation increases and for 40 kPa, 80 kPa and 160 kPa the value of coefficient of consolidation decreases.

4. Plus Pattern of bamboo (MC4_PB)

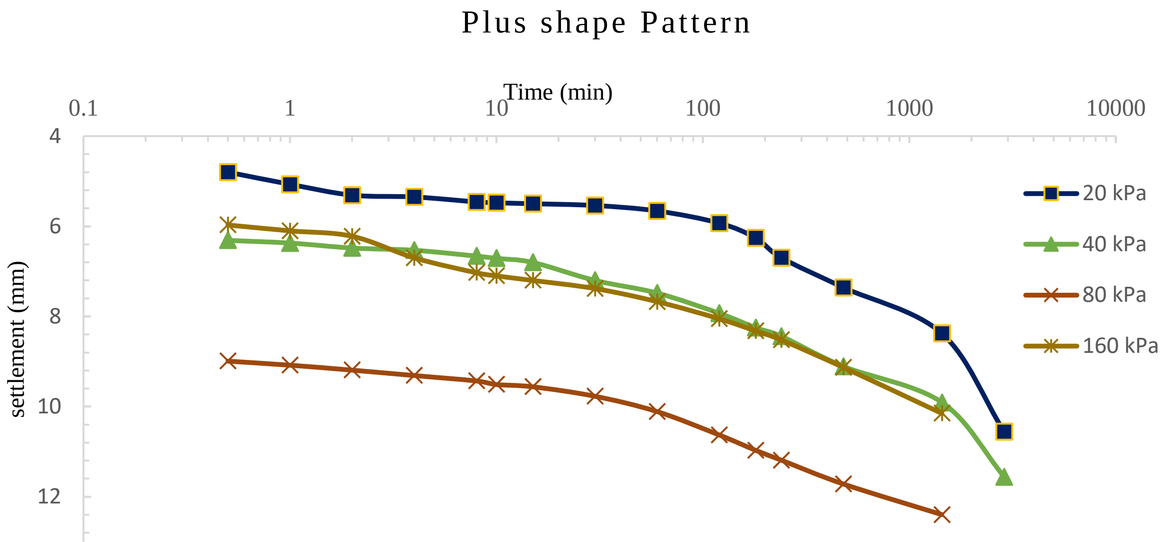


Fig.17 s vs log t for MC4_PB

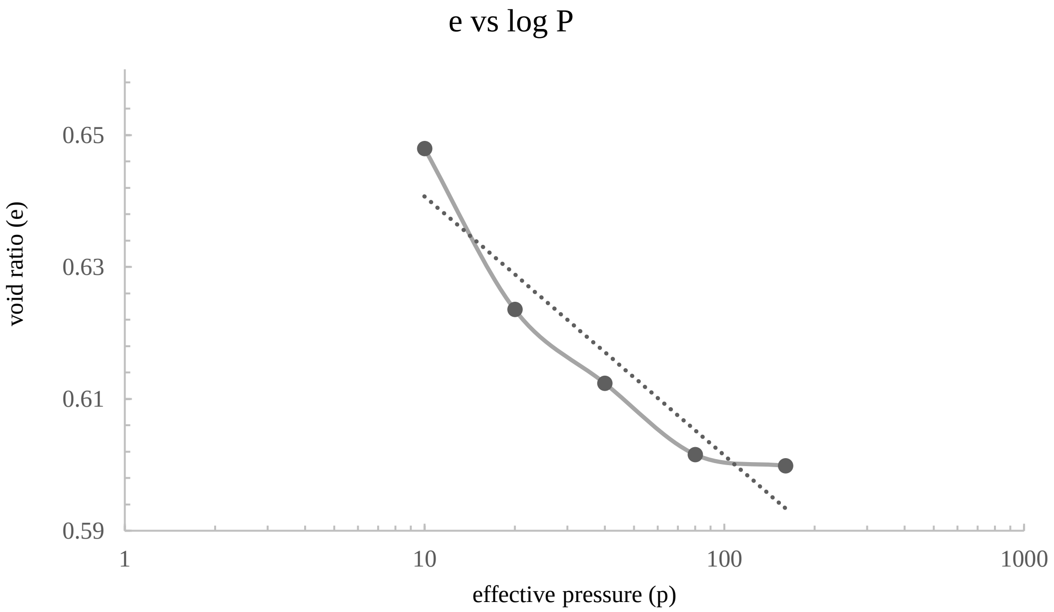


Fig.18 e vs log P for MC4_PB

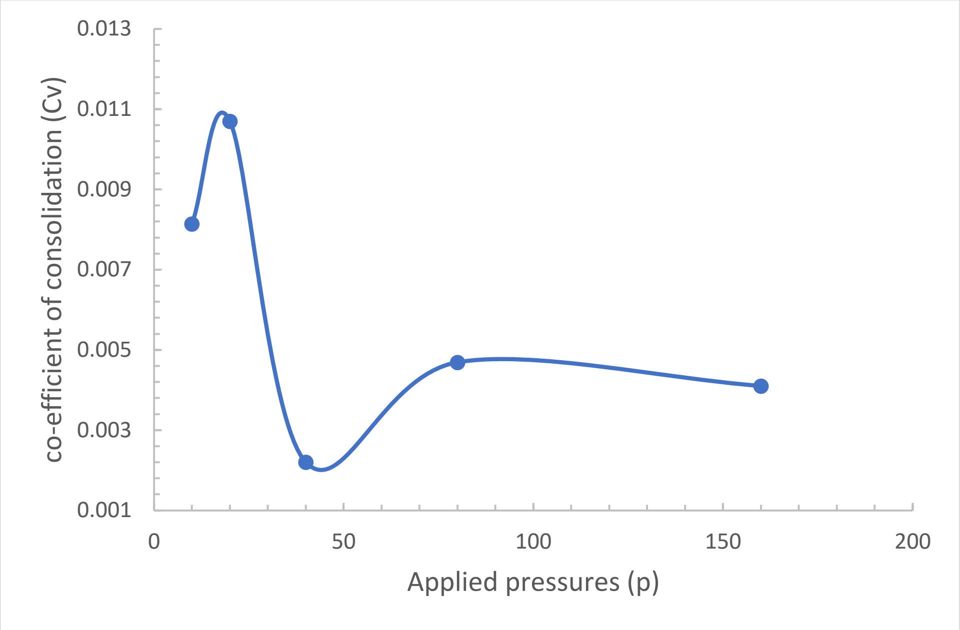


Fig. 19 Coefficient of consolidation (c_v) vs. applied pressure (σ')

Fig.17 shows plot of settlement vs log time for applied pressure ranging from 10 kPa, 20 kPa, 40 kPa, 80 kPa and 160 kPa. For all applied pressure value of co efficient of consolidation decreases with increases in degree of consolidation which derived from plot of settlement vs log t. total settlement of soft clay using cross pattern of bamboo is 53.43mm which is more than MC1_SB and MC3_SB. As shown in fig.18 void ratio decreases compared to MC1_WB but in rate of decrease in void ratio is less in MC4_PB than MC2_CB AND MC3_SB. So, value of compression index for MC4_PB is more than MC2_CB and MC3_SB. Value of Cc is less than MC1_WB. The time required for 50% consolidation for virgin soil using model consolidation test without bamboo at applied pressures 10 kPa,20 kPa, 40 kPa, 80 kPa and 160 kPa are 492 min, 376 min, 1820 min,853 min and 976 min respectively. Figure19 shows the plot of coefficient of consolidation vs. applied pressure for model consolidation test without bamboo. For analysis time required for 50% (T50) consolidation is taken for all applied pressures. the average value of coefficient of consolidation are $8.14 \times 10^{-3}cm^2/sec$ for 10 kPa,$1.07 \times 10^{-2}cm^2/sec$ for 20 kPa,$2.20\times 10^{-3}cm^2/sec$ for 40 kPa,$4.69 \times 10^{-3}cm^2/sec$ for 80 kPa, and $4.10 \times 10^{-3}cm^2/sec$ for 160 kPa. For Applied pressure 10kPa,80 kPa and160kPa, value of coefficient of consolidation increases and for 20 kPa and 40 kPa the value of coefficient of consolidation decreases.

3.2 Comparison between relationship of void ratio to consolidation pressure: -

The results of four model tests show that, under the same loading increment and consolidation time, void ratio decreases(fig.20) which reveals that square pattern of bamboo reinforcement can effectively improve the soil. From the plot value of compression index was calculated. Value of Cc for without bamboo test is 0.76 and for circular, square and cross pattern are 0.63, 0.49 and 0.62 respectively.

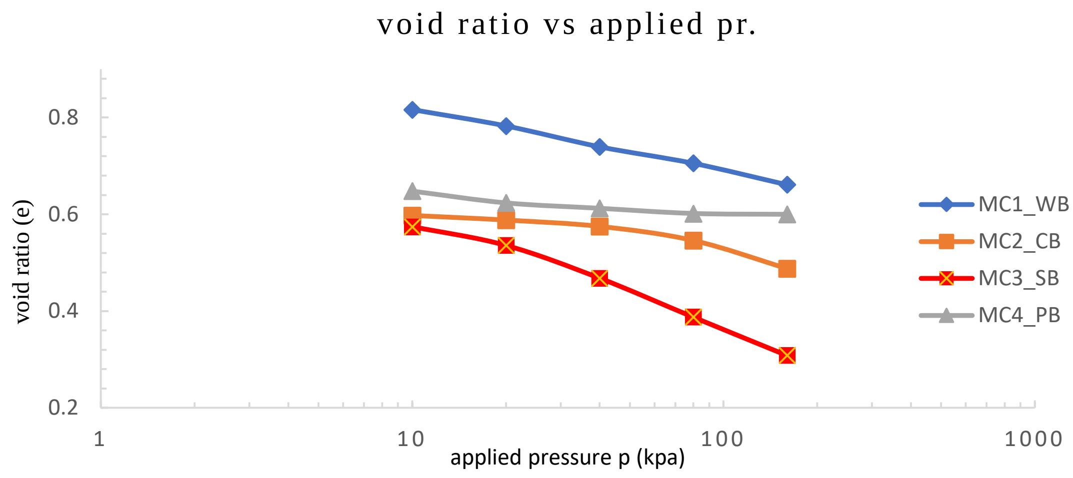


Fig.20 t of e vs log P

3.3 Effect of bamboo pattern on shear strength of soft clay: -

Figure 21 shows shear strength relationships with post vane shear test for model consolidation test with bamboo and without bamboo. The maximum gain in shear strength post consolidation is achieved for square pattern of bamboo i.e., 75 kPa. This clearly indicate that square pattern of bamboo has proven to be more efficient as compared to other patterns of bamboo. Shear strength for MC1_WB, MC2_CB and MC4_PB are 17 kPa, 51 kPa and 43 kPa respectively. Shear strength increase to some extent towards drain for any drain material.

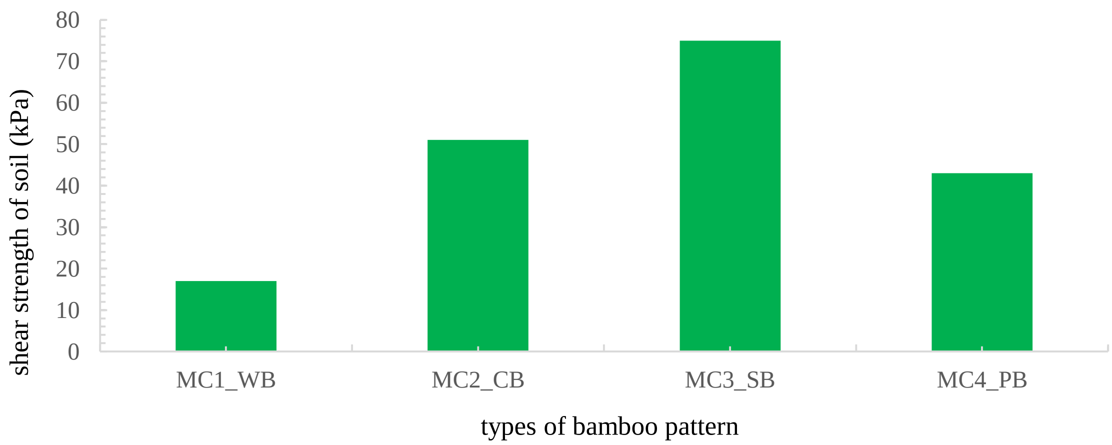


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Fig.21 shear strength of soil vs bamboo patterns

4. Conclusion

From above results and analysis, it can be concluded that compressibility characteristics play a vital role and they are influenced by different patterns of bamboo. In present study results of large-scale model consolidation tests are studied and following conclusion are made.

1. From plot of settlement vs log t, it can be concluded that Total settlement decreases while using bamboo. Total settlement is less in MC3_SB than MC3_WB, MC3_CB and MC3_PB.
2. From plot of e vs log P, it is clear that void ratio decreases with use of bamboo which means holes around the surface of the bamboo accelerate the consolidation process.

3. Value of compression index for MC3_SB is 0.49 which proves that bamboo filled with sand can work effectively as a drainage medium.
4. Results of vane shear tests show that bamboo increased the shear strength of soft clay. It proves that bamboo can work effectively as a reinforcement. Shear strength of MC3_SB is more than MC1_WB, MC2_CB and MC4_PB because more influence zone of bamboo covered in MC3_SB.

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