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The Effects of Different Surcharge Pressures on 3-D Consolidation of Soil

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Abstract
The aim of the study is to predict precisely consolidation characteristics and their effects based on 3-D consolidation of soil under different surcharge pressures. In this study a 3-D consolidation apparatus is developed and performed a series of 3-D consolidation test under different surcharge pressures. During the 3-D consolidation test, vertical and lateral strains of the soil and vertical and lateral movements of pore water are allowed. In this study, two different types of soil are used to perform the 3-D consolidation tests under different surcharge pressures. It is observed that the 3-D consolidation settlement of a same soil changed with the change of surcharge pressure. With the increase of surcharge pressure, lateral strain of soil reduces during the consolidation process and due to this, compression index and coefficient of consolidation also reduced. By using developed apparatus, 3-D consolidation characteristics of soil can be evaluated under different surcharge pressures. As this apparatus allows vertical and lateral strain with vertical and lateral pore water movement under different surcharge pressures, it is possible to correlate with in-situ field conditions during the consolidation process.

Keywords: Surcharge pressure, 3-D consolidation, Lateral strain, Pore water, Compression index, Coefficient of consolidation.

INTRODUCTION

Deformation analysis of the soil is one of the most uncertain and indecisive tasks in Geotechnical engineering. The work presented in this paper is concerned with the deformation analysis of the soil under surcharge pressure. In the present days, the settlement of supporting soil has been calculated using one-dimensional consolidation of soil. Three-dimensional consolidation cases of soil have been considered as modification to the one-dimensional consolidation. Natural porous medium like, soil may have been created by sedimentation process and this sedimentation makes horizontal stratification layers and this makes the permeability of soil different in horizontal and vertical directions. Due to the anisotropic nature of soil in horizontal and vertical direction and different seepage characteristic through different direction of soil, the coefficient of consolidation and coefficient of permeability in the horizontal direction are typically different from the coefficient of consolidation and coefficient of permeability in the vertical direction. There is also a large effect of surcharge pressure on the consolidation of soil. The effect of surcharge pressure is underestimated in the process of consolidation. Hence, in this study it is proposed to use the three-dimensional consolidation cases as the basic problem rather than a further extension of one-dimensional consolidation theory, where the effect of surcharge pressure on the 3-D consolidation process is also taken under consideration. In three-dimensional consolidation cases with the application of load and surcharge pressure, there will be vertical as well as the lateral strain of soil along with vertical and radial drainage of water.

Great efforts have been made in the development of concepts, theories and formulations for evaluating consolidation characteristics of saturated soils during the last three decades. However, experimental confirmation has not kept pace with theoretical advance. The general theory of three-dimensional consolidation was first introduced by Biot (1941) [1], in which coupling between solid and fluid was considered. In the past few decades, many investigators have been developed different analytical solution based on Biot's consolidation theory. To bring two and three-dimensional effects on consolidation of soil, a correction factor (μ) has been introduced to modify one-dimensional consolidation settlements [2]. Numerical analysis also has been presented for 3-D consolidation with an anisotropic permeability of a layered soil system and the effect of anisotropy of permeability on the consolidation behaviour has been discussed [3]. To solve the Biot's consolidation problem, alternative approaches have been taken and obtained an organized solution to the consolidation problems [4-5]. Several attempts by different authors are also have been taken to evolve an analytical procedure to solve the Biot's consolidation equations by directly using Laplace transform [6-7]. The effects of soil particles on consolidation characteristics have been evaluated and it was found that the fine fraction has a greater significant influence on the consolidation characteristics [8]. In all of the past investigations, evaluation technique of three-dimensional consolidation was analytical or numerical based and assumptions are not as replicating to the field condition. Hence, it is important to develop an experimental solution for three-dimensional consolidation problems with surcharge pressure.

DEVELOPMENT OF A 3-D CONSOLIDATION APPARATUS

Fig. 1 shows the developed 3-D consolidation apparatus, where 3-D consolidation can perform under different surcharge pressure. A large strain consolidation cell is fabricated to test the soil samples. Soil sample is bounded by this porous cast iron consolidation cell which is open at top and bottom sides. Internal and external dimension of this porous cast iron consolidation cell is 300 mm × 300 mm × 450 mm (depth) and 310 mm × 310 mm × 450 mm (depth) respectively. This porous box is surrounded by porous stone plates of 12 mm thick. A concrete tank of internal dimension 334 mm × 334 mm × 450 mm (depth) is fabricated to hold that porous consolidation cell along with porous stone plates. Surcharge pressures are applied on top of the soil sample by using cast iron plates (surcharge loading plate) of cross sectional area 299 mm × 299 mm, with 61 mm diameter centre hole and under this surcharge loading plate a porous stone plate is placed of same cross sectional area and centre hole as surcharge loading plate. A filter paper, a porous stone and a perforated loading plate of 60 mm diameter are consecutively inserted through 61 mm diameter hole of surcharge loading plate. Below the porous stone plate of 60 mm diameter, a filter paper is used having the same diameter. To apply the load on that loading plate a lever loading frame is fabricated as shown in Fig. 1. A dial gauge (0.0 - 25 mm) of sensitivity 0.01 mm is installed in the loading frame to measure the vertical settlement of loading plate.

THEORETICAL CONSIDERATIONS FOR CONSOLIDATION

Assumptions of present three-dimensional consolidation test are as follows:

1. The soil layers are homogeneous and the soil properties are isotropic;
2. The soil layers are two faced saturated;
3. Vertical and horizontal movements of soil particles are allowed during the process of consolidation;
4. The compression of the soil layer is due to the change in volume only, which in turn is due to the squeezing out of water from the void space in vertical as well as in horizontal directions;
5. Darcy’s law is valid;
6. In case of plastic settlement, if all the soil particles are interconnected, then vertical movement of soil particles occurs due to horizontal movements of underneath soil particles; and
7. Lower boundary of stress remains constant throughout the consolidation process.

TESTING MATERIALS AND PROGRAM

Silty-sand with clay and silty-clay soils are used in this investigation. A series of standard classification tests are carried out to categorize these test materials. The physical properties along with maximum dry density (MDD) and optimum moisture content (OMC) using standard Proctor compaction energy of two types of soils are listed in Table 1.

By using silty-sand with clay and silty-clay soils, six numbers of 3-D consolidation tests are performed under different surcharge pressures.

SPECIMEN PREPARATION AND EXPERIMENTAL PROCEDURES

Soil samples are remoulded at a maximum dry density (MDD) in the porous cast iron box with three consecutive layers and these soil samples are considered as an ideal two face soil-system during the test. The inner sides of the cast iron consolidation cell are covered by filter paper before moulding the soil sample. After moulding the sample, four consecutive sides of the cast iron consolidation cell are covered by porous stone plates (side porous stone plate) as shown in Fig. 1. Over the soil sample, filter paper, porous stone and cast iron plate of cross-sectional size of 299 mm × 299 mm, with centre hole of 61 mm diameter are placed one above the other. The cast iron plate is placed over the soil specimen to apply surcharge pressure. A filter paper, a porous stone and a perforated loading plate of 60 mm diameter has been placed consecutively through the 61 mm diameter centre hole. Load is applied by the lever loading frame system to the top perforated loading plate of 60 mm diameter through a plunger connecting the loading frame and perforated loading plate. Initially, 5.00 kN/m^2 stress is applied as a seating load and kept it for 48 hours to saturate the soil sample. After 48 hours, 0.00, 10.00 and 15.00 kN/m^2 stresses are applied as a surcharge load over the initial loading plate and 100.00, 200.00, 400.00 and 800.00 kN/m^2 stresses are consecutively applied on the soil sample by the 60 mm diameter loading plate and each stress is applied for 24 hours. With the application of stresses on soil, vertical settlements corresponding to different time interval are measured by a strain gauge.

TEST RESULTS AND ANALYSIS

The physical properties along with maximum dry density (MDD) and optimum moisture content (OMC) using standard Proctor compaction energy of two types of soils are listed in Table 1. In this study, 3-D consolidation tests are performed using developed three-dimensional consolidation apparatus shown in Fig. 1. Silty-sand with clay and silty-clay soils are used in this study. Consolidation tests are performed under different surcharge pressures like 0.00, 10.00 and 15.00 kN/m^2. Figs. 3 and 4 shows the compression indices of silty-sand with clay and silty-clay soils and Figs. 5 and 6 shows the coefficient of consolidation values of silty-sand with clay and silty-clay soils under different vertical stresses and surcharge pressures.

DISCUSSION

In this study, 3-D consolidation tests are performed on silty-sand with clay and silty-clay soils under different surcharge pressures using developed 3-D consolidation apparatus as shown in Fig.1. In the 3-D consolidation of soil, lateral and vertical movements of soil particles and lateral and vertical movements of pore water are taken under consideration. The soil under consolidation may have surrounding soil as shown in Fig. 2, which affects the lateral movements of soil particles under consolidation and it also effect the lateral movement of pore water. If surcharge pressure increases on the surrounding soil particles then the surrounding soils are getting denser and as a result lateral movements of soil under consolidation resisted and horizontal pore water movements will also reduces. The compression indices and coefficient of consolidation values of silty-sand with clay and silty-clay soils under different vertical stresses and surcharge pressures are shown in Figs. 3 to 6. From Figs. 3 to 6, it is observed that with the increase of surcharge pressure, the compression indices and coefficient of consolidation values decrease for both the soils. The surcharge pressures have a great effect on consolidation characteristics. The rate of consolidation of soil is proportional to the rate of extraction of pore water from the soil sample. With the extraction of pore water from soil mass, the arrangement of skeleton of soil changes and due to which settlement occurs. At the time of rearrangement of soil particles with the extraction of water, it may move in horizontal as well as in vertical directions. With the increase of surcharge pressure on the surrounding soil of consolidating soil, the void ratio of surrounding soil reduces and it becomes denser and as a result, the lateral movement of soil particles under consolidation as well as lateral extractions of pore water reduces and corresponding compression index and the rate of consolidation also reduces.

CONCLUDING REMARKS

This study concentrates on the development of a 3-D consolidation apparatus through which 3-D consolidation tests are performed under different surcharge pressures. The entire tests are performed on silty-sand with clay and silty-clay soils of Agartala, Tripura, India. In case of 3-D consolidation of soil, the consolidation characteristics are largely affected by the surcharge pressures. With the increase of surcharge pressure on the surrounding soil of consolidating soil, the surrounding soils are becoming denser and it reduces the lateral movements of consolidating soil particles and also reduces the lateral pore water movement. The compressibility and the rate of consolidation of the soil under 3-D consolidation reduced due to increase of surcharge pressure on the surrounding soil.

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Table 1 Physical properties and compaction characteristics of soils used in the test

Soil Properties	Silty- sand with clay soil	Silty-clay soil
Specific gravity	2.58	2.50
Liquid limit (%)	25.30	53.35
Plastic limit (%)	19.03	29.32
Plasticity index (%)	4.27	24.03
Grain size		
Sand (%)	61.60	4.86
Silt (%)	21.68	41.46
Clay (%)	16.72	53.68
Optimum moisture content (OMC) (%)	13.10	25.75
Maximum dry density (MDD) (kN/m^3)	18.80	15.60
Coefficient of Permeability at MDD (m/sec)	8.87E-09	3.39E-10

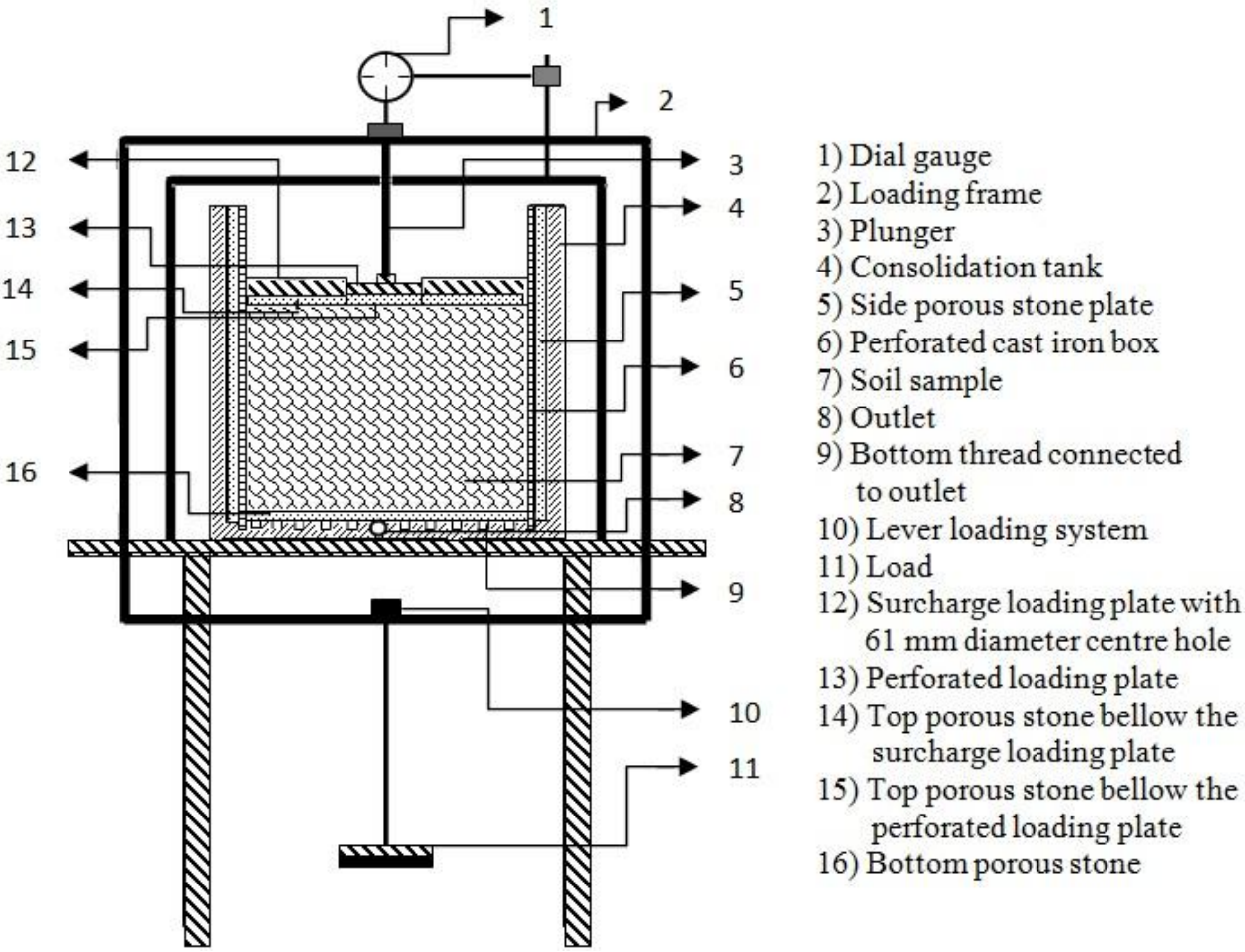

Figure 1. Schematic diagram of developed three-dimensional consolidation apparatus

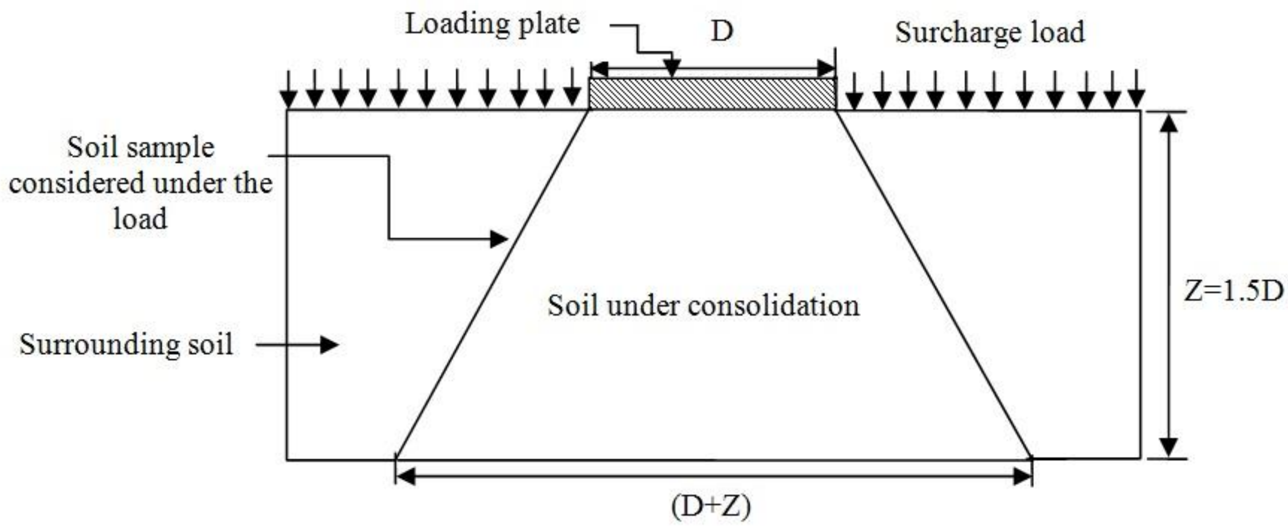

Figure 2. Schematic diagram of soil under consolidation and surcharge pressure on surrounding soil

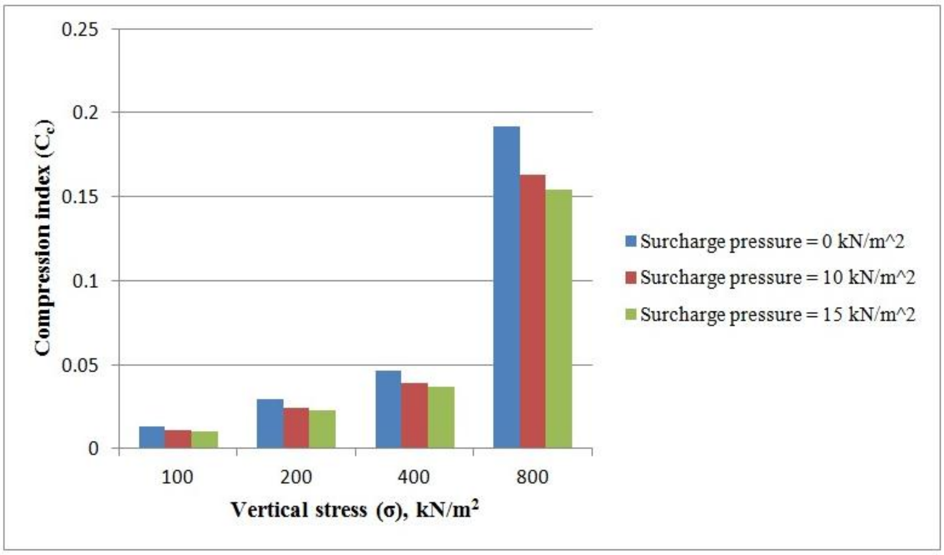

Figure 3. Compression indices of Silty-sand with clay soil under different vertical stresses and surcharge pressures

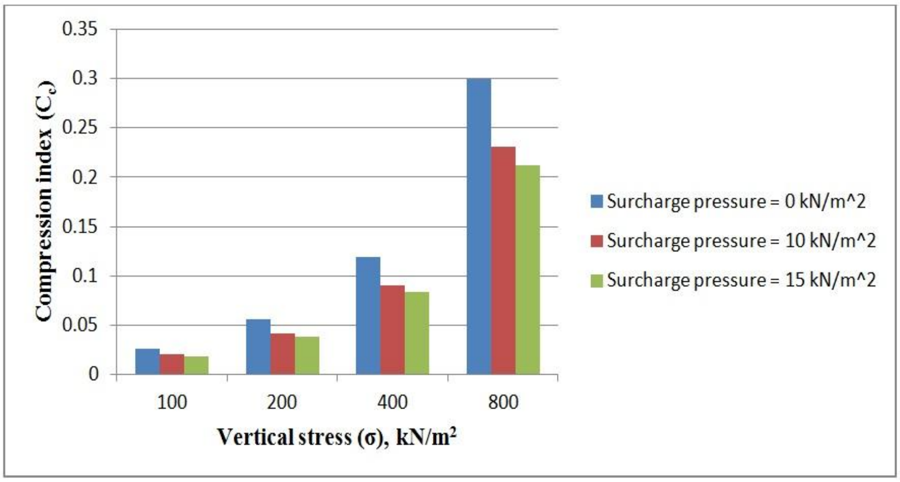

Figure 4. Compression indices of Silty-clay soil under different vertical stresses and surcharge pressures

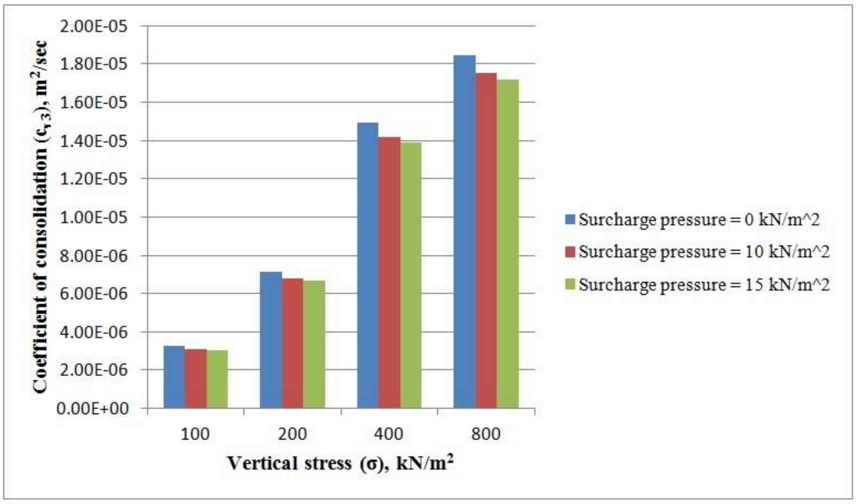

Figure 5. Coefficient of consolidation values of Silty-sand with clay soil under different vertical stresses and surcharge pressures

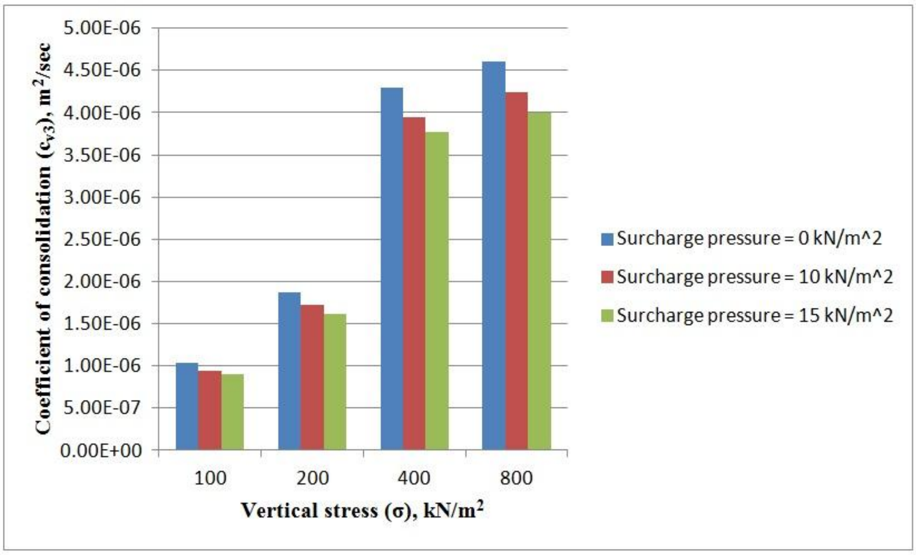

Figure 6. Coefficient of consolidation values of Silty-clay soil under different vertical stresses and surcharge pressures

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