Laboratory Study on Consolidation Settlement of Soft Saturated Marine Clay Overlain by Geo-Cells In-filled with Sand

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Abstract. In the present study, laboratory one dimensional consolidation studies under sustained loads have been carried out on pure soft saturated clay of 250 mm thickness in tank having inside dimensions of 570 mm x 570 mm. The clay bed was loaded at its center with the aid of a circular steel plate of 170 mm diameter and 20 mm thickness. Similar tests were performed by placing a layer of geocell mattress having opening 40 mm by 40 mm and 25 mm height. For these cases, the sustained load applied varied from 0.01 kg/cm², 0.1 kg/cm², 0.2 kg/cm², 0.3 kg/cm², 0.4 kg/cm², 0.8 kg/cm², 1.6 kg/cm² and 3.2 kg/cm² for the time duration up to 90 % consolidation for each load. The termination criteria considered was a maximum stress of 3.2 kg/cm² or 70 mm whichever is early. Tests results of Geo-Cells were compared with the pure clay condition. This paper presents result of time vs settlement & load vs settlement for the various cases studied.

Keywords: Marine clay; Geo-cell; one dimensional consolidation

1 Introduction

Marine clay is found along the coastal regions of India. 2/3rd of the Indian continent is surrounded by ocean and bay, thus giving rise to soft saturated clay all along the coast may be Mumbai, Cochin, Vishakhapatnam, Hooghly, so on and so forth. Thus, the main question arises here is how the settlement behavior of civil engineering structure is going to behave under sustained loading. With new technology several techniques for ground improvement have immerged over the past few decades. The concept of soil reinforcement is being used extensively in the field of geotechnical engineering. There are many types of geosynthetic we have been using for years according to their applications. The research carried out for couple of decades shows that geocell is the most effective and most advantages because of its three dimensional nature. Cellular mattress used in combination with geo-materials is termed as geocell mattress. The concept of cellular confinement was first adopted by United States Army Corps of

Engineer (Webster 1979) in 1970s. Geocell is three dimensional structures which provide a lateral confinement to the infill material and such confinement further improves the shear strength of infill material. Geocell mattress protects weak subgrade by reducing the penetration of infill base material in soft subgrade leading to high lateral confining stress from wall and contact wall friction. When geocells re-filled with compacted infill material, the infill soil gets confined within the cellular walls, and then the composite forms a rigid to semi rigid structure which acts as a raft and it distribute the footing pressure over a wider area and reduces the footing settlement (de Garidel and Morel 1986). The geocell system of higher stiffness forms a mattress composite with bending stiffness just like a slab and thereby, reduces the stress on subgrade (Pokharel et al. 2011).

The present study investigates the consolidation settlement characteristics of soft saturated marine clay when subjected to sustained vertical stresses. This proposed experimental study has involved performing three consolidation tests by varying different parameters as detailed in the paper in later section.

Materials

The experimental study involves soft saturated marine clay, sand and geocell. Marine clay used in the present study was collected from JNPT area near Navi Mumbai, India. Specific gravity of the marine clay is 2.65. It contains clay particles 48.5%, silt particles 49% and sand particles 2.5%. Liquid limit, plastic limit and shrinkage limit of this marine clay are 94.66%, 31.6%, and 12.38% respectively. The pH value is 7 and Chloride content is 2.55%. Direct shear test was performed on the sample at density of 1.58 gm/cm^3, at 82% moisture content and void ratio of 2.10 and the cohesion (c) was observed to be 0.084 kg/cm^2 and angle of internal friction (ϕ) 4.65°. Sand was used as infill material for geocell had specific gravity of sand is 2.63 and ϕ is 45°.

Laboratory Model Tests

Test setup

Soft saturated marine clay and HDPE geocell were used to achieve the aims and objectives of the proposed study. To achieve the aims and objectives by using material described above, loading frame of size 1000 mm × 1000 mm × 1000 mm was fabricated. Jack was mounted on the frame. Calibrated proving ring of capacity 30 kN was used. Four dial gauges with least count of 0.01 mm were used to measure the settlement. The model tests were conducted in a tank with a length of 570 mm, width of 570 mm and height of 350 mm.

Preparation of Clay Bed and Test Procedure

Soft saturated clay was filled in the tank up to a height of 250 mm. This 250 mm thick clay bed was prepared in 50 mm thick layers with proper procedure so as to achieve the uniform density throughout the tank and without having any moisture loss. The required amount of clay for every layer was weighted out and then placed in tank. Water content and compaction was well controlled throughout the testing period. The tank was oiled properly to avoid the side friction. In second test tank was filled with 250 mm thick clay overlaid by geocell having aperture of 40 mm × 40 mm by thickness 25 mm, in filled with sand of 30 mm thickness. Throughout the test we tried to maintain the density of clay about 1.58 gm/cm^3 and moisture content about 82%.

After the preparation of clay bed, circular loading plate of diameter 170 mm was placed in the centre of the tank. Load was transferred concentrically from through plunger to plate. The applied load was measured through the pre-calibrated proving ring between the plate and hydraulic jack. Four dial gauges were fixed on the plate to record the settlement for each day for every load applied.

Traditional consolidation test were carried out in laboratory on three samples of soft saturated clay and consolidation parameters were calculated from the data obtained from the same. Based on the laboratory consolidation test data, arrived from average of 3 tests carried out, it was observed that the t_{90} for 20 mm clay sample worked out to 85.50 minutes. As we were carrying out a test on 250 mm thick soft saturated clay in the large scale test setup, the time required for 90% consolidation under single drainage condition works out to 9.5 days, hence, in our study we have applied the sustained load for 14 days. Based on this time calculation of 90% consolidation all the large scale test for each of the loading that is 0.01 kg/cm^2, 0.1 kg/cm^2, 0.2 kg/cm^2, 0.3 kg/cm^2 and 0.4 kg/cm^2 have been carried out for 14 days each. The other consideration in terms of settlements that have been considered when the test is terminated was, when the settlement reaches a value of 70 mm or up to 3.2 kg/cm^2 which is the capacity of the present proving ring within its permissible design limit. Fig. 1(a) and 1(b) shows the schematic plan and section of proposed test set up.

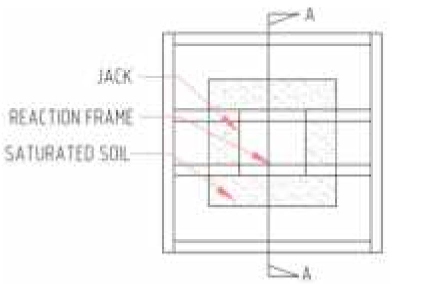

Fig. 1(a) Plan showing the loading frame.

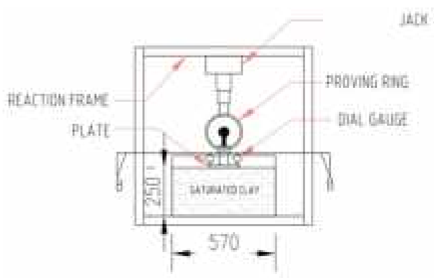

Fig. 1(b) Section A-A

2 Observations

After the completion of test, observations were taken in form of time vs settlement for each set of sustained load varying from 0.1 kg/cm², 0.2 kg/cm², 0.3 kg/cm², 0.4 kg/cm², 0.8 kg/cm², 1.6 kg/cm^2 and 3.2 kg/cm². From the data collected from two tests(Clay, Clay & GC), time vs settlement graph was plotted for all stress level and same is presented in Fig. 2(a). We have also plotted time vs settlement graph for individual stress levels, typical of which is shown in Fig. 2(b).

From Fig. 2(a) it is seen that at a stress level of 0.4 kg/cm^2 at the end of 70 days i.e., 1,00,800 minutes, the cumulative settlement observed for clay was 68.83 mm. Hence, a decision was taken to terminate this test at this stage. Similarly under similar conditions settlement of 16.51 mm was observed in case of clay overlaid by 25 mm geocell embedded in 30 mm of sand. Total settlement at the end of each stress level for all the three cases is given in Table. 1. Time vs Settlement graph was plotted and presented in Fig. 3. It is clearly seen that there is a drastic reduction in settlement that is taking place due to the introduction of geocell, at each and every stress level, which can be clearly seen from Table 1. Comparing the settlements with respect to pure clay condition for each stress level, the improvement in settlement due to introduction of 25 mm geocell (IF for GC) is given in Table 2.

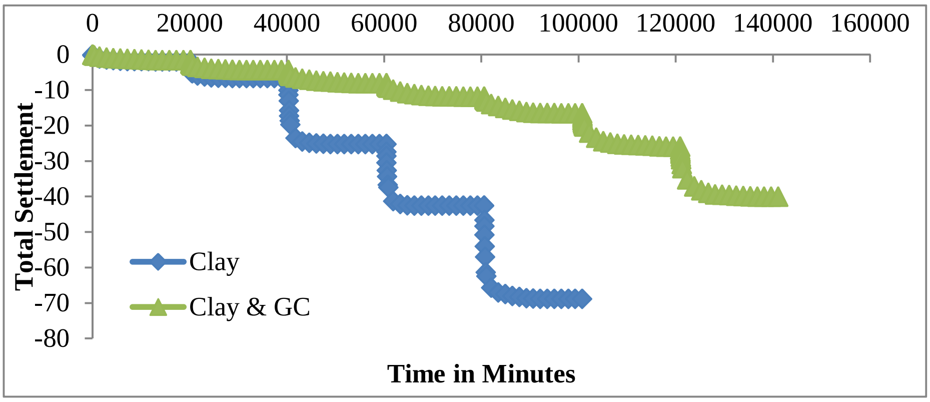

Fig. 2(a) Time vs settlement under all stress levels for all three cases

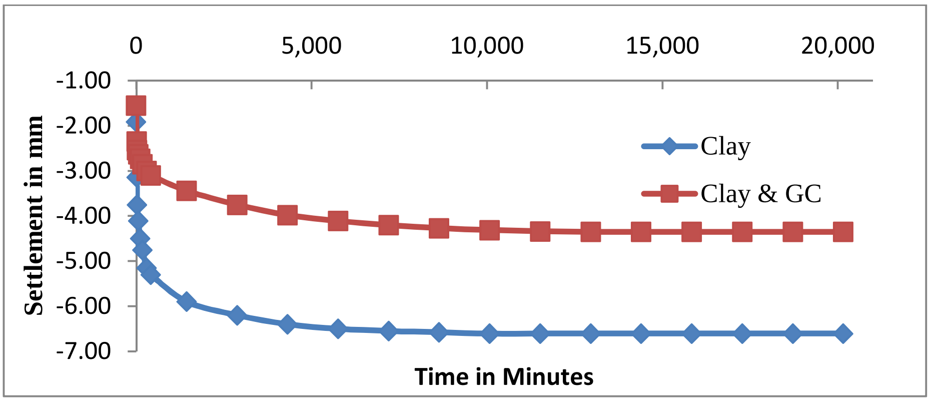

Fig. 2(b) Time vs settlement under sustained stress of 0.1 kg/cm^2

Table 1. Settlement at the end of each stage of loading.

Stress Level (kg/cm^{2})	Clay (mm)	Clay & GC (mm)
0.1	-6.61	-4.35
0.2	-25.24	-8.06
0.3	-42.50	-11.81
0.4	-68.83	-16.51
0.6	Test Terminated	-25.90
0.8	Test Terminated	-40.05

Based on the Fig. 3 Stress at settlement of 5 mm, 10 mm, 15 mm, 20 mm, 25 mm and 30 mm was calculated and a graph was plot to calculate the improvement in the stress at respective settlement. The same is presented in Table 3 and Fig. 4.

From Table 3 it can be observed that the load carrying capacity at settlement 30 mm is improved by 2.64 times.

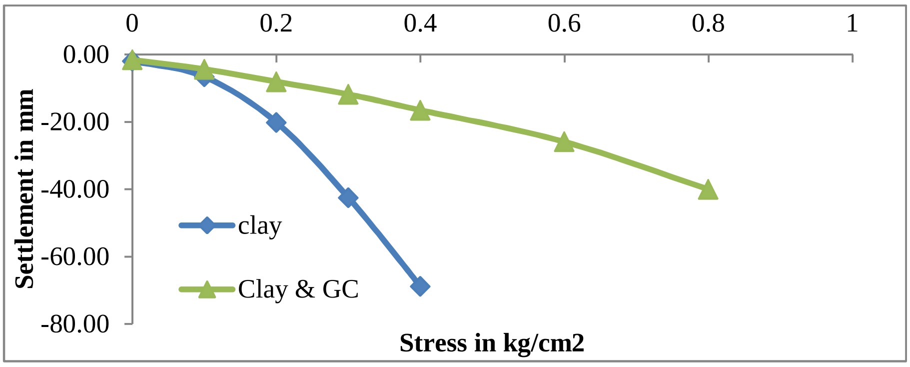

Fig. 3 Comparison of Settlement at the end of 90 % consolidation with respect to Stress

Table 2. Settlement at end of 90% consolidation (20160 minutes) and improvement factor (IF) for each stress level

Stress Level	Clay	Clay & GC	IF for GC
kg/cm^{2}	mm	mm	
0.1	-6.61	-4.35	1.52
0.2	-25.24	-8.06	2.5
0.3	-42.50	-11.81	3.6
0.4	-68.83	-16.51	4.17

Table 3. Stress at respective settlement

Settlement	Clay	Clay & GC
mm	kg/cm^2	kg/cm^2
5	0.08	0.11
10	0.13	0.24
15	0.17	0.36
20	0.20	0.45
25	0.23	0.52
30	0.25	0.66

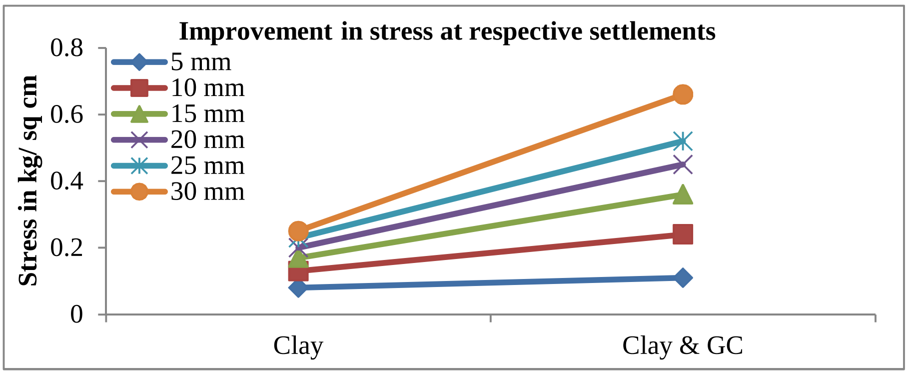

Fig. 4 Improvement in stress at respective settlement

The time required for 90 % consolidation (t_{90}) is evaluated from settlement versus root of time plot and observed in all the cases for stress level between 0.1 kg/cm^2 and 0.4 kg/cm^2 is presented in Table 4, from the ratios of the large scale test upon laboratory test shows that, for clay upon laboratory ratio is 5.84 and clay & geocell upon laboratory is 7.04 at a stress level of 0.1 kg/cm^2. Subsequently as the stress increases this ratio remains nearing constant at 4.00 for clay upon laboratory and 3.85 for clay & geocell upon laboratory, which can be seen from Fig. 5.

Table 4. Observations of t_{90}

Stress Level	Lab Test	Clay	Clay & GC	Clay & GC/ Clay	Clay/ Lab	Clay & GC/ Lab
kg/cm^2	min	min	min			
0.1	82.81	484.00	583.22	1.21	5.84	7.04
0.2	60.06	361.00	441.00	1.22	6.01	7.34
0.3	90.25	555.07	529.00	0.95	6.15	5.86
0.4	144.00	576.00	555.07	0.96	4.00	3.85

While comparing the ratios of clay & Geocells with respect to clay, it is observed that these values are nearing to 1 as can be seen in Fig. 6.

The settlement at t_{90} observed in all the cases for stress level between 0.1 kg/cm^2 and 0.4 kg/cm^2 is presented in Table 7, from the ratios of the large scale test upon laboratory test shows that, for clay upon laboratory ratio is 6.36 and clay & geocell upon laboratory is 3.89 at a stress level of 0.1 kg/cm^2. Subsequently as the stress increases this ratio goes on increasing and for 0.4 kg/cm^2 it becomes 26.84 for clay upon laboratory and 5.68 for clay & geocell upon laboratory, which can be seen from Fig 7.

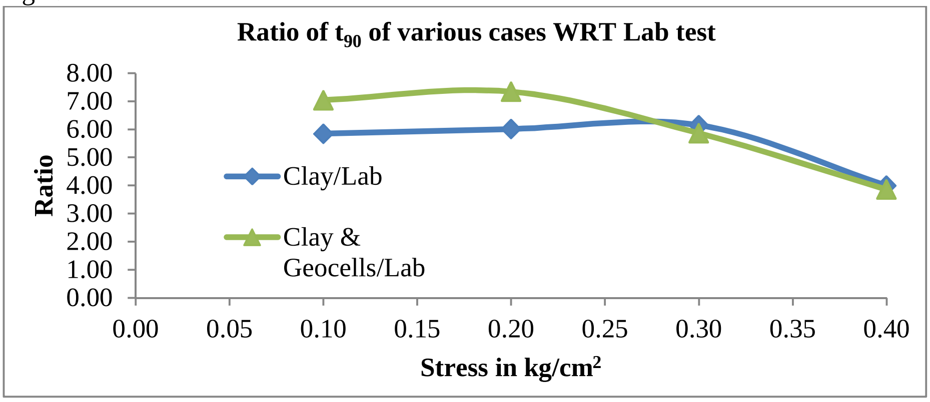

Fig.5 Ratio of t_{90} of various cases WRT Lab test

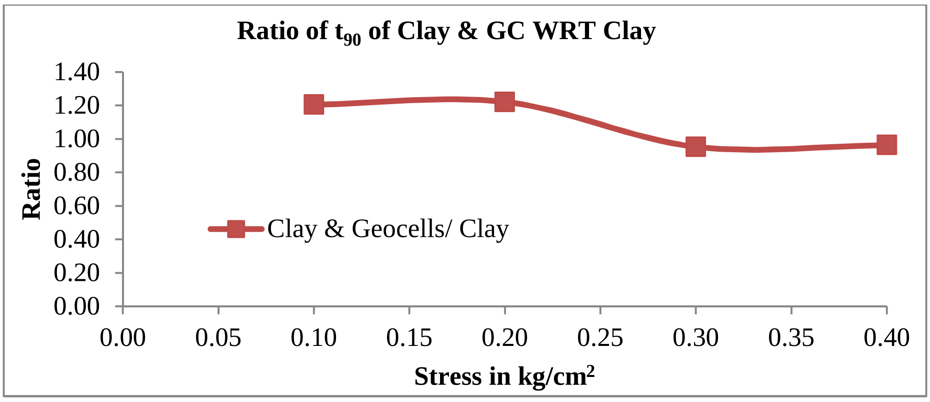

Fig. 6. Ratio of $t_{90}$with respect to Clay

Table 5. Observation of Settlement at t_{90}

Stress Level	Lab Test	Clay	Clay & GC	Clay & GC/ Clay	Clay/ Lab	Clay & GC/ Lab
kg/cm^2	mm	mm	mm			
0.1	-0.81	-5.15	-3.15	0.61	6.36	3.89
0.2	-1.33	-16.25	-6.05	0.31	14.47	4.55
0.3	-1.86	-38.90	-9.40	0.24	20.91	5.05
0.4	-2.35	-63.00	-13.35	0.21	26.81	5.68

Similar attempts have been carried out by taking a ratio of clay & geocell upon clay which is presented in Fig.8. In this case it is seen that the ratio of clay & geocell upon clay it drops from 0.61 to 0.21.

The settlement at end of 90 % consolidation observed in all the cases for stress level between 0.1 kg/cm^2 and 0.4 kg/cm^2 is presented in Table 6, from the ratios of the large scale test upon laboratory test shows that, for clay upon laboratory ratio is 6.48 and clay & geocell upon laboratory is 4.26 at a stress level of 0.1 kg/cm^2. Subsequently as the stress increases this ratio goes on increasing and for 0.4 kg/cm^2 it becomes 27.21 for clay upon laboratory and 6.53 for clay & geocell upon laboratory, which can be seen from Fig. 9.

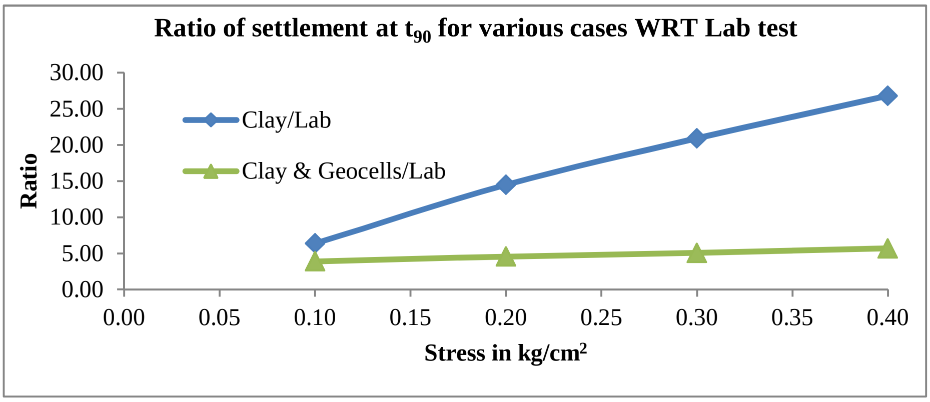

Fig. 7 Ratio of settlement at t_{90} of various cases WRT Lab test

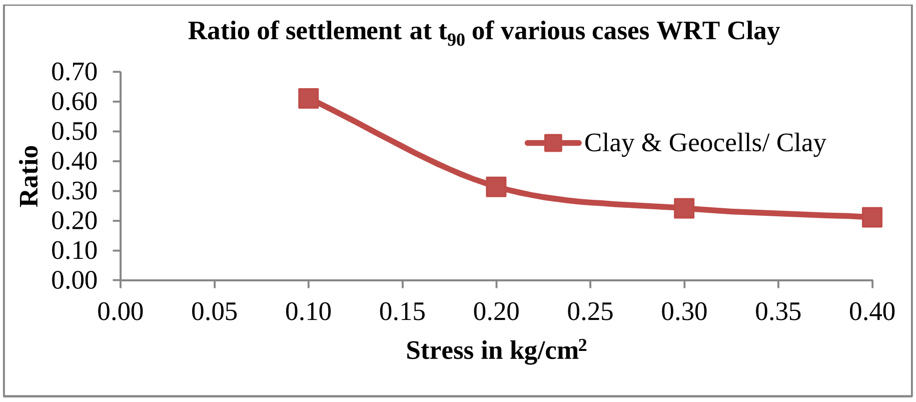

Fig. 8. Ratio of settlement at t_{90} of various cases WRT Clay

Table 6. Observation of Settlement at end of 90% consolidation

Stress Level	Lab Test	Clay	Clay & GC	Clay & GC/ Clay	Clay/ Lab	Clay & GC/ Lab
kg/cm^2	mm	mm	mm			
0.1	-1.02	-6.61	-4.35	0.66	6.48	4.26
0.2	-1.65	-25.24	-8.06	0.32	15.29	4.88
0.3	-2.11	-42.50	-11.81	0.28	20.14	5.60
0.4	-2.53	-68.83	-16.51	0.24	27.21	6.53

Attempts have been carried out by taking a ratio of clay & geocell upon clay which is presented in Fig. 10. In this case it is seen that the ratio of clay & geocell upon clay it drops from 0.66 to 0.24

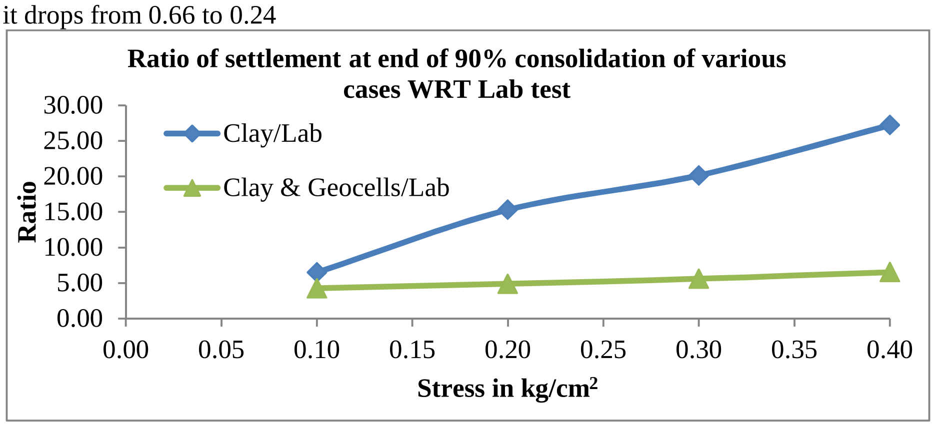

Fig.9 Ratio of settlement at end of 90% consolidation of various cases WRT Lab test

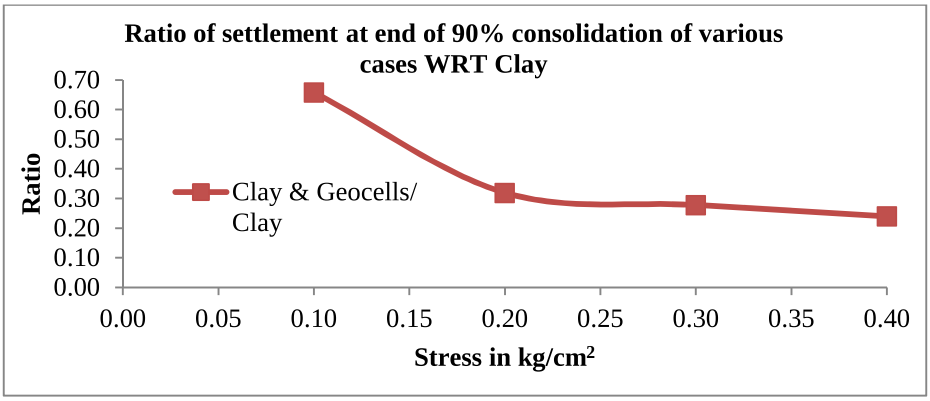

Fig.10 Ratio of settlement at end of 90% consolidation of various cases WRT Clay

Based on the data collected, coefficient of consolidation (Cv) is evaluated from t_{90} for all the stress levels between 0.1 kg/cm^2 to 0.4 kg/cm^2 the Cv evaluated for all the cases is tabled Table 7. From the ratios of the large scale test upon laboratory test shows that, for clay upon laboratory ratio is 106.93 and clay & geocell upon laboratory is 88.74 at a stress level of 0.1 kg/cm^2. Subsequently as the stress increases this ratio remains nearing constant 156.25 for clay upon laboratory and 162.14 for clay & geocell upon laboratory, which can be seen in Table 7 and in Fig. 11

Similar attempts have been carried out by taking a ratio clay & geocell upon clay which is presented in Fig. 12 In this case it is seen that the ratio of clay & geocell upon clay it increases from 0.83 to 1.04.

Table 7. Evaluation of C_v

Stress Level	Lab	Clay	Clay & GC	Clay & GC/Clay	Clay/Lab	Clay & GC/ Lab
kg/cm^2	cm^2/sec	cm^2/sec	cm^2/sec			
0.1	1.71E-04	1.83E-02	1.51E-02	0.83	106.93	88.74
0.2	2.35E-04	2.45E-02	2.00E-02	0.82	103.99	85.12
0.3	1.57E-04	1.59E-02	1.67E-02	1.05	101.62	106.63
0.4	9.81E-05	1.53E-02	1.59E-02	1.04	156.25	162.14

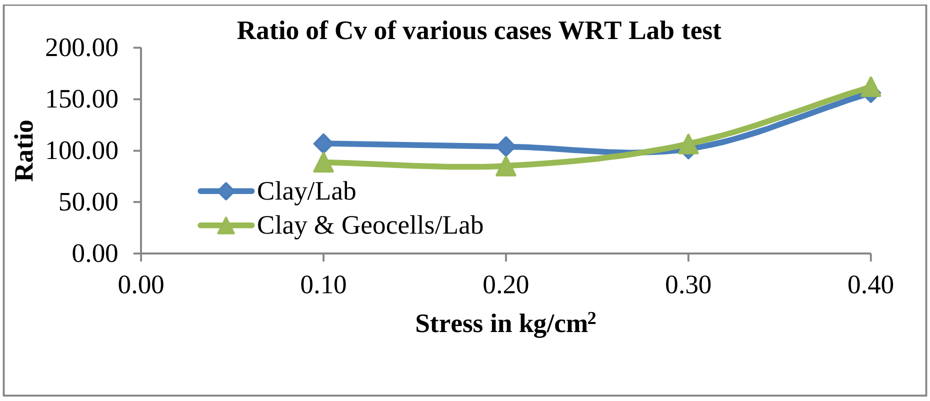

Fig. 11 Coefficient of consolidation of various cases WRT Lab

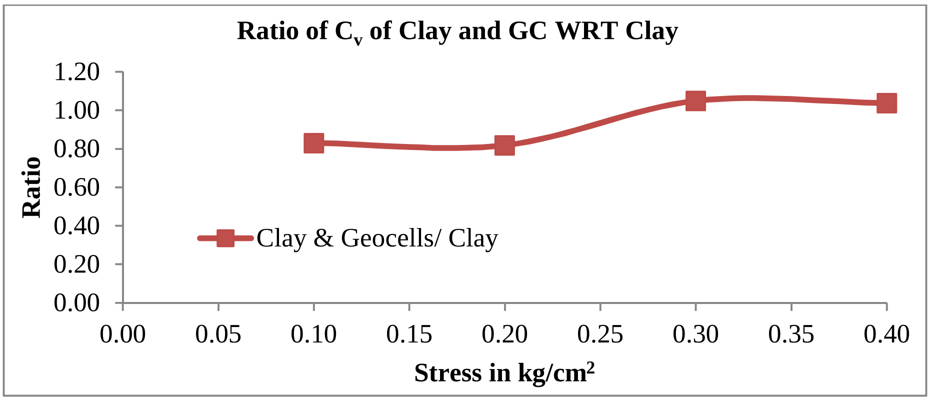

Fig. 12 Coefficient of consolidation of various cases WRT Clay

3 Summary

Based on the experimental investigation conducted in our study, it is observed that there is good amount of reduction in settlement due to introduction of geocell on soft saturated clays. The comparison of settlement and other parameters of consolidation are given below:

- It is observed that settlement in clay & geocell is 4.17 times lesser than that of in Pure Clay.
- It can be observed that the ratio of Clay & GC upon Lab and Clay & GC upon Clay is 3.85 and 0.96 respectively for t_{90}.
- It is observed that the ratio of Clay & GC upon Lab and Clay & GC upon Clay is 5.08 and 0.21 respectively for settlement at t_{90}.

- It is observed that the ratio of Clay & GC upon Lab and Clay & GC upon Clay is 6.53 and 0.24 respectively for settlement at end of 90% consolidation.

4 Conclusion

It is observed that at 0.4 kg/cm^2 the settlement observed in clay was of the order of 68.83 mm, corresponding at the same stress level the settlement in clay overlaid by GC was only 16.51 implying a reduction in settlement by more than 4 times.

In case of clay, punching shear failure was observed, while in the case of clay overlaid by GC it was observed to be uniform settlement.

The ultimate bearing capacity evaluated for clay was found to be 0.18 kg/cm^2 and the stress at 40 mm settlement was observed to be 0.29 kg/cm^2, while in case of clay overlaid by GC at the end of 0.8 kg/cm^2 the total settlement observed was only 40.05 mm.

Acknowledgement

The authors are thankful to the authorities of NYSS Airoli and Datta Meghe College of Engineering for making facilities available in the laboratory for conducting the tests. They are also thankful to STRATA Geosystems, INDIA for manufacturing and supplying the GC used in the experimental work.

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