Study of Consolidation Accelerated by Sand Drains

Radhakrishnan, G.  
Assistant Professor  
e-mail: radhakrishnan.gunupudi@gmail.com  

Kumar, M. Anjan  
Principal  
e-mail: anjan_mantri@yahoo.com  

Raju, G.V.R. Prasada  
Professor  
e-mail: gvrp.raju@yahoo.com  

Prasad, D.S.V.  
Principal  
e-mail: dsvp@yahoo.com  

Venkateswarlu, D.  
Associate Professor  
e-mail: Dumpa.venkateswarlu@gmail.com  

Ideal Institute of Technology, Kakinada  
1B.V.C. College of Engineering, Palcharla  
2Department of Civil Engineering, JNTUK, Kakinada  
3B.V.C. Engineering College, Vodalaravu  
4GIET, Rajahmundry

ABSTRACT

Marine clays found in coastal region are problematic as regards their nature and behavior. A number of Industries, dams, buildings and embankments are being constructed along the inland coastal areas where the soil is of soft clay associated with problems of settlement and stability. In order to analyze the stability of an embankment constructed on these compressible marine clayey deposits, laboratory consolidation testing is the basis for computing the settlement. Providing vertical sand drains offers a better solution in accelerating the process of consolidation to eliminate the deleterious post construction settlements and also to acquire sufficient additional shear strength. Attention has been paid towards the possibilities for providing all the field conditions in the laboratory and to study the properties of the soil. This paper summarizes the results of the testing and also the variation of percentage of consolidation with construction time by providing and without providing sand drains is studied. A rapid increase in percentage of consolidation is observed by providing sand drains.

1. INTRODUCTION

Prediction of settlement constitutes one of the most important criteria in ensuring the safety of a structure, when an embankment is placed on a soft marine clayey deposit. The settlement of soil is caused by the phenomenon of consolidation, which is the process of extruding the water out of porous medium. Deflection of the soil is not instantaneous but is gradual adaptation of the soil to variation. If the clay deposit is very thick, it requires long period of time to consolidate (Hansbo, 2004). In such cases damages caused by the post-construction settlements can be avoided by allowing a portion of the settlement to take place before construction of the structure. This is usually done either by preloading alone or provision of sand drains in conjunction with preloading (Ali, 1989). However, when the layer of soil is very thick or the permeability is very low, vertical sand drains offer a better solution in accelerating the consolidation process (Lekha et al., 1998).

2. DETAILS OF EMBANKMENT AND SUB SOIL

An embankment was constructed as an approach to a Railway Bridge, which is underlain by a soft marine clay layer of thickness varying from 3.5m to 15.6m at the critical location, for a length of nearly 600 meters. There is an impermeable weathered rock below the clay layer and the total height of the embankment at the critical location is 14 meters.

Construction of the embankment was done in 3 stages. The total construction time is 2 years. The construction time for the 1st, 2nd, 3rd, stages are 3 months, 2.5 months, 5 months respectively and there is a rest period after the completion of each stage. Sand drains were provided in conjunction with the preloading in the form of 1st stage of the embankment. Filling of 1st stage is done in three layers i.e Murom 1.6m, Sand 0.3m, Murom 0.3m. The first serves as a working platform for the sand drain installation and second serves as a drainage layer. Sand drains of 300mm dia were installed in triangular pattern with an effective spacing of 2.75m.
Properties of Sub Soil
Undisturbed samples were collected from clay layer and tested in the laboratory. The physical properties of clay layer are as furnished below in table 1.

<table>
<thead>
<tr>
<th>Table 1: Sub -Soil Properties are as Follows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural moisture content (w)</td>
</tr>
<tr>
<td>Specific Gravity (G)</td>
</tr>
<tr>
<td>Dry Density (γd)</td>
</tr>
<tr>
<td>Void Ratio (e)</td>
</tr>
<tr>
<td>Degree of saturation (Sr)</td>
</tr>
<tr>
<td>Liquid Limit</td>
</tr>
<tr>
<td>Plastic Limit</td>
</tr>
<tr>
<td>Shrinkage Limit</td>
</tr>
<tr>
<td>Un-drained Shear Strength</td>
</tr>
<tr>
<td>(from vane shear test)</td>
</tr>
<tr>
<td>Compression index(Cc)</td>
</tr>
<tr>
<td>Coefficient of Consolidation (Cv)</td>
</tr>
</tbody>
</table>

3. TESTING PROGRAMME
Testing is carried out on the undisturbed samples collected from the clay layer, using automated consolidation testing system which consists of consolidation cell of Rowe-Barden type and computer is linked through digital pressure controllers for the precise measurement of Liquid Pore Pressure, Back Pressure and Axial Load applied on the soil sample. The diameter of the sample is 100mm and thickness of the sample 30mm. During sampling the Degree of Saturation may fall below 100%, owing to swelling on the release of in-situ stresses and in addition there is a possibility that compacted specimens will have a Degree of Saturation below 100%. Therefore a Back Pressure of 20 kpa. is maintained throughout the test and simultaneously the confining pressure may be raised by an equal increment.

![Fig. 1: Basic Form of the Cell](image1.png)

Testing of the Sample without Providing Sand Column
Initial overburden pressure on the sample is calculated, assuming that the sample is collected from the mid depth of the clay layer and is $r_{sub} \times H/2 = 43$ kpa. The magnitude of the initial seating load is taken as $43+20 = 63$ kpa. As the degree of consolidation is same in the field and laboratory, $T_v$ & $C_v$ are taken as same in both cases. Therefore the time required to attain certain Degree of Consolidation is directly proportional to the square of the drainage path, $t/H^2$ in the field is equal to $t'/h'^2$ in the sample. The construction of each stage of the embankment is taken as constant rate of loading and the rest period is taken as constant loading. Testing time in the laboratory is calculated as $t_2 = 0.032$ hours and the rate of loading to be applied on the sample is taken as $29/0.032 = 906$ kpa/hour.

The intensity of axial stress and the increase in the axial stress corresponding to the different stages of loading on the clay layer are shown in Fig 2.

![Fig. 2: Graph Showing Various Stages of Loading to be Applied on the Sample (Without Providing Sand Drain)](image2.png)

Testing by Providing a Sand Column in the Sample
Comparing the values of ratio of effective drain spacing to drain diameter in the field and sample in the Consolidation Cell, the diameter of the sand drain to be provided in the specimen is calculated as 10.4 mm. The resulting consolidation due to the installation of sand drains will involve horizontal as well as vertical flow. But the consolidation in vertical direction is very small that can be neglected.

The time factor ($T_v$) and the coefficient of consolidation ($C_v$) in horizontal direction are considered same in both the cases. The rate of loading to be applied on the sample is 11.2 kpa/hour. The intensity of axial stress and rate of increase in the axial stress corresponding to the different stages of loading on the clay layer, provided with sand drains are as shown in Fig 3.

![Fig. 3: Graph Showing Various Stages of Loading to be Applied on the Sample (By Providing Sand Drain)](image3.png)
4. RESULTS AND DISCUSSION

The test results are presented in the following sections.

Consolidation Test

Consolidation testing is carried out on the soil sample for finding the coefficient of consolidation \(C_v\) which is equal to \(1.612 \text{ m}^2/\text{year}\). The final settlement of the clay layer was found to be \(1.9698 \text{ m}\). Since time factor \((T_v)\) is constant for a given degree of consolidation and given boundary conditions, the time required to attain certain degree of consolidation is directly proportional to the square of the drainage path in the field and laboratory. Therefore 90% of this settlement is possible to occur in a time period of 128 years.

Consolidation Testing Without Providing Sand Drains

From the Laboratory Testing the settlement observed at the end of the different stages of loading, on the 30mm thick soil sample is \(0.4847 \text{ mm}\). Therefore the expected settlement in the field for 15.6 meter thick clay layer at the end of Construction of Embankment i.e at the end of 2 years was \(0.25 \text{ meters}\), which is only 12% of the total settlement of the clay layer. This would lead to large amounts of Post Construction Settlements. Hence expedition of consolidation process is essential to achieve total settlement (min 90%), during the construction phase itself. The initial and final values of the testing are tabulated in Table 2. The sample thickness during different stages of loading is as shown in Fig 4.

Consolidation Testing by Providing Sand Drains

The settlement of 30 mm thick sample at the end of the test is \(3.4602 \text{ mm}\). The same load is maintained for one week of time and the settlement of the sample at the end was found to be \(3.744 \text{ mm}\). The expected settlement of clay layer at the end of the construction period by providing the sand drains was found to be \(1.7993 \text{ meters}\), which is nearly 91% of the total settlement of the clay layer. Hence providing the sand drains offers a better solution. The results of the testing are tabulated in Table 3. The changes in the sample thickness during the testing are as shown in Fig 5.

Table 2: Initial and Final Values of Testing Without Providing Sand Drains

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial Values</th>
<th>Final Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen Height</td>
<td>30mm</td>
<td>29.5153mm</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>2.0118</td>
<td>1.8819</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>81%</td>
<td>72.73%</td>
</tr>
<tr>
<td>Degree of Saturation</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 3: Initial and Final Values of Testing by Providing Sand Drains

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Initial Values</th>
<th>Final values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen Height</td>
<td>30mm</td>
<td>26.5398mm</td>
</tr>
<tr>
<td>Void Ratio</td>
<td>2.045</td>
<td>1.6313</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>84.4%</td>
<td>72.90%</td>
</tr>
<tr>
<td>Degree of Saturation</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The variation of the percentage of consolidation with construction time by providing and without providing sand drains is shown in fig 6. It is observed that at the end of 10 months, the percentage of consolidation without and by providing sand drains were about 9% and 31% respectively. Similarly for 20 months it is about 12% and 65%. Hence there is a rapid increase in the percentage of consolidation by providing the sand drains.
5. CONCLUSION

1. Installation of Sand Drains within the soft marine clayey soil offers a better solution in accelerating the process of consolidation and to improve the shear strength of clayey deposits.

2. In the conventional method of predicting consolidation settlements under given field conditions and proposed sequence of operations, several assumptions are required to be made, but in the present work, simulation of field conditions was made to the possible extent, which had given a reasonable accurate solution.

3. At the end of 10 months, the percentage of consolidation without and by providing sand drains were about 9% and 31% respectively. Similarly for 20 months it is about 12% and 65%. Hence there is a rapid increase in the percentage of consolidation by providing the sand drains.

REFERENCES


