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Accelerated Consolidation of Clay by using Combined Vacuum-Surcharge Pressures

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***Abstract*— Soft soil has always been a challenge for geotechnical engineers for constructing stable structures. They are highly compressible which influences the settlement of structure for a long period of time even after the structure is put into service. To avoid this, the soft soil at the site can be improved by suitable ground improvement technique. Soil improvement is frequently termed soil stabilization, which in its broadest sense is alteration of any property of a soil to improve its engineering performance. Vacuum consolidation is one such technique to improve the strength of soft clays. In this study, tests are performed on the soil sample by applying vacuum, surcharge and combined vacuum-surcharge loading to understand the behavior of vacuum consolidation. Experimental tests were conducted using conventional consolidation cell and the efficiency of vacuum consolidation was compared with the conventional surcharging method. From the results, it is observed that the coefficient of consolidation increases with increase in vacuum pressure and combined vacuum-surcharge pressure. The time taken for 90% consolidation is reduced by 32% in vacuum and 38% in combined vacuum-surcharge loading and the settlement is accelerated by 25% in vacuum loading and 45% in combined vacuum-surcharge loading.**

Keywords—Vacuum; consolidation; stabilization; surcharge

I. 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. These soft clay deposits have low bearing capacity and excessive settlement characteristics. Therefore, it is essential to stabilize the existing soft soils before commencing the construction activities, in order to prevent differential settlements. Also in such low-lying areas, it is necessary to raise the existing ground level to keep the surface area above the ground water table or flood level. One of the best ways to stabilize these soft soil deposits is by accelerating the rate of consolidation. Accelerating the rate of consolidation is also useful in certain civil engineering works, such as highway and airfield embankments on compressible soils, wherein it is essential that the major portion of the settlement should have occurred during construction and not after construction. Also in order to increase the shear strength of a dam foundation to permit more rapid construction, acceleration of consolidation is required. 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.

Preloading is one of the most successful ground improvement techniques that can be used in low- lying marshy areas. Preloading increases the bearing capacity and reduces the compressibility of weak ground. Preloading allows cheaper spread footings and thus allows savings on foundation costs. It involves loading of the ground surface to induce a greater part of the ultimate settlement that the ground is expected to experience after construction. It helps to lower water table in cohesion less soil and gravel. It is most effective in soft cohesive ground. Since most compressible soils are characterized by very low permeability and considerable thickness, the time needed for the required consolidation can be long, and also the surcharge load required may be significant high, so surcharge preloading may not be possible with busy construction schedules. Preloading can be speed up by the installation of vertical sand drains. But the main disadvantage of sand drains is the effect of smear zone which reduces the coefficient of permeability in radial direction. So to overcome this instead of sand drains, PVDs can be used. PVDs have many advantages over sand drains. But it cannot be used in highly sensitive soils, cold weather conditions and if compressive soil layer overlain by dense fills or other obstructions. Vacuum consolidation can be used to overcome the drawbacks of above methods

Vacuum consolidation is a technique used to improve the strength of soft clayey soils. It can be used to overcome the drawbacks of other methods to accelerate consolidation. The vacuum consolidation method utilizes the atmospheric pressure to consolidate soft saturated sediments by similar principles as those used in surcharge preloading by vertical drains. Instead of increasing the effective stress in the soil mass by increasing the total stress by means of conventional mechanical surcharging, vacuum assisted consolidation preloads the soil by reducing the pore pressure while maintaining a constant total stress. The change in soil pore water pressure produced from applied vacuum preloading induces discharge of pore water which results in consolidation thereby increase the shear strength of the soil. As an alternative to the conventional preloading, vacuum assisted consolidation can be used to consolidate soft clayey soils.

II. LITERATURE REVIEW

"Prediction of the stress state and deformation of soil deposit under vacuum pressure" by Steeva Gaily Journal of Transportation Geotechnics, 2015: This paper used the results of laboratory vacuum consolidation test under triaxial

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condition with proper confinement to predict vacuum pressure induced deformations in the field. The test results indicated that the effective confinement from the surrounding soils to the vacuum treated area is close to active earth pressure for a zone about 5 m depth from the ground surface, and below it is between active and at-rest states.

"Improvement of soft clays by combined vacuum consolidation and geosynthetic encased stone columns" by **S** Ganesh Kumar, R G Robinson Indian Geotech J, 2014: This paper used a laboratory study on silty clay to investigate the load carrying capacity of encased stone columns before and after application of vacuum and are compared with before application of vacuum. Through model tests they found out that both load carrying capacity and stiffness of encased stone column increase significantly due to the application of vacuum and undrained shear strength of soil depends on magnitude of applied vacuum pressure.

"Stabilization of soft clay using PVDs by combined vacuum-surcharge pressures" by S. Sakthiraja, K. Ilamparuthi, IGC 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. For the tests with and without PVD conducted on consolidation cell the coefficient of consolidation of vacuum and vacuum-surcharge technique is higher than the conventional surcharge technique.

"Consolidation of soft clay by vacuum method" by G. Nithya, K. Ilamparuthi, IGC 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 and their difference in C_V values is marginal. The total settlement achieved is higher in vacuum than surcharge and combined vacuum-surcharge loading

From the above literature reviews it can be inferred that vaccum consolidation of soft soils can be conducted in laboratory by using consolidation apparatus and a comparative study on the effect of coefficient of consolidation can be carried out between surcharge, vacuum, vaccum-surcharge loading.

III. OBJECTIVE

To compare the effect on coefficient of consolidation by surcharge, vaccum and combined vacuum-surcharge loading in conventional consolidation cell.

IV. SOIL USED

Experiments were carried out on clayey soil sample collected from the banks of Amayizhanchan Thodu near KIMS hospital Trivandrum, Kerala

V. METHODOLOGY

A. Preparation of soft clay

Vacuum consolidation has been effectively practiced to improve the strength of very soft clays which is naturally at a consistency nearly equal to or greater than liquid limit. Therefore the tests were carried out at a water content of 72% which is 4% greater than the liquid limit. The soil collected from the pit was completely dried. The required water content is added to it and soaked for 24 hours and then thoroughly mixed before placing it in the oedometer. The soil sample is then filled in the oedometer carefully by removing the air bubbles.

B. 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.

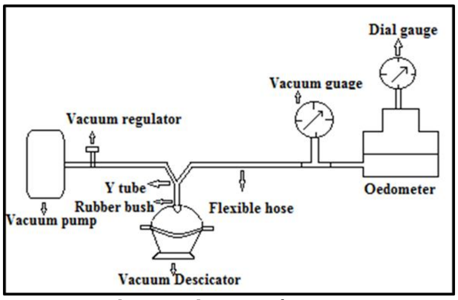

Fig.1 Schematic diagram of experiment setup

C. Tests in consolidation cell

In this study tests were carried out in Oedometer. Three series of tests were carried out by applying surcharge pressure, vacuum pressure and combined vacuum surcharge pressures. The magnitudes of vacuum pressure applied are 30, 60, 90 KPa respectively.

Surcharge loading

For samples prepared in the consolidation cell, tests were carried out according to the procedure of IS: 2720 Part XV. The consolidation cell was placed on the frame and tests were carried out by applying surcharge pressure. The dial readings are recorded continuously at predetermined time intervals as in regular consolidation test procedure.

Vacuum loading

The test is conducted by adopting following procedure. Vacuum pressure of required intensity is set by operating the vacuum pump and by adjusting the regulator. Now the vacuum pump is turned off and the vacuum pressure line from the vacuum pump is connected to the drainage line of the clay sample in the consolidation ring. The dial gauge was placed in position to record the settlement of the clay sample. The surface of the consolidation ring is thoroughly sealed by means of grease to prevent the leakage. 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. Generally in consolidation ring tests were over within a period of the test by adjusting the knob of the regulator. The test is carried out till the dial gauge reading remains constant for long time. Generally in consolidation cell tests were over within a period of 5 hrs.

Fig.2 Vacuum loading arrangement

Combined Vacuum-Surcharge loading

All the steps for vacuum pressure application is done as explained previously and then the consolidation cell was placed on the conventional loading frame. Now the required surcharge and vacuum pressure was applied simultaneously and the dial guage readings were recorded in the similar fashion at predetermined time intervals.

VI. RESULTS AND DISCUSSIONS

A. Soil properties

Table 1. Geotechnical properties of sample

Liquid limit	68 %
Plastic limit	34 %
Shrinkage limit	20.3 %
Plasticity index	6.3
Specific Gravity	2.68
Percentage of clay	41 %
Percentage of silt	50 %
Percentage of sand	10 %
Coefficient of consolidation	2.446 x 10^{-4} cm^2/s

B. Effect on coefficient of consolidation by vaccum loading

By vacuum loading, coefficient of consolidation and total settlement increases with increase in vacuum pressure. Maximum value of coefficient of consolidation and total settlement was obtained by applying high vacuum pressure 90 KN/m^2.

Table 2. Results of tests on consolidation cell by vacuum loading

Vacuum pressure (KPa)	$\sqrt{t_{90}}$ ($\sqrt{min}$)	C_v x10^{-4} (cm^2/s)	D_{90} (mm)	Total Settlement (mm)
30	7.3	2.652	2.66	2.96
60	5.8	4.201	3.68	4.09
90	5.2	5.23	4.19	4.66

C. Effect on coefficient of consolidation by combined vacuum-surcharge loading

By vacuum- surcharge loading, test results indicated that total settlement achieved is higher in vacuum than surcharge and combined vacuum-surcharge loading. Coefficient of consolidation increases with increase in vacuum-surcharge pressure. Maximum value of coefficient of consolidation of 6.39 x 10^{-4} cm^2/s is achieved at combined vaccum surcharge pressure of 99.81 KN/m^2.

Table 3. Results of tests on consolidation cell by vacuum-surcharge loading

Vacuum-surcharge Pressure (KPa)	$\sqrt{t_{90}}$ ($\sqrt{min}$)	C_v x10^{-4} (cm^2/s)	D_{90} (mm)	Total Settlement
30	7.3	2.652	2.66	2.96
60	5.8	4.201	3.68	4.09
90	5.2	5.23	4.19	4.66

D. Effect on coefficient of volume change(m_v) by vacuum and vacuum-surcharge loading

From the test results it was found that coefficient of volume change decreases with increase in vacuum pressure and combined vacuum surcharge pressure than in surcharge loading. Minimum value of 2.06 x $10^{-5}$$m^2/KN$ was obtained at a vacuum surcharge pressure of 99.81 KN/m^2.

Table 3. Change in coefficient of volume change for different types of loading

Type of loading	Pressure (KPa)	m_v(m^2/KN)
Surcharge	9.81	1.2 x 10^{-4}
Vacuum	30	4.9 x 10^{-5}
	60	3.33 x 10^{-5}
	90	2.61 x 10^{-5}
Vaccum-surcharge	30	2.39 x 10^{-5}
	60	2.72 x 10^{-5}
	90	2.06 x 10^{-5}

E. Variation of U_v v/s T_v for vacuum and vacuum-surcharge loading

The validity of Terzaghi's one dimensional equation for the consolidation process by vacuum technique is revised by means of establishing the relation between degree of consolidation and time factor. The relationship between time factor and degree of consolidation for vacuum loading and combined vacuum-surcharge loading agrees well with the Terzaghi's theoretical curve.

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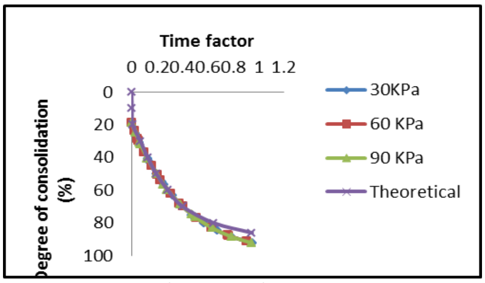

Fig.3 Variation of U_V v/s T_v for vacuum loading

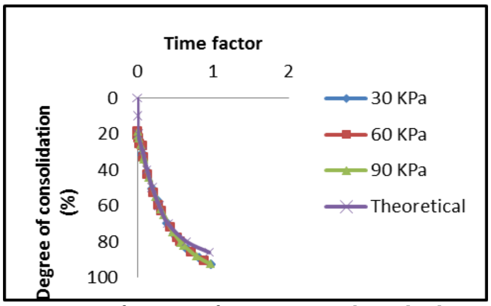

Fig.4 Variation of U_V v/s T_v for vacuum-surcharge loading

VII. CONCLUSIONS

Based upon the results obtained from laboratory tests following conclusions were derived:

(1) The coefficient of consolidation increases with increase in vacuum and vacuum-surcharge pressure

(2) The value of coefficient of consolidation is more for combined vacuum-surcharge loading than vaccum and surcharge loading. Hence accelerated consolidation occurs by combined vaccum-surcharge loading

(3) The relationship between time factor and degree of consolidation agrees well with the Terzaghi's theoretical curve irrespective of loading

(4) The coefficient of volume change decreases with increase in vacuum pressure and combined vacuum surcharge pressure than in surcharge loading

(5) The settlement is accelerated by 25% in vaccum loading and 45% in combined vacuum-surcharge loading

(6) The time taken for 90% consolidation is reduced by 32% in vacuum and 38 % in combined vacuum-surcharge loading

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