Settlement Performance of Soft Clays using Prefabricated Vertical Geodrains with Varying Diameter

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ABSTRACT: The paper presents a detail laboratory study to consolidate soft clays using large size hydraulically pressurized oedometer through outward radial drainage. The aim of the present work is to study One-dimensional consolidation of soft clay by modeling vertical geodrains made from both synthetic and natural materials like coir-jute, polypropylene fibers and sand. The vertical geodrains of 'n' (ratio of sample diameter to drain diameter) equal to 11.04, 16.93 and 21.71 are taken for investigation. The optimacy of 'n' value dictate the economy and the efficiency of the functioning of the drain. Comparison is also made to study influence of distinctive material (synthetic and natural) and diameter of vertical Geodrains. Time – settlement observations were recorded under different applied stress under long termed duration for all types of drain so as to compute coefficient of consolidation and average degree of consolidation using the theoretical solutions developed by the authors. The results show a fair agreement between measured and predicted values for all types of drains. Out of all vertical geodrains the coir-jute drain proved to be better one in all respects of consolidation characteristics. The experimental results were compared with theoretical solutions developed by authors.

1 INTRODUCTION

Large deposits of marine clays are encountered along the coastal plains of country like India. The common feature of marine clay is the basic mineral composition having base exchange capacity of 37-40 milli equivalents per 100 gms.The properties of marine clays are very much influenced by the salt content and the amount of skeleton of micro structure present. The leaching process creates a metastable structure of marine clay. The rate of consolidation for soft clay purely depends on the expulsion of pore water. According to Barden (1968) for primarily consolidation the total stress is shared by pressure in the free pore water, plastic resistance in the highly viscous adsorbed double layer, by virtually solid to solid contacts between clay particles. The aim of the present paper is to study radial consolidation of Kaolinite clay using vertical geodrains fabricated from materials like sand, coir, jute, polypropylene fibers, and filter paper to provide guideline to the field engineer regarding optimization of drain material with reference to influence zone. The efficacy of experimental findings are also attempted to compare with field observations. The hydraulically pressurized Oedometer described by Rowe and Barden (1966) and further modified (Shroff & Shah, 2005) for pore pressure measurement during radial flow is employed in the present investigation. The sample in the Oedometer is a representative of one influence zone. The present investigation covers (a) comparison of average degree of consolidation computed from settlement measurements for various vertical geodrains with author's theoretical solution. (b) Influence of drainage path (tortousity) on the consolidation process. (c) To know the efficacy of filler materials and to compare synthetic materials with natural materials which are more popular now a days. (d) Comparison of post shear strength achieved at the end of consolidation for various drains.

2 EXPERIMENTAL PROGRAM

2.1 Experimental Setup

The 254mm & 152mm diameter oedometer was machined from an aluminum bronze castings including base plate (Figure 1) while top cover is made from aluminum for easy handling. A uniform pressure is applied by means of conventional hydraulic pressure system on the convoluted rubber jack which transfers uniform pressure on the soil sample placed in the cell. To achieve equal strain condition a rigid op platen is inserted between the jack and the sample. The vertical settlement is measured at the center of the sample by means of brass hollow rod attached to the jack and passing out the cell cover to a suitable dial gauge. Pore pressures are measured at the three radial points located at 120 degree each with r/re distances as r/4, r/2 and 3r/4 respectively.

2.2 Sample preparation

The sample is made from soft kaolin clay obtained commercially in the form of powder from the vadodara city. The clay powder was tested by doing dehydration test with G = 2.592, liquid limit (LL) = 67%, plastic limit (PI) = 34 and belonging to CH (clay of high plasticity) group according to I.S.Classification system. To ensure full maturation of the sample the clay was mixed to form slurry with twice the liquid limit using de-aired distilled water. The sample was then preconsolidated under a gradually applied static load of, 10kPa with $\Delta p/p = 1$ so that the consolidation occurring is normal.

2.3 Preparation of vertical geodrains and testing

Four types of vertical geodrains were fabricated with indigenous technology viz. sand drains, sandwick (woven polypropylene sheet with sand as filler material), coir drains (coir-jute fibers of maximum 120mm length placed radially wrapped by filer paper), polypropylene drains (white polypropylene fibers of maximum 80-100mm length placed radially wrapped by filer paper).The diameters of vertical drains are in accordance with'n' value(ratio of sample diameter to drain diameter) equal to 11.04, 16.93 and 21.71.All the filler materials were made completely saturated before placing. The drain sample thus prepared is inserted (placed) in the predrilled hole, formed by thin mandrel at centre of the soil sample in the oedometer with sufficient care so that no smearing occurs to the wall of the predrilled hole.

2.4 Testing procedure

After the consolidation by static load, cell was sealed, settlement dial gauge along with displacement transducers and Bishop Pore pressure measuring apparatus with pore pressure transducers interfaced with data logger system were connected at their respective locations. Excess pore water pressure of 10kPa is applied by help of screw pump and hydraulic system. Pressures are applied in the range of 20kPa, 40kPa, 80kPa, 160kPa and 320kPa with $\Delta p/p = 1.0$.Each load increment is kept constant for about 96 hrs and secondary compression is also recorded.

3 TEST RESULTS

3.1 Analytical solutions

Out of many theories, (Barron's, 1948) "equal strain" theory which better applies to oedometer tests with rigid top platens theory is still widely used for obtaining solutions both by researchers and design engineers. The general equation for the radial consolidation equation is given as:

$\partial u/\partial t = Cr\,[\partial^2 u/\partial r^2 + 1/r\ \partial u/\partial r]$

The average degree of consolidation for radial drainage, Ur, can be obtained from: $U_R = 1 - e^{(-8\,T_{vr}/f(n))}$

Shroff & Shah (2006) proposed a new mathematical theory which incorporates type of the drain material, tortousity effect, k_h/k_v ratio under load variation, effect of 'n' value (drain diameter) and drainage path. The lump parameter (λ) incorporates above all factors. The degree of consolidation (U_R) for different values of λ can be obtained using

$$U_R = \frac{e - e_o}{e_1 - e_o}$$

$$= \exp\{(\lambda/2)\}\left[\frac{Sinh\,\lambda/2\,R}{Sinh\,\lambda/2} + 2\pi\sum_{n=1}^{\infty}\frac{(-1)^n.n\,Sin(n\pi R)}{\lambda^2/4 + n^2\pi^2}\exp-\{(\lambda^2/4 + n^2\pi^2)T\}\right] +$$

$$\exp\{-(\lambda/2)\}$$

$$\left[\frac{Sinh\,\lambda/2\,(1-R)}{Sinh(\lambda/2)} - 2\pi\sum_{n=1}^{\infty}\frac{n\,Sin(n\pi R)}{\lambda^2/4 + n^2\pi^2}\exp\{-(\lambda^2/4 + n^2\pi^2)T\}\right]$$

Positive and negative values of λ ranging from 0 to 0.7 are selected and analyzed and appropriate value λ is fitted accordingly. Each value of λ is selected and a series of curves are prepared for average degree of consolidation U_R and time factor Tr.

3.2 Experimental results

For comparison and analysis purpose, settlement and excess pore dissipation values at load of 40 kPa, 160 kPa and 320 kPa are selected and shown here. The notations used for circular sand drain is 'csd', sandwick as 'swd',coir drain as 'cjd' and polypropylene fibers drain as 'ppd'. In the analysis presented here 160 kPa is taken as ideal engineering stress and all the results are shown thereof. In the present work Casagrande logarithm time curve fitting method is employed to determine the coefficient of consolidation (Cr_{80}) with respect to t_{80} and Tr_{80}.This is done in accordance with assumptions made by authors in mathematical development of above theoretical solution to get degree of consolidation.

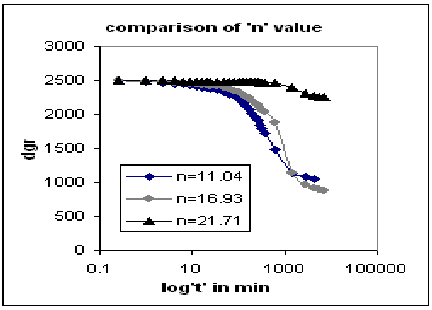

Figure 1.Comparison of settlement readings for 'swd'for all 'n' values at 160kPa

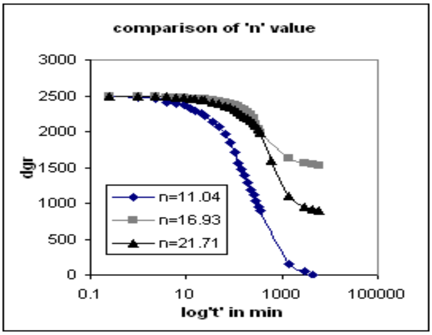

Figure 2. Comparison of settlement readings for 'cjd'for all 'n' values at 160kPa

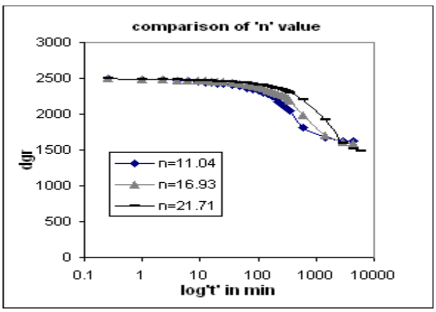

Figure 3. Comparison of settlement readings for 'csd'for all 'n' values at 160kPa

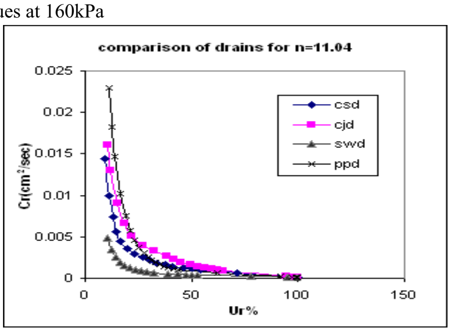

Figure 4. Comparison of coefficient of consolidation (Cr) vs. degree of consolidation (Ur) for all vertical geodrains at 160kPa

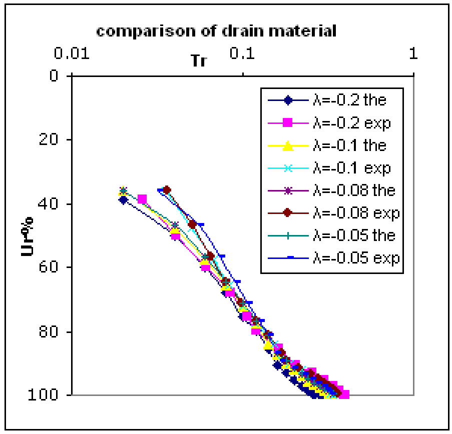

Figure 5.Comparison of degree of consolidation (Ur) vs. Time factor (Tr) for all vertical drains at 160kPa for n=11.04

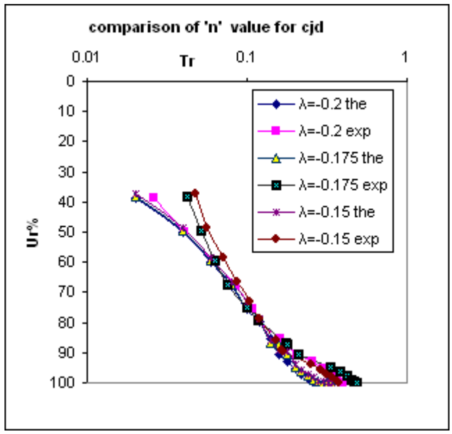

Figure 6. Comparison of degree of consolidation (Ur) vs. Time factor (Tr) for all 'cjd' at 160kPa for all 'n' values

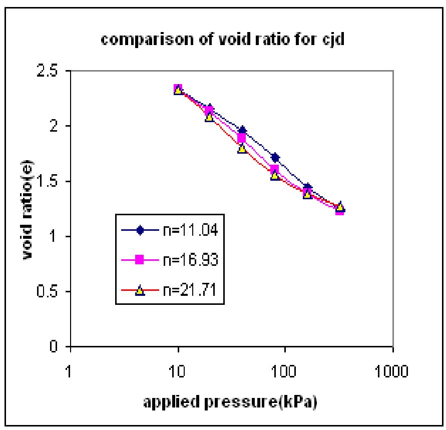

Figure 7.Comparison of void ratio (e) vs. applied pressure for 'cjd' for all 'n' values

4 CONCLUDING REMARKS

- All the vertical Geodrains employed in the present investigation has increased effectively the rate of settlement and thus, allowed early consolidation for a particular construction loading. From the figure1, 2 and 3 it is observed that time required for 80% consolidation for 'cjd' is 550min, 760min and 1050 min, for 'swd' it is 720min, 1150min and 2000min, for 'ppd' it is 940min, 1000min and 1300min respectively for n equal to 11.04, 16.93 and 21.71.From the above it is very clear that out of all drains 'cjd' for n=11.04 proved to be most efficient in accelerating rate of settlement.
- The general characteristic of graphical relationship between C_r and U_r % (average degree of consolidation) is initially dropping fast upto 20% Ur there after it is declining at very slow rate upto100%. The curve of C_r vs. Ur for 21.71 drops more compare to n=16.93 for any load intensity. This variation is major for initial stresses like 20kPa where the clay water system is under just stage of orientation.
- General characteristic of graphical relationship between Cr and Ur is initially dropping and then remaining more or less constant later on for all pressures for all vertical drains and for all 'n' values.(refer figure 4.)
- The void ratio curve shows the characteristic behavior of normally consolidated kaolinitic clays. The value of precompression ratio was founding the range of 0.939 to 0.960 for n=11.04, 0.959 to 0.990 for n=16.93 and 0.969 to 0.989 for n=21.71 for 'cjd, while for 'ppd' for n=11.04 it was ranging from 0.973 to 0.987.Coir-Jute drains shows higher value of Cc compare to other drains.
- From the figure 5. & 6. it is observed that authors theoretical solution of computing average degree of consolidation from settlement observations fits well with experimental results for all drains and for all 'n' values. For 'cjd' at 160kPa applied pressure lumped parameter λ=-0.2 fits better for average degree of consolidation (Ur), while λ=-0.1 fits for 'swd' at 160kPa for n=11.04.Generally it is observed that value of λ decreases as time of consolidation increases for all type of vertical drains.
- The post vane shear test results indicate that shear strength has increased 20kPa to 145kPa in case of 'cjd' for n=11.04.Overall shear strength increased 5 to 7 times for all drains and for all 'n' values. Some bulging was observed at the middle of drain sample in case of 'swd'for n=21.71. In case of 'ppd' the polypropylene fibers had remained intact and also the final dater of drain sample did not change. The figure 8. shows the clay sample with central vertical 'swd' and 'cjd' at the end of consolidation.

Figure 8. Final consolidated clay sample of 'swd' and 'cjd' of n=11.04 (end of 320kPa pressure)

- At every stage of consolidation on each pressure it is observed that though equal strain condition is applied at the finite distance dissipation of pore water pressure must not be passing though equal gradient developed as a whole by each saturated particle though an equal surface area of drain is available. It is atmost necessary at this stage to know at drain interface and at some intermediate level what is rate of fluid to pass from macro channels and this path is same for every pressure or not. This can be known by the settlement readings and its rate when related to volume of pore water collected. The distinct behavior with respect to the rate of consolidation at any stress is attributed to the low tortuosity of horizontal flow in the flocculated soil structure of Kaolinitic clay water system.
- Author's theory of consolidation with radial drainage predicts average degree of consolidation with fair accuracy. Different values of lumped parameter(λ) gives direct clue to both researchers and design engineers regarding selection of vertical geodrain.Modelling of vertical drains of higher diameter using Modified oedometer gives better picture of simulation of field conditions.

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