A Comparative Study on Consolidation of Clay for Various Loading Conditions

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Abstract: ***Settlement can be defined as the vertical, downward movement of soil due to decrease in the volume of soil and it occurs mainly in soils having low strength. Various problems encountered like settlement can cause serious problems to the structures constructed above it. New techniques are adopted to minimise these problems created by the soil like accelerating the rate of consolidation. In this project consolidation of clay under conventional, vacuum-surcharge loading providing a sand drain has been studied. Tests were conducted for various pressures of 20, 40, 50, and 80kPa with and without sand drain. From the result obtained it was found that the coefficient of consolidation and total settlement is higher for soil with sand drain. The coefficient of volume change is minimum under vacuum loading without drain. The time taken for 90% consolidation was lesser and the settlement was higher in combined vacuum-surcharge loading having drain than without drain. Settlement increased by 1.15 times by using vertical sand drain when compared with the settlement of soil without sand drain.***

Keywords: Consolidation, stabilization, surcharge, vacuum.

1. Introduction

Due to rapid increase in population, numerous economic developments are taking place in the world during the last few decades .Construction activities are concentrated on low-lying marshy areas, which comprise of highly compressible weak organic and silty clays of varying thickness. Soft clayey soils usually have low bearing capacity and show higher settlement characteristics. Because of this reasons soft soils should be stabilized before commencing the construction activities, to prevent differential settlements. One of the method to stabilize soft soil deposits is by accelerating the rate of consolidation. The various techniques which can be used to accelerate consolidation are preloading, installation of sand drains, prefabricated vertical drains, vacuum consolidation and high vacuum densification method.

Vacuum consolidation is a technique used to improve the strength of soft clayey soils. Vacuum consolidation is more advantageous than other method mentioned above. Vacuum consolidation can be used as an alternative method to conventional preloading technique, to consolidate soft soils, to improve bearing capacity prior to construction, and to reduce settlement after construction.

The objective of this paper is to compare the effect on coefficient of consolidation, settlement by surcharge, vacuum and combined vacuum-surcharge loading with and without sand drain.

2. Literature Survey

“Accelerated consolidation of clay by using combined vacuum-surcharge pressures” by Soumya S.B. International Journal of Engineering Research and Technology,2016: In this paper tests are performed on the soil by applying vacuum, surcharge and combined vacuum-surcharge loading to understand the behavior of vacuum consolidation. From the result, it was observed that the coefficient of consolidation increases with the increase in vacuum pressure and combined vacuum surcharge pressure. Time taken for 90% consolidation was reduced and settlement was accelerated with increase in vacuum pressure.[1]

“Stabilization of soft clay using PVDs by combined vacuum-surcharge pressures” by S.Sakthiraj and K.Illamparuthi, IGC pp 396-400,2009: In this study tests are performed in conventional consolidation apparatus with and without PVD and the test results are compared with that on larger mould. The three vacuum pressures used for study are 30, 60, 90 KPa the settlement achieved is higher for the vacuum-surcharge loading. The time taken for 90% consolidation for vacuum loading is just higher than the value of vacuum-surcharge loading and it is about 0.65 times that of surcharge loading. The total settlement achieved is 15% high for the combined vacuum-surcharge loading than other two methods of loading.[2]

“Consolidation of clay by vacuum method” by G.Nithya and K. Illamparuthi, IGC pp 421-424,2011: In this study tests are performed in conventional consolidation apparatus with and without PVD and the test results are compared with that on larger mould. The three vacuum pressures used for study are 30, 50, 80 KPa respectively .The results obtained indicated that the coefficient of consolidation for the tests on consolidation cell is higher for vacuum and vacuum-surcharge loading. The time taken for 90% consolidation is reduced by 25% and the settlement is accelerated by 35% in vacuum and combined vacuum-surcharge loading than surcharge loading.[3]

“Ground improvement using vacuum loading together with vertical drains”, by G. Mesri, and A.Q.Khan, ASCE Journal for Geotechnical Engineering, 680-689, 2012: investigated Ground improvement using vacuum loading together with vertical drains. The test results indicate that in highly stratified soil profiles, the total magnitude of vacuum that is available within the vertical drains may not be reached in some soil layers. The increase in undrained shear strength of soft clay and silt deposits subjected to a constant increase in effective vertical stress with depth, resulting from either vacuum load or fill load remains constant with depth for soil.[4]

3. Methods

3.1 Soil and Materials used.

The clayey soil was collected from the banks of Akkulam lake ,Trivandrum, Kerala. A mould of 10cm diameter and 12.8cm height ,vacuum pump of 0.25 HP, vacuum gauge, drainage chamber were the materials used for the study.

3.2 Methodology

3.2.1. Preparation of Soft Clay

The soil collected from the pit was completely dried and the sand particles were removed. The tests were carried out at a water content of 68% ie 5% greater than the liquid limit The required water content is added to it and soaked for 24 hours and then thoroughly mixed before placing it in the mould. The soil sample is then filled in the mould carefully by removing the air bubbles.

3.2.2 Experimental Setup

An experimental setup is developed in this study to conduct consolidation test under vacuum pressure. The arrangement consists of a vacuum pump of capacity of 180 kPa, a vacuum regulator, a vacuum desiccator and a vacuum gauge. The required vacuum pressure is applied to the sample by operating the regulator and the vacuum gauge is used to measure and monitor the vacuum pressure applied on the sample. The water draining from the sample is collected in the desiccator.

Tests were carried out in a large mould having 10 cm diameter and 12.8cm height. The test was conducted for vacuum pressures of 20, 40, 50 and 80 kPa and the test was conducted for surcharge, vacuum and combined vacuum-surcharge pressures.

Another series of test containing a vertical sand drain at the middle of the sample were also conducted. The drain diameter was fixed based on $n=r_w/r$.(1) The sand drain of diameter 27mm was provided along the height of the soil sample and the series of tests were conducted and hence a comparison was made between the results obtained for sample with and without sand drain

Figure 1: Experimental setup

3.2.3 Vacuum Loading Procedure

The test for vacuum loading is conducted by adopting the procedure given below.

Vacuum pressure of required intensity is set by operating the vacuum pump and by adjusting the regulator. Vacuum pump is then turned off and the vacuum pressure line from the vacuum pump is connected to the drainage line of the clay sample in the mould. The dial gauge was placed on top of the mould to record the settlement of the clay sample. The vacuum pump is operated and the settlement was recorded continuously for predetermined time intervals. The vacuum pressure of required intensity is maintained throughout the test by adjusting the knob of the vacuum regulator.

3.2.4. Combined Vacuum- Surcharge Loading

The procedure includes the same step mentioned above for vacuum pressure application and the mould was placed and now the vacuum pressure and surcharge was applied simultaneously and the dial gauge readings were noted for predetermined time intervals.

4. Results and Discussions

4.1 Soil Properties

Table 1: Geotechnical Properties of soil used

Property	*Value*
Specific Gravity	2.41
% clay	50.44
% silt	31.5
% sand	18.06
Liquid Limit (%)	63
Plastic Limit (%)	35.29
Shrinkage Limit (%)	21.93
Plasticity Index (%)	27.71
Maximum Dry Density (g/cc)	1.25
Optimum Moisture Content (%)	32
Unconfined Compressive strength (kg/cm^2)	0.30
Coefficient of permeability(m/sec)	$2.46x10^{-7}$

Table 2: Properties of sand used for sand drain

Property	*Value*
Specific Gravity	2.65
% sand	99.92
% silt and clay	0.076
Coefficient of permeability(m/sec)	5.65×10^{-3}

4.2 Effect on Coefficient of Consolidation for Different Loading Conditions

4.2.1Surcharge Loading

Coefficient of consolidation and total settlement obtained from surcharge loading by applying a surcharge pressure of 0.2 Kg/cm^2 of sample with and without drain is conducted.

Table 3: Results of tests by surcharge loading without sand drain

Surcharge Pressure (Kg/cm^2)	*t_{90} (min)*	*$C_V \times 10^{-3}$ (cm^2/s)*	*90% consolidation (mm)*	*Total settlement*	
				mm	*%*
0.2	77.44	6.15	7.1	7.8	6.5

Table 4: Results of tests by surcharge loading with sand drain

Surcharge Pressure (Kg/cm^2)	*t_{90} (min)*	*$C_{vr} \times 10^{-3}$ (cm^2/sec)*	*90% consolidation (mm)*	*Total settlement*	
				(mm)	*(%)*
0.2	64	7.32	8.75	9.73	8.11

4.2.2 Vacuum Loading

From the result it was found that the coefficient of consolidation and total settlement increases with the increase in vacuum pressure and the coefficient of consolidation and total settlement is more in sample having
sand drain when compared with the sample without drain.

Table 5: Results of tests by vacuum loading without drain

Vacuum Pressure (kPa)	*t_{90} (min)*	*$C_V \times 10^{-3}$ (cm^2/sec)*	*90% consolidation (mm)*	*Total settlement*	
				(mm)	*(%)*
20	72.25	6.52	8.1	9.0	7.5
40	68.89	6.84	8.2	9.11	7.59
50	67.24	6.99	8.4	9.34	7.78
80	64	7.31	8.88	9.87	8.23

Table 6: Results of tests by vacuum loading with sand drain

Vacuum Pressure (kPa)	*t_{90} (min)*	*$C_{vr} \times 10^{-3}$ (cm^2/sec*	*90% consolidation (mm)*	*Total settlement*	
				(mm)	*(%)*
20	57.76	8.06	8.9	10.5	8.75
40	54.76	8.48	9	10.7	8.92
50	50.41	9.2	9.1	10.9	9.10
80	46.24	9.99	9.4	11.35	9.46

4.2.3. Combined Vacuum -surcharge Loading

From the result it was found that coefficient of consolidation increases with increase in vacuum-surcharge pressure. It was found that the coefficient of consolidation and settlement obtained in sample with drain is more than in sample alone.

Table 7: Results of tests by combined vacuum surcharge loading without sand drain

Vacuum-surcharge Pressure (kPa)	*t_{90} (min)*	*$C_V \times 10^{-3}$ (cm^2/sec)*	*90% consolidation (mm)*	*Total settlement*	
				mm)	*(%)*
20	62.41	7.44	9.7	10.7	8.92
40	59.29	7.79	10.3	11.4	9.5
50	56.25	8.19	10.4	11.56	9.63
80	49	9.31	11.5	12.78	10.65

Table 8. Result of tests by comb vacuum surcharge with drain

Vacuum-surcharge Pressure (kPa)	*t_{90} (min)*	*$C_{vr} \times 10^{-3}$ (cm^2/sec)*	*90% consolidation (mm)*	*Total settlement(mm)*	
				(mm	***(%)***
20	42.25	10.79	10.6	12.8	10.67
40	38.44	11.8	11.2	13.4	11.17
50	36	12.56	11.4	13.75	11.46
80	30.25	14.83	12	14.65	12.21

4.3. Effect on Coefficient of Volume Change for Different loading Conditions

From the result it was found that coefficient of volume change decreases with increase in vacuum pressure and combined vacuum surcharge pressure. It was found that the coefficient of volume change is minimum in vacuum loading of soil sample without drain than in the soil sample with sand drain.

Table 9: Variation in coefficient of volume change for soil sample without sand drain

Loading Conditions	*Vacuum Pressure (kPa)*	*Coefficient of volume change, m_v (m^2/kN)*
Surcharge	20	3.25×10^{-3}
Vacuum	20	3.75×10^{-3}
	40	1.89×10^{-3}
	50	1.56×10^{-3}
	80	1.03×10^{-3}
Vacuum-surcharge	20	4.46×10^{-3}
	40	2.38×10^{-3}
	50	1.93×10^{-3}
	80	1.33×10^{-3}

Table 10: Variation in coefficient of volume change for soil sample with sand drain

Loading Conditions	*Vacuum Pressure (kPa)*	*Coefficient of volume change m_v (m^2/kN)*
Surcharge with drain	20	4.05×10^{-3}
Vacuum with drain	20	4.37×10^{-3}
	40	2.23×10^{-3}
	50	1.82×10^{-3}
	80	1.18×10^{-3}
Vacuum- surcharge with drain	20	5.33×10^{-3}
	40	2.79×10^{-3}
	50	2.29×10^{-3}
	80	1.52×10^{-3}

4.4 Comparison of Settlement, Coefficient of Consolidation and Volume Change for Different Loading Conditions

From the results obtained above, a comparison was made for the soil sample with drain and without drain. It was seen that the total settlement and coefficient of consolidation was found to be higher in the case of drains than the one without it. The coefficient of volume change was smaller in the case of soil sample without sand drain than the one with it.

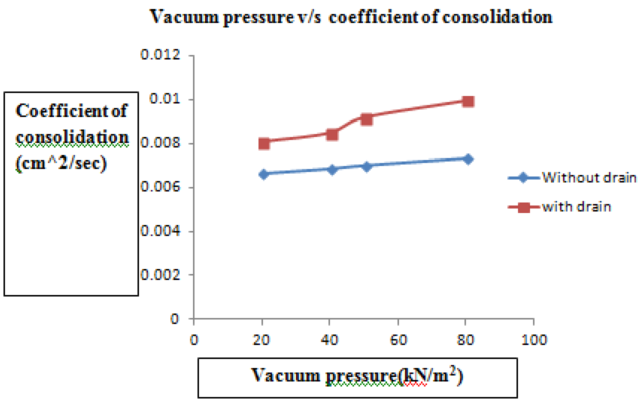

Figure 2: Variation of coefficient of consolidation for vacuum loading

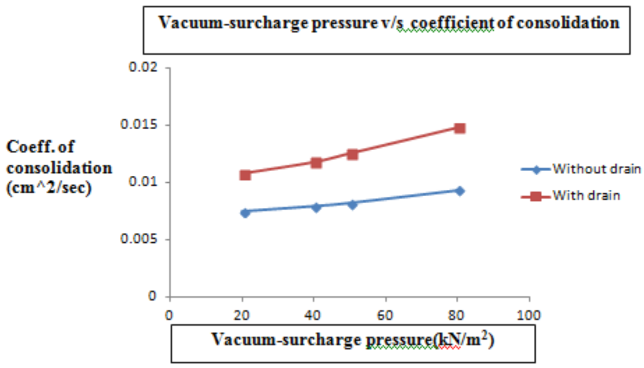

Figure 3: Variation of coefficient of consolidation for combined vacuum-surcharge loading

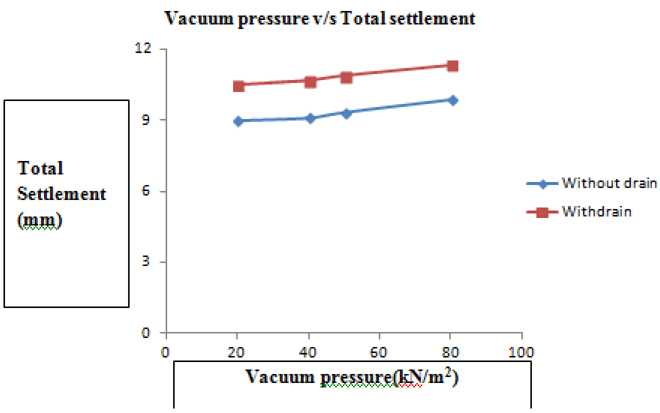

Figure 4: Variation of total settlement for vacuum loading

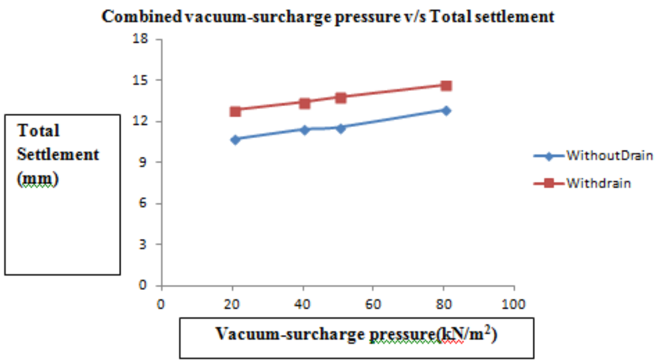

Figure 5: Variation of total settlement for combined vacuum-surcharge loading

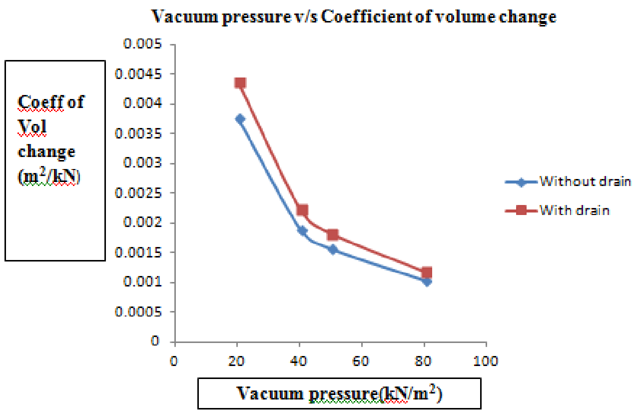

Figure 6: Variation of coefficient of volume change for vacuum loading

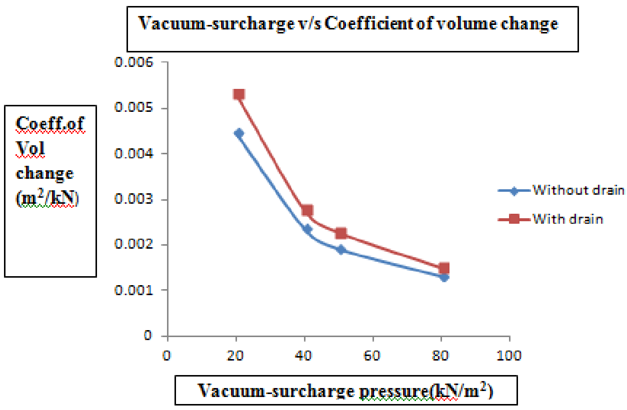

Figure 7: Variation of coefficient of volume change for combined vacuum-surcharge loading

4.5Variation of Degree of Consolidation v/s Time Factor for Vacuum Loading and Combined Vacuum-surcharge loading

From the graph given below it is seen that vacuum and combined vacuum loading in both the case of soil sample(ie. with drain and without sand drain) agree with the Terzaghi's theoretical curve.

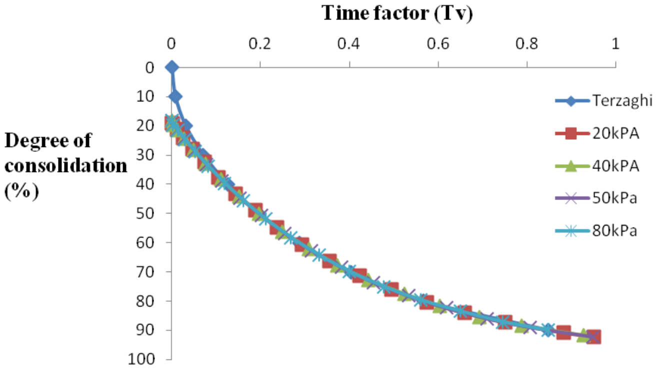

Figure 8.Variation of U_v v/s T_v for vacuum loading of sample without sand drain

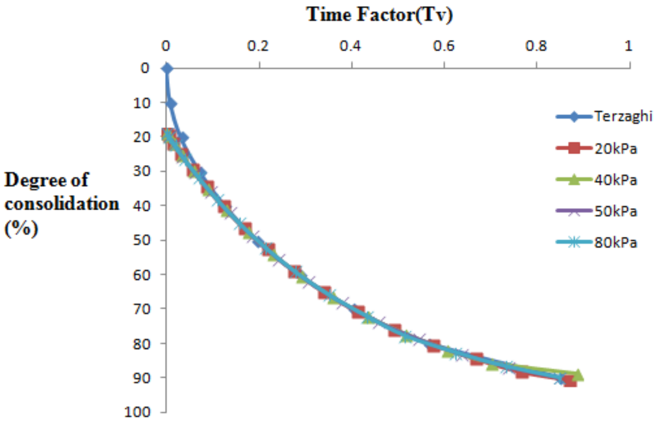

Figure 9: Variation of U v/s T_v for combined vacuum-surcharge loading of sample without sand drain

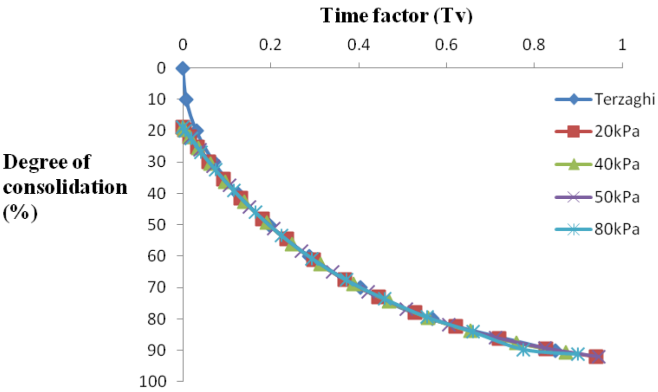

Figure 10: Variation of U_V v/s T_v for vacuum loading of sample with sand drain

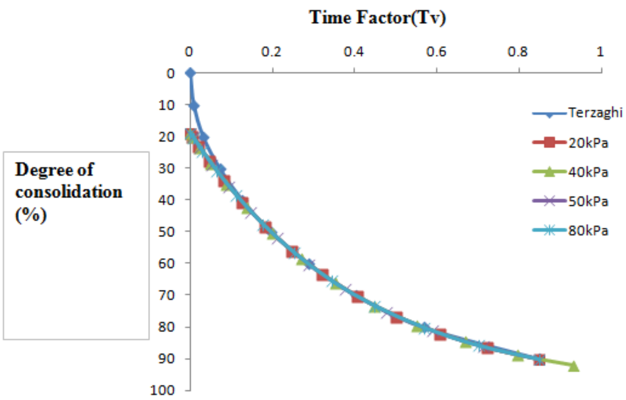

Figure 11: Variation of U_v v/s T_v for combined vacuum-surcharge loading of sample with sand drain.

5. Conclusions

In this study, from the obtained results the following conclusions were made:

- The coefficient of consolidation is higher in combined vacuum-surcharge loading in soil sample with sand drain than in the sample without drain.
- The maximum value of coefficient of consolidation obtained in sample without drain was $9.31x10^{-3}cm^2/sec$ and in sample with drain was $14.83x10^{-3}$ cm^2/sec.
- The minimum value of coefficient of volume change obtained in sample with drain was $1.18x10^{-3}$ m^2/kN and in sample without drain was $1.03x10^{-3}$ m^2/kN.
- The settlement increased by 15.39% in vacuum and by 37.18% in combined vacuum-surcharge loading and in the case of sample with sand drain the settlement is increased by 34.6% in vacuum and 64.10% in combined vacuum surcharge pressure.
- The time taken for 90% consolidation was decreased by 6.70% in vacuum and by 19.41% in combined vacuum-surcharge pressures and in the case of sample with sand drain the time taken for 90% consolidation was decreased by 25.41% in vacuum and 45.44% in combined vacuum surcharge pressure.
- From the results obtained in vacuum and combined vacuum-surcharge loading it was seen that the settlement increased by 1.15 times by using vertical sand drain when compared with the settlement containing soil without sand drain.
- The relationship between time factor and degree of consolidation agrees with the Terzaghi's theoretical curve.

6. Future Scope

The scope for future study is by conducting the test on a larger mould of greater size than the size of sample used in the study using vacuum pressures and/or by providing various number of drains on the soil sample.

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