International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

2010 - Fifth International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

26 May 2010, 4:45 pm - 6:45 pm

Soil-Structure Interaction of Soft Clay Using Prefabricated Vertical Geodrains Under Seismic Stresses

Manish V. Shah
The M.S University of Baroda, India

Arvind V. Shroff
The M.S University of Baroda, India

Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

SOIL-STRUCTURE INTERACTION OF SOFT CLAY USING PREFABRICATED VERTICAL GEODRAINS UNDER SEISMIC STRESSES

Manish v. Shah
PhD Student, Applied Mechanics Dept,
Faculty of Technology & Engineering,
The M.S University of Baroda, Vadodara, India-390001

Dr. Arvind v. Shroff
Professor Emeritus, Applied Mechanics Dept,
Faculty of Technology & Engineering,
The M.S University of Baroda, Vadodara, India-390001

ABSTRACT

Experimental model study was carried out on soft Kaolinite clay using modified hydraulically pressurized oedometer with vertical sandwick of different diameter using open mandrel technique to investigate consolidation characteristics based on settlement and excess pore water pressure dissipation measurements. The main aim of this paper is to know the behavior of this consolidated mass under seismic stresses for different periods of time using shaking table.Pre and post shear strength of consolidated soil mass is evaluated using vane shear apparatus under seismic stresses. The interaction phenomena between clay and sandwick drain is also studied in oedometer to know stability of vertical geodrain under vibratory loads. Average degree of consolidation is computed from settlement and pore pressure measurement readings and is compared with theoretical solutions developed by authors. The results clearly indicate that by using sandwicks the % loss in strength can be reduced within the limits. Also it was concluded that clay-drain interface was not much disturbed under seismic stresses and quick clay condition can be reduced by using sandwicks.

INTRODUCTION

Long coastal area of Gujarat state (India) is covered by soft clays. Various structures at Kandla port where suffered because of the higher sensitive nature of the coastal soft clays. Soil has lost its in-situ strength during seismic stresses because of change of metastable card house structure of illitic coastal soils. Construction on soft clays follows heavy settlement under static and dynamic loading conditions. This is because of typical card house structure ad leaching of salts of coastal soft clays .Strengthening of these soft soils by accelerating consolidation through radial drainage with the help Prefabricated Vertical Geodrain help mitigating the danger of becoming soft clay quick. The applied mechanics department of The M.S. University of Baroda, India started many years back research on finding most optimum drain in terms of materials(both natural and synthetic type), size(diameter of drain) and geometry to accelerate consolidation of soft marine clays both under static and dynamic stresses with a complete set-up of hydraulically pressurized modified oedometer of different diameters with both conventional bishop pore pressure measuring system and electronic data acquisition system consisting of displacement transducers and pore water pressure transducers. Out of many theories, the circular sand drains (Barron's, 1948) theory is still widely used for obtaining solutions by design engineers. Hansbo (1960) gave theory on Band shape drain assuming equivalent circular shape is also used for band shape drains available now days in the market under different commercial names. To accelerate the consolidation process and gain strength use of vertical sandwicks (cylindrical geotextile bags filled with saturated sand) wells are used for present investigation. The drain well permits the control over the water migrating in radial (horizontal) direction. This reduces the excess pore water pressure that is built up in the soil mass and reduces the drainage path thus increasing the rate of consolidation manifold. Using shaking table, consolidated soil mass is examined under different vibratory loads for different periods of time so as know the complete behavior of sandwick drain and its interaction with clay.

SCOPE AND OBJECTIVE

The aim of the present work is to study consolidation due to radial drainage of Kaolinite clay using sand drains and sandwicks and study the effect of 'n' value (ratio of drain dia to sample dia) on consolidation parameters. The hydraulically pressurized Oedometer described by Rowe and Barden (1966) and further modified by (Shroff & Shah, 2006) for pore pressure measurement during radial flow is employed in the present investigation.

- Paper presents experimental model of sandwick reinforced soft soil mass to expedite the rate of consolidation due to radial drainage taking advantage of having more horizontal permeability than vertical.

- The effects of sandwick of different 'n' values (ratio of drain diameter to sample diameter) on consolidation characteristics (coefficient of consolidation 'Cr' due to radial drainage) of Kaolinitic clay are undertaken to investigate the settlement characteristics.
- The variation of ratio of zone of influence (**r_e**) to the diameter of drain has been varied to access the optimization of drain diameter for better performance with respect to increase of quick strength on the basis of settlement and pore pressure dissipation characteristics.
- After getting optimum 'n' value, the shear strength by vane shear was measured before installation of central vertical drain and after the consolidation of soft clay through radial drainage under different design embankment loadings post strength is attempted to measure by vane shear. Further this consolidated soil mass placed on a shaking table and simulating the in-situ seismic stresses by vibrating table, the influence on strength is measured with respect to time as one of the variable. Seismic stresses of same intensity were applied with different interval of timings as 5s, 15s, 30s, 60s and 120s repecively.Sandwicks of two different 'n' values is analysed with reference to strength before and after the application of seismic stresses.
- Comparison of average degree of consolidation of sandwick of various 'n' values with author's theoretical solution.

The above study will definitely give us a clue on regarding the efficacy of sandwick to withstand seismic stresses and to avoid quick clay condition.

EXPERIMENTAL INVESTIGATIONS

Modified Oedometer

The large size diameter of Oedometer of 254mm were used for testing the remolded samples (see figure 1).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. Pore water 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. The important factor in all the above set-up is full control over drainage and uniform settlement measurement of the sample. For all the n' values the test diameter to height ratio of soil sample was kept constant. Three 'n' values i.e. 11/04, 16.93 and 21.71 are taken for investigation. The sample in the Oedometer is a representative of one influence zone.

Drainage and Pore pressure measurement

Inward radial drainage was provided in our case. The drainage outlet is via the centre of the settlement hollow rod and a short length of flexible tube leading to valve at the edge of the cell cover. No vertical drainage is allowed and so the top of the sample is sealed with the jack alone or with a rigid impervious top platen between the sample and the jack. The important factor in all the above set-up is full control over drainage and uniform settlement measurement of the sample. The side friction was reduced by means of application of silicon grease on the walls of the cell.

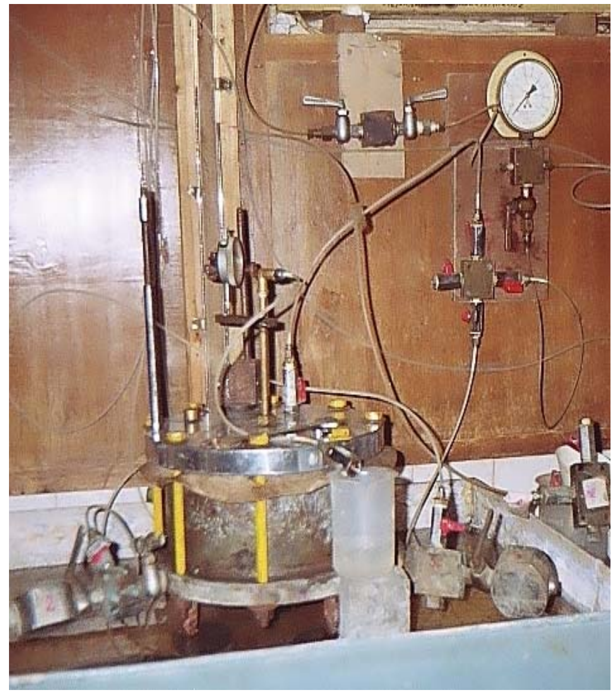

Fig. 1 Complete test set-up of 254mm diameter of modified hydraulically pressurized oedometer

Shake Table

The shaking table used for the investigation along with set-up of oedometer and vane shear test instrument is shown in the figure 3.Also the instrument to measure vibration is shown. The vibrations were applied for 5s, 15s, 30s, 60s, 120s and vane shear strength was measured at the end of each vibration. The vane shear strength was measured at the end of consolidation as well as at the end of each vibration period. This vibration was equivalent to seismic coefficient of 0.1g.

Formation of Clay Samples & Sandwicks

Table 1. Properties of Clay Used In the Present Investigation

Type of Clay	Kaolin
Specific Gravity(G)	2.6
Liquid Limit(L_L)	67 %
Plastic Limit(P_L)	33.50 %
Plasticity Index(PI)	33.50
Soil Classification	CH
Swelling Index	None

Table 2. Properties of Sand Used for Sand wick

Specific Gravity(G)	2.645
Permeability (K)	8.45 x 10^{-3} cm/sec
Cu = 2.023, Cc = 1.295	Sand is coarse well graded

Table 3. Properties of Polypropylene used for Sandwick

Description	Values
Type of Fabric	Multifilament woven fabric(polypropylene)
Weight per square meter	230.33gms
Threads per square inch (a)Longitudinal (b)Transverse	43(average) 18(average)
Denier of Threads (a)Longitudinal (b)Transverse	896.04 (gms/m) 817.47 (gms/m)
Tensile strength of 1cm x 30cm strip (a)Longitudinal (b)Transverse	29.50(kg/cm) 37.75(kg/cm)
Bursting strength	>30 kg/cm^2
Air permeability at 1.27cm water pressure drop	1500 m^3/m^2/hr

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. To ensure full maturation of the sample the clay was mixed to form slurry with twice the liquid limit using de-aired distilled water. After 24 hours of placing the slurry into the cell a static load of 10KPa is applied gradually for the period upto 25days. The clay is then scribed level and a filter paper followed by saturated flexible bronze drain is placed on the top. Free water is poured onto the drain and the rubber jack is lowered into the position through the water to exclude all air. Before that initial moisture content and void ratio are determined. Also the shear strength is measured with the help of laboratory vane shear apparatus. The sandwick consists of prepacked geotextile cylindrical bag having diameter according different 'n' values selected. The polypropylene geotextile bag prepared before the test with height equal to that of sample. The sand and bag are saturated in water for thorough de-air. Saturated sand is filled in the bag under the syphonic action to get required density. The wick thus prepared is then inserted in the predrilled hole, formed by thin mandrel at centre of the soil sample in the oedometer with help of guide platen having a two guide screws by the side for correct vertical installation. During installation care is taken for the full saturation of the sandwick. Water sprinkling is done to ensure water continuity with porous stone.

Testing Program

After installation of sample and fixing top platen along with dial gauge, displacement transducers, bishop's apparatus are connected to their respective locations. Load increment is applied from constant pressure system to sample through water filed jacket, with closed position of the drainage valve at the top plate. Pressures are applied in the range of 20 KPa, 40 KPa, 80 KPa, 160 KPa and 320 KPa with $\Delta p/p = 1.0$.Each load increment is kept constant for about 96 hrs and secondary compression is also recorded. After completion of the test, the sample is taken for final moisture content measurement. After end of each consolidation test the vane shear test was carried out to know gain in strength under different diameters of drains. The same sample was then putted over shaking table for the application of peak horizontal and vertical acceleration equal to 0.1g for durations above mentioned. (Refer figure 3)

Fig.3. Shaking table with oedometer, vane shear and vibration meter

RESULTS AND ANALYSIS

Theoretical Review

Karl Terzaghi gave the general equation for consolidation due to radial flow.

$$\partial u/\partial t = C_{vr} [\partial^2 u/\partial r^2 + 1/r \, \partial u/\partial r] \qquad (1)$$

Shroff & Shah (2006) proposed a new mathematical theory whose general solution directly gives a clue to design engineers for selection of most economical drain. This theoretical treatment incorporates non-homogeneity, time effects intrinsic to the soil skeleton along with physico-chemical changes, compressibility of pore fluid and solid, variation of compressibility and permeability during consolidation, 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

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

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

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

Isochrones for various positive and negative values of parameter λ are obtained from which degree of consolidation at various radial points against time factor is possible to deduce by the expression: $U_R = 1 - \frac{u_r}{u_i}$ where u_r denotes the pore pressure at any radial distance 'r' and u_i is the initial value of pore pressure while in experimental studies will be the value of increment of pressure applied. We can obtain values of λ either positive or negative according to drain material, geometry and diameter of drain. From the results so far analyzed it is observed that maximum value of λ is +0.7 and minimum -0.7.

Experimental Analysis

It is categorized into two groups. In the first group results of consolidation through radial drainage using sand wicks of three n' values i.e. 11.04, 16.93 and 21.71 are presented. In the second group post analysis of consolidated soil sample with central sandwick drain under seismic stresses is presented. The vane shear strength is measure in three stages. First at the end of static load of 10KPa, second at the end of 320KPa, third at the end of seismic stresses for different period at three radial points' r_1, r_2 and r_3 at varying height of consolidated sample. The experimental investigation presents the results of prefabricated vertical sandwicks having n=16.93 & 21.71 where 'n' is the ratio of diameter of sample to the diameter of drain.

Group-I:-

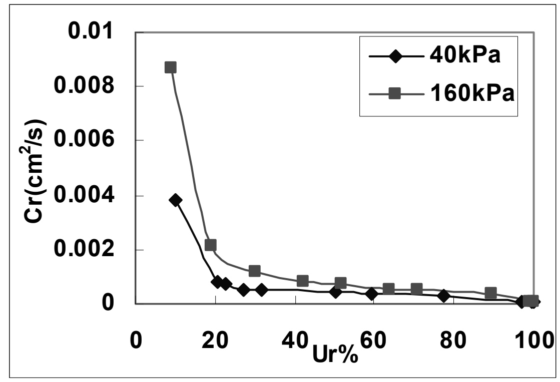

Fig 4. Comparison of Cr vs. Ur% for n=11.04, Sandwicks

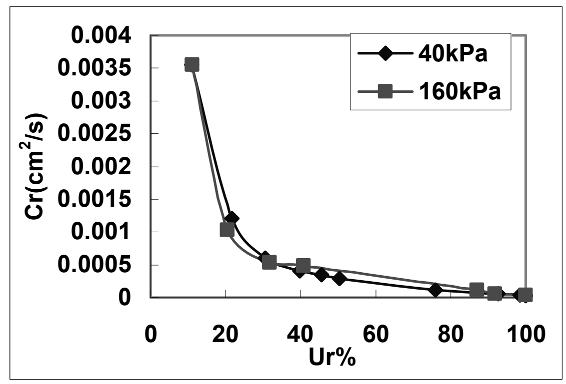

Fig 5. Comparison of Cr vs. Ur% for n=16.93, Sandwicks

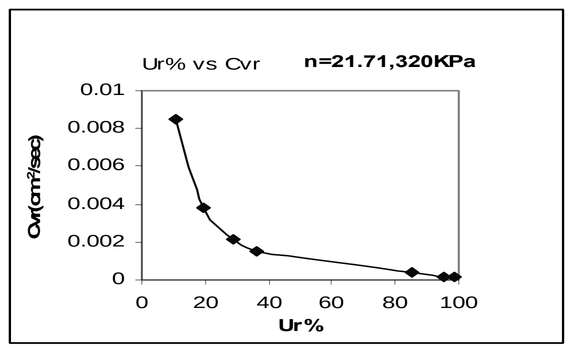

Fig 6. Comparison of Cr vs. Ur% for n=21.71, Sandwicks

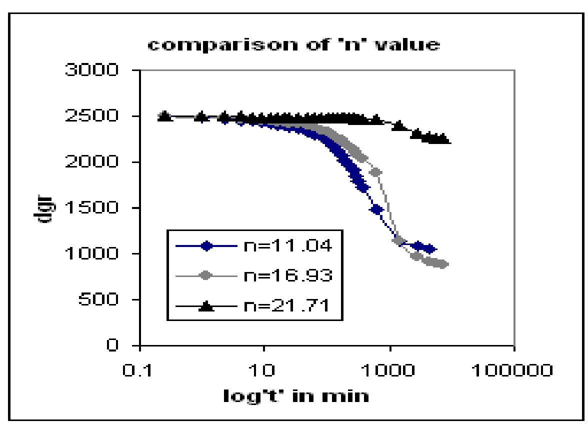

Fig 7. Comparison of settlement readings for all 'n' values at 160KPa applied stress

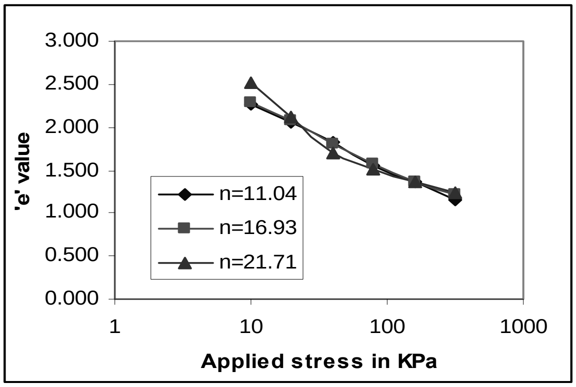

Fig 8. Comparison of void ratio for all 'n' values

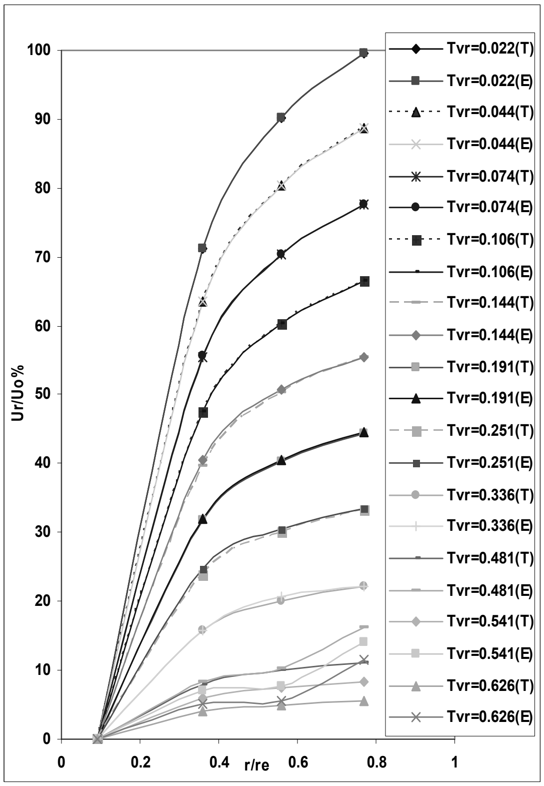

Fig 9. Comparison of theoretical & experimental Isochrones under 40KPa and n=11.04, sandwicks

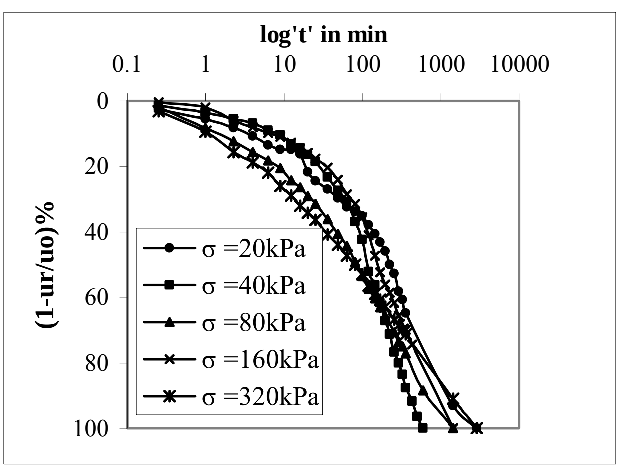

Fig 10. Dissipation of pore water pressure with respect to time under applied stress

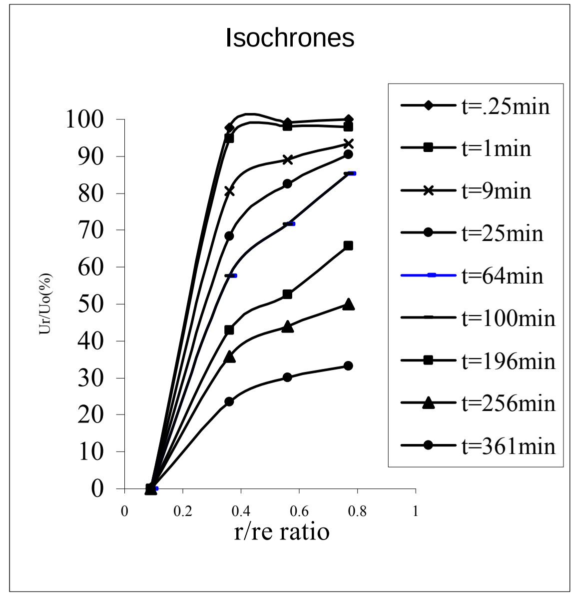

Fig 11. Experimental isochrones for 160 KPa.

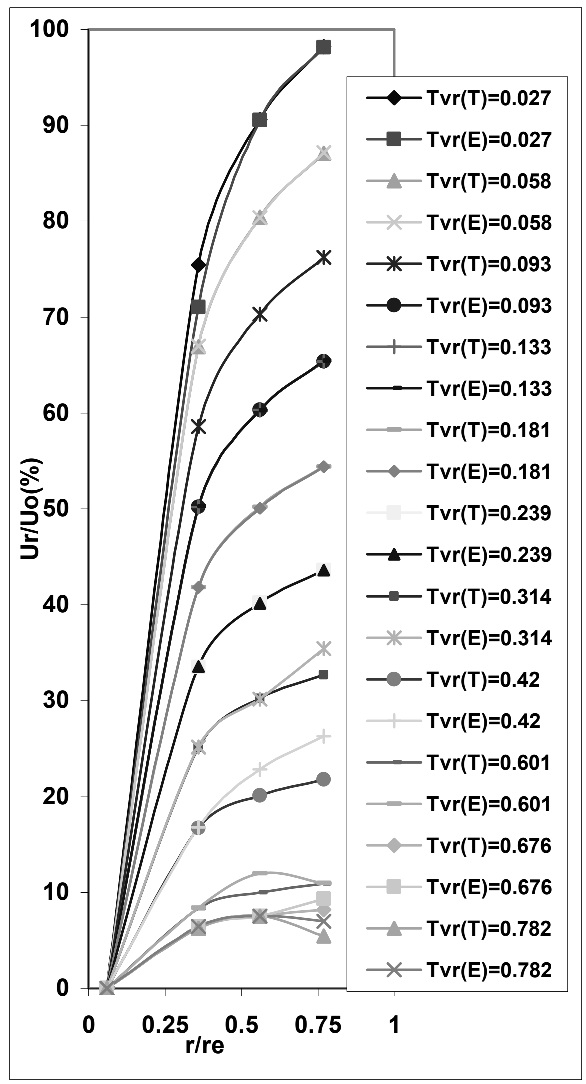

Fig 12. Comparison of theoretical & experimental Isochrones under 40KPa and n=16.93, sandwicks

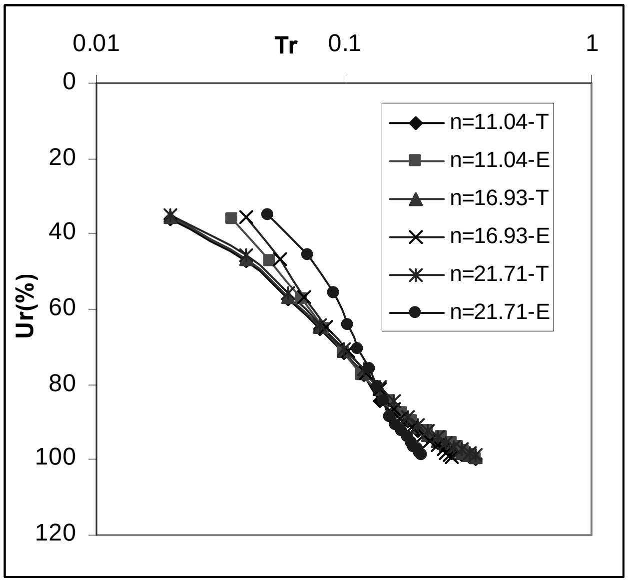

Fig 13. Comparison of theoretical & experimental average degree of consolidation for 160KPa for all 'n' values

Fig 14. Kaolin clay sample with central sandwick at the end of consolidation

Analysis of Group-I

- Time required for 50 percentage consolidation is reduced to 560 minutes compared to 1100 minutes of vertical drainage. The time required for any percentage of consolidation under lighter loads is less compared to the time required for same degree of consolidation under lighter load but here the additional advantage of sandwick and more horizontally permeability help to accelerate the process. Time required for 50% consolidation under 40kPa, 160kPa & 320KPa is 325min, 210min & 150min respectively. Settlement decreases as value of 'n' increases for any applied stress.(Ref.fig.7)
- General characteristic of graphical relationship between Cr and Ur is initially dropping and then remaining more or less constant later on for all pressures. It seems from the fig.4,5 & 6 of' Cr versus Ur, that little more variation is observed up to an engineering stress of 80kPa.Thereafter, the coefficient of consolidation due to radial drainage increases with pressure gradually. Lower values of Cr are observed as when diameter of drain increases. I.e. as 'n' increases from 11.04 to 21.71 at any pressures.(Ref.fig.4,5 & 6)
- In case of pore pressure readings, out of three radial points the mid plane radial point was selected here for pore pressure dissipation rate. It was observed that time required for 50% consolidation with radial drainage is 125min, 160min and 122min under 40kPa, 160kPa and 320kPa respectively.(Ref.fig10.)
- From the plot of isochrones plotted for various pressures it was found that the nature of isochrones remains same for any 'n' value. For initial pressures it is observed that for up to nearest radial point there is a linear relationship and thereafter parabolic nature is observed while at higher stresses a little curvature is observed beyond middle radial point. Experimental and theoretical isochrones mostly were matching for all 'n' values. This also reflected the true time taken for complete dissipation and thus accelerating the rate of settlement.(Ref. fig 9,11 & 12)
- It was observed that as pressure increases the degree of consolidation was achieved at low time factor (Tr), which suggests that at pressures upto 40kPa there is fast change in rate of compression compare to lower rate of compressions at higher pressures during initial stages of consolidation. From the fig.13 it is observed that the experimental and theoretical degree of consolidation was nearly same, except that for higher pressures lower degree of consolidation was achieved for the same time factor. Author's theory for finding average degree of consolidation fits very well with experimental findings. The lump parameter λ =-0.1 fits with n=11.04, λ =-0.08 fits with n=16.93 and λ =-0.03 fits with n=21.71.
- Referring to fig. 8 of void ratio versus log'p' the value of compression index found was 0.760 for n=11.04, 0.796 for n=16.93 and 0.897 for n=21.71.

Group-II

Table 4. Initial vane shear strength at the end of static consolidation of 10KPa

Vane shear strength ζ	r_1 (KPa)	r_2 (KPa)	r_3 (KPa)
n=16.93	14.6	13.0	13.0
n=21.71	12.1	12.1	12.9

Table 5. Final vane shear strength at the end of consolidation without seismic stresses.

Vane shear strength ζ	r_1 (KPa)	r_2 (KPa)	r_3 (KPa)
n=16.93	113.7	110.4	101.5
n=21.71	100.7	99.1	97.4

Where,

r= radius of clay sample equal to 76mm and 127mm

r_1=first radial point for measurement of pore pressure at a distance of $r/4$

r_2=second radial point for measurement of pore pressure at a distance of $r/2$

r_3= third radial point for measurement of pore pressure at a distance of $3r/4$

Table 6. Vane shear strength at the end of seismic stresses equivalent to 0.1g under different durations by using shaking table

Time in sec	Vane shear strength (ζ) in KPa	
	n=16.93	n=21.71
0-5	51.10	46.30
0-15	58.40	42.20
0-30	63.30	31.60
0-60	58.40	32.40
0-120	57.60	31.60

Table 7. Percentage loss in strength at the end of each period due to seismic effect

Time in sec	% loss in shear strength	
	n=16.93	n=21.71
0-5	52.91	53.23
0-10	46.18	57.37
0-30	41.67	68.08
0-60	46.18	67.27
0-120	46.92	68.08

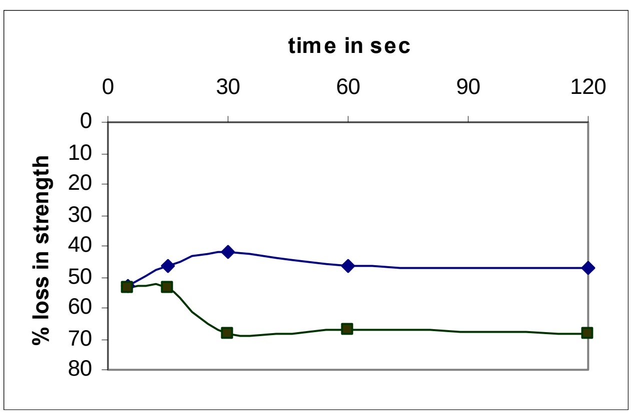

Fig 15 Plot of %loss of strength versus time interval in seconds

.

Analysis of Group-II

- For n= 16.93 the results of vane shear strength indicates that strength increases from 14.6kpa to maximum of 113.7kpa i.e. 88% increment. It was also observed that strength is more towards the first radial point r_1 while it is less at r_3 i.e. 101.5kpa.But generally for analysis the mid radial point (r_2) is consider in design. For n=21.71 the strength increased from 12.1kpa to 99.1kpa i.e. 87% increment without application of seismic stresses. In this case also the strength was maximum at r_1 while it was minimum at r_3 i.e. 97.4kpa.This results indicates that as the diameter of drain increases the soil shear strength also increases.
- For n=16.93 under seismic stresses the results of vane shear strength indicates that the % loss in strength is more during first or initial vibration, afterwards the loss in strength is more or less constant. The average strength for n=16.93 decreased from 108.53kpa to 51.10kpa i.e. 53% decrement for vibration period of 5 seconds. While for n=21.71 the average strength decreased from 99.0kpa to 46.3kpa i.e. 53% decrement for 5 seconds which clearly indicates that though their strength achieved were different but the loss in strength for the first seismic shock (vibration) is governing factor in loss of strength. The same conclusion was also given by Mandal and Kanagi [3] in their investigations using centrifuge modeling method.
- For n=16.93 under seismic stresses the results of vane shear strength for seismic period of 15 secs, 30 secs, 60 secs and 120 secs indicates that %loss in strength is 46% averagely remaining constant though seismic periods was increased while if we consider the net effect in strength then it is only 6 to 8%which may be an indication of particle rearrangement or the card house structure of soft clay to have became horizontal whose metabolism was not affected by adsorbed water at later stages to some extent. While or n=21.71 the % loss in strength was averagely 68%which is much higher compare to n=16.93values.Also it was observed that there was no change in in-situ placed condition of sandwick or even no settlement of only sandwick was observed nor any change in its diameter was observed indicating sandwick as a stable drain under seismic conditions which prevents the soft soil to get liquefy. The shaking table test proved to be very useful to check the applicability of sandwicks in seismic areas and proved to be a remediation to natural disasters.

CONCLUDING REMARKS

The use of Geodrain namely sandwick employed in the present investigation under static and dynamic conditions has increased effectively the rate of pore pressure dissipation and thus, allowed early consolidation for a particular construction loading**.**

- ✓ From the analysis made of group-I, Consolidation versus time factor plotted for all ‘n’ values and for all pressures it is found that theoretical and experimental degree of consolidation using pore water pressure measurements fits more exactly with Author’s solution, so it can be concluded that for estimating degree of consolidation pore pressure measurements are more reliable as compressibility of soft clays depend upon excess pore water pressure developed at different stress levels. This proved to be true for all ‘n’ values that is for bigger drain and smaller drain diameter. Author’s lump parameter theory predicts degree of consolidation for any drain material and diameter. Different values of λ give direct selection of optimum drain diameter for any site.

- ✓ The coefficient of consolidation remains nearly constant for all the pressures for all 'n' values and at any radial point. Also it is clear that as radial distance increases away from the drain the time required for dissipation of pore water pressure also increases. But for comparison in analysis middle radial point is considered.
- ✓ Clay-drain surface interaction plays an vital role in deciding the rate of dissipation of excess pore water pressure because as clogging rate will increase due to fast rate of dissipation of excess pore water pressure. Outside polypropylene cover is hindered by smaller silt particles of inner sand and outside colloidal particles of clay .This will be true for nay 'n' value. As load increases and hydrodynamic lag decreases some partial deformation of drain surface is observed and particle rearrangement of filler material sand will further create clogging because of elastic deformation of clay as pore water dissipates. Under seismic stresses it was observed that at lower time periods clay-drain surface does no get disturbed except some deformation is observed at top most surface of drain. At higher time periods of seismic loads once particulate water rearrangement is over though it is very-very less no major change is observed in loss of shear strength. Only initial vibratory loads of lesser periods are playing important role in loss of shear strength. Yet sandwick drain proved to be better to control quick clay condition.
- ✓ Horizontal permeability decrease with increase of pressure under lighter load and then it is more or less constant for higher intensity loading for radial drainage.
- ✓ The behavior of void ratio and pressure shows characteristic curve of normally consolidation soil for all the 'n' values of sandwick drains.
- ✓ There is considerable gain in shear strength of soil due to radial consolidation compared to vertical consolidation for all the 'n' values. The maximum advantage is observed in case of n=11.04 and n=16.93.
- ✓ Experimental and theoretical isochrones mostly were matching for all 'n' values. Isochrones reflects the true time taken for complete dissipation of excess pore water pressure and thus accelerating the rate of settlement. With the increase of load intensity, the respective isochrones of higher load lies above the previous at any radial time factor.
- ✓ The degree of consolidation obtained from the pore pressure readings experimentally are 5-8 % lower then that obtained by Author's theory but higher compare to settlement readings.
- ✓ The behavior of consolidated soil mass using sandwick under vibratory loads for varying time periods can be well understand by using Shaking table test. The rate of loss of shear strength can be very well reduced by using sandwick of appropriate diameter under seismic conditions.

Use of prefabricated vertical geodrain for soft soil improvement like sandwick for earthquake prone areas can be well emphasized from the above findings. Such static and dynamic analysis of sandwick drain gives better understanding to design engineers for its generous application.

ACKNOWLEDGEMENTS

The authors are highly thankful to the Prof. B.S Parekh, Dean of Faculty of Technology & Engineering, Prof. (Dr) K.R. Biyani, Head, Applied Mechanics Department, Prof. (Dr) D.L. Shah, P.G Section, Prof.K.S.Agarwal, Principal, Polytechnic, The M.S. University of Baroda, India for providing all the necessary research facilities.

REFERENCES

Barron .R (1948), "Consolidation of fine grained soils by drain wells", *Trans A.S.C.E.*, Vol.113, pp. 718-742

Berry P.L. and Wilkinson W. B. (1969), "The radial consolidation by clay soils", *Geotechnique*, Vol. 19, pp. 253-284.

Hansbo .S (1960), "Consolidation of clay, with special reference to influence of vertical sand drains", *Proc. Swedish Geo-tech Instt*. No.18, pp.160

Rowe .P. (1959), "Measurement of the coefficient of consolidation of lacustrine clay", *Geotech*, Vol.9, No.1, pp.107-118

Rowe P. W. and Barden .L. (1966),"A new consolidation cell", Geotechnique, 16:2:162.

Shroff A.V., Shah M.V. (2005), "Experimental study on performance of sand drain with varying drain diameter", *Proc. of National conference on GEOPRACTICE*-2005, pp.207.

Mandal .J and Kanagi (1988),"Centrifuge Modeling of Vertical Drains", *Indian Geotechnical journal*, Vol. 28, No.1. pp 71-92