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Theoretical Simulation of Experimental Results with Barron's Theory for Consolidation of Soft clay by Radial Flow using PVD

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Abstract. The rapid development and associated urbanization have compelled Engineers to construct earth structures, including major highways, over soft clay deposits of low bearing capacity coupled with excessive settlement characteristics. Consolidation due to radial drainage using PVD is one of the ground improvement techniques in which the consolidation is accelerated by reducing drainage path. Soil improvement is required to provide adequate bearing capacity and improve shear strength of the soft cohesive soils to satisfy the need for various type of construction on sites underlain by such soft soils. Amongst various ground improvement techniques the technique of preloading or pre-compression used in combination with vertical drains is one of the oldest and most widely used techniques to preconsolidate and strengthen weak compressible soils. Present research work presents experimental model of various drain material to expedite the in-situ settlement due to excess pore water pressure dissipation under preloading by radial drainage taking advantage of having more horizontal permeability than vertical. The Hydraulically pressurized Rowe Type Oedometer was developed in the applied mechanics department of The M.S. University of Baroda, India. The present research work focuses 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 clays with a complete set-up of hydraulically pressurized modified oedometer with conventional bishop pore pressure measuring system and measuring settlement with dial gauge. The effect of PVD of 'n' value (ratio of zone of influence to the diameter of drain) of 10, n = 12.09, n = 14.76 on consolidation characteristics of Kaolinitic clay were undertaken to investigate the dissipation characteristics using isochrones & settlement characteristics. Time-pore pressure dissipation and Time-settlement observations were recorded for different applied stress under long duration test. Average Degree of consolidation was computed using isochrones.

Barron`s equal vertical strain theory with no smear and no well resistance has been used to carry out the analysis for radial consolidation. Present work shows the Comparison of Experimental Results with Barron's theoretical curve with all the drain materials.

Keywords: Barron's Theory, Free and fixed vertical strain theory, Co-efficient of consolidation due to radial flow, Time factor.

1 Introduction

Beginning with the classical work of Terzaghi on three dimensional consolidation process and thereafter Barron's theory on consolidation due to radial flow which was further extended by Hansbo, number of research workers carried out research and focused the attention on various influencing factors of vertical geodrain on consolidation characteristics of clayey soil due to radial flow either by laboratory model or in the field. Most of the soil deposits have greater permeability in horizontal direction which can be utilized efficiently by the use of prefabricated vertical drains. After the use of sand drains, several new types of geo-drain has come on the horizon, with different shapes and material namely Sand wick Drain, Jute Drain, Polypropylene Drain, Card board drain, Rope Drain etc.

At first three dimensional consolidations problem was given by Terzaghi (1923). Prior to this three dimensional consolidation problems were solved using one dimensional approximation to three dimensional problems using Terzaghi`s famous consolidation theories. Further modified in Terzaghi (1943) and Barron (1948) reported simplified expression for the design of vertical drains. The theory after Tan (1961) includes stress strain relationship for clays during radial flow as a function of time, which he approximately solved using linear, integrated equation. The fourth theory was propagated and enhanced by workers namely Hansbo (1960), Henrich and Desoyer (1961), Escario et al (1961), Tan et al (1971) and Hansbo (1981). They have extended the scope of the theory, considering with respect to variable nature of loads, permeability, compressibility and structural viscosity. The equations of Barron were also used by Rowe (1969) in analyzing the consolidation of lacustrine, laminated Clays. This work was subsequently developed by Horne (1964), which includes and gives for laminated or layered clays having sequence of identical layers.

2 Theoretical Development on Three Dimensional Consolidation

2.1. Terzaghi`s theory

The one dimensional theory given by Terzaghi is

$$\frac{\partial u}{\partial t} = C_{vz}\frac{\partial^2 u}{\partial z^2} \dots\dots.(1)$$

Where, u = Pore water pressure
Cv = $k/mv\gamma w$
k = co-efficient of permeability
mv = coefficient of volume change

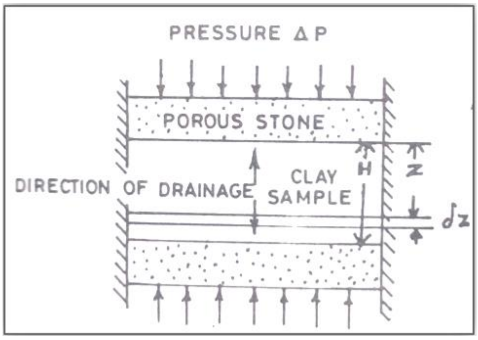


Fig. 1. Three Dimensional Consolidation

The basic equation of One dimensional theory of Terzaghi is :

$$\frac{\partial u}{\partial t} = C_v \frac{\partial^2 u}{\partial z^2} \text{ with initial condions } U(x,y,z,t) = U_o(x,y,z,o) \ldots\ldots(2)$$

It relates the rate of change of excess hydrostatic pressure to rate of expulsion of excess pore water from a unit volume of soil during the same time interval.

The three dimensional consolidation equation is:

$$\frac{\partial u}{\partial t} = C_{vx} \frac{\partial^2 u}{\partial x^2} + C_{vy} \frac{\partial^2 u}{\partial y^2} + C_{vz} \frac{\partial^2 u}{\partial z^2} \ldots\ldots(3)$$

Where

Cv = Coefficient of consolidation in (cm 2/sec) various co-ordinates.

= Kmvγw

$$U(\%) = f(T_v) \ldots\ldots(4)$$

Where

$$T_v = \frac{C_v t}{H_2}$$

is time factor.

In the case of sand drains, where the process of three dimensional consolidation is symmetrical about vertical axis, it is more convenient to express equation 3.2 into polar co-ordinates as

$$\frac{\partial u}{\partial t} = C_h \left[\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right] + C_v \frac{\partial^2 u}{\partial z^2} \quad \ldots\ldots(5)$$

If the radial flow takes place in planes at right angle to z axis, the term $\partial^2 u/\partial z^2$ equals to zero and so equation reduces to

$$\frac{\partial u}{\partial t} = C_{vr} \left[\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right] \ldots\ldots(6)$$

Fig 3.3, 3.4 gives the isochrones for different types of drainage and different distributions of consolidation pressures in vertical direction.

In the present investigation mid plane pore pressure is measured and the pressure distribution will be as shown in Fig 3.2 with pore pressure in central drain zero.

2.2 Barron's Theory (1948)

His theory was based on all of the simplifying assumptions of Terzaghi uncoupled one dimensional consolidation theory. Barron considered two types of vertical strains which might occur in a clay layer.
(1) Free strain case. (2) Equal strain case.

(1) Free Strain Case.

If the surcharge load placed over the sand blanket is flexible, free strain case occurs. In this case, there is uniform distribution of surface loads, but the settlements at the surface are uneven. The basic differential equation for radial drainage is given by Eq. 12.65, is

$$\frac{\partial u}{\partial r} = C_{vr}\left[\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right] \quad \ldots\ldots.(7)$$

In the case of free strain case, the boundary conditions are as under

$$At\ time\ t = 0, \bar{u} = \overline{u_r}, At\ time\ t > 0, \bar{u} = 0\ at\ r = rw\ and\ r = R, \frac{\partial \bar{u}}{\partial r} = 0$$

This solution for excess pore water pressure $\bar{u}$ at any time t and at a radial distance r is obtained by the solution of the differential equation as

$$\bar{u} = \sum_{\alpha 1, \alpha 2..}^{\alpha=\infty} \frac{-2U1(a)U_0(\frac{\alpha_r}{\alpha_w})}{\alpha[n^2 U_0{}^2(\alpha n) - U^2{}_1(\alpha)\ ]} \quad e^{-4\alpha^2 n^2}T_r \quad \ldots\ldots\ldots(8)$$

-Where $n=R/r_w$ and

$U_1(\alpha) = J_1(\alpha)\ Y_0(\alpha)$ - $Y_1(\alpha)\ J_0(\alpha)$

$U_0(\alpha n) = J_0(\alpha n)\ Y_0(\alpha)$ - $Y_0(\alpha n)\ J_0(\alpha)$

$and \quad U_0(\alpha r/r_w) = J_0(\alpha r/r_w)\ Y_0(\alpha)$ - $Y_0(\frac{\alpha r}{r_w})\ J_0(\alpha)$

Where J_0 = Bessel function of first kind of zero order.
J_1 = Bessel function of first kind of first order
Y_0 = Bessel function of second kind of zero order
Y_1 = Bessel function of second kind of first order
And α_1, α_2.... are roots of Bessel function which satisfy the equation
$J_1(\alpha n) =\ Y_0(\alpha)$ - $Y_1(\alpha n)\ J_0(\alpha)$=0
Also $T_r = C_{vr}\ t/(2R)^2$
Where

$C_{vr} = \frac{K_r}{m_v \gamma_w} = \frac{k_h}{m_v \gamma_w}$

In which k_h is co efficient of permeability in horizontal direction

The average pore water pressure u_{av} throughout the soil mass may be written as

$$u_{av} = ui \sum_{\alpha 1, \alpha 2 ....}^{\alpha = \infty} \frac{4U_1^{\,2}(\alpha)}{\alpha^2 (n^2 - 1)\left[n^2 U_0^{\,2}(\alpha n) - U_1^{\,2}(\alpha)\right]} e^{(-4\alpha^2 n^2 T_r} \quad ....(9)$$

The Average degree of radial consolidation U_r with the time factor T_r by dotted lines for different values of n, where $n = R/r_w$

2) Equal Strain case

This case occurs when the surcharge applied is rigid, such as heavy steel plates. In this case, the settlements are uniform but the distribution of pressure is non-uniform. The problem was solved by Barron, who gave the expression for excess pore pressure $\bar{u}$ as

$$\bar{u} = \frac{4\,u_{av}}{(2R)^2\,F(r)} \left[R^2 \log_e\left(\frac{r}{r_w}\right) - \frac{(r^2 - r_w^{\,2})}{2}\right] \quad ....(10)$$

Where $F(n) = \frac{n^2}{n^2-1} \log^{(n)}{}_e - \frac{3n^2-1)}{4n^2}$

U_{av} = Average value of pore water pressure throughout the embankment

$U_{av} = \bar{u}_1 e^{\gamma}$ in which $\gamma = \frac{-8T_r}{F(n)}$

FORMATION OF BARRON'S EQUATION FOR CONSOLIDATION DUE TO RADIAL FLOW:

The Terzaghi equation for 3 dimensional consolidation in Cartesian coordinate is:

$$\frac{\partial u}{\partial t} = C_{vx}\frac{\partial^2 u}{\partial x^2} + C_{vy}\frac{\partial^2 u}{\partial y^2} + C_{vz}\frac{\partial^2 u}{\partial z^2} \quad ....(11)$$

The same in cylindrical coordinate

$$\frac{\partial u}{\partial t} = C_{cvr}\left[\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial u}{\partial r}\right] + C_v\frac{\partial^2 u}{\partial z^2} \quad ....(12)$$

The equation can be split into two parts:

Radial Flow:

$$C_{cvr}\left[\frac{\partial^2 u}{\partial r^2} + \frac{1}{r}\frac{\partial r}{\partial t}\right] = \partial u/\partial t \quad ....(13)$$

Where,

$$C_{vr} = \frac{kr}{mv\gamma w -}$$

This equation is Barron's theoretical equation for radial flow which is similar to the radial flow in Rowe type oedometer used for research work.

Vertical Flow:

$$C_{vz}\frac{\partial^2 u}{\partial z^2}=\frac{\partial u}{\partial t}\ \dots\dots(14)$$

Where,

$$C_{vz}=\frac{kz}{mv\gamma w-}$$

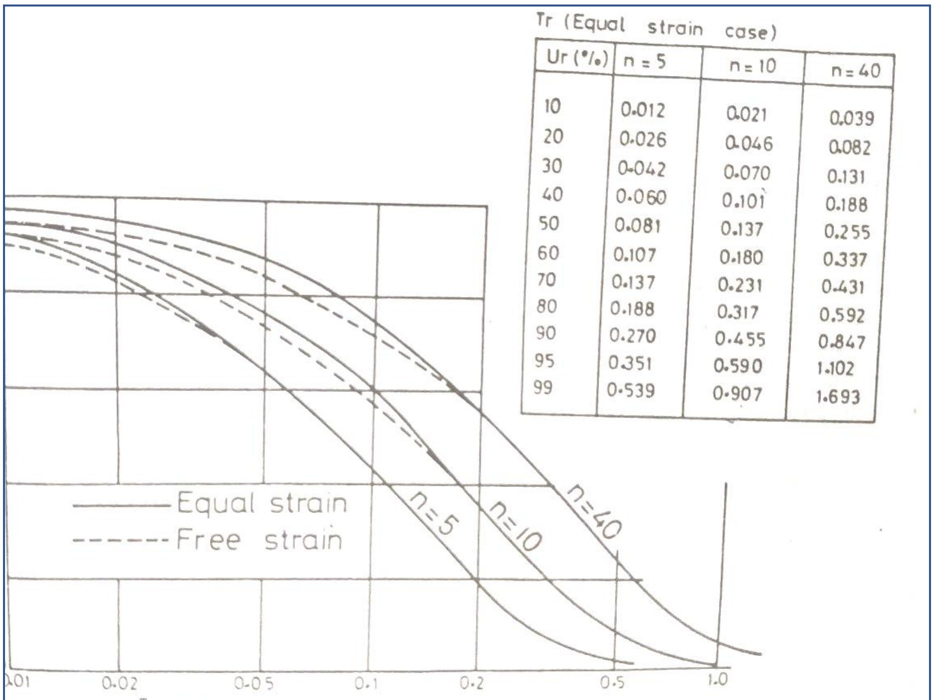
This equation is given by Terzaghi in One dimensional condition

Considering the radial drainage and applying the boundary condition, solution for excess pore water pressure at any time t and at radial distance r can be obtained.

The degree of consolidation of radial consolidation for equal strain with no smear

Ur= 1-$e^{(-8Tvr/f(n)}$ **where** the value of Tvr and F(n) are explained as follows:

Barron`s equal vertical strain theory with no smear and no well resistance has been used to carry out the analysis for radial consolidation. Figure shows the relationship between Tvr and Ur. Using this curve, the time factor, Tvr for 50% percent consolidation is found out.



Tr (Equal strain case)

Ur (%)	n = 5	n = 10	n = 40
10	0.012	0.021	0.039
20	0.026	0.046	0.082
30	0.042	0.070	0.131
40	0.060	0.101	0.188
50	0.081	0.137	0.255
60	0.107	0.180	0.337
70	0.137	0.231	0.431
80	0.188	0.317	0.592
90	0.270	0.455	0.847
95	0.351	0.590	1.102
99	0.539	0.907	1.693

Fig. 12.28. Variation of U_r which T_r.

The Average degree of consolidation in radial direction is given by U_r *with* T_r *by firm lines for 3 values of n*

Table 1. T_r (Equal strain case)

Ur%	n =5	n=10	n=40
10	0.012	0.021	0.039
20	0.026	0.046	0.082
30	0.042	0.070	0.131
40	0.060	0.101	0.188
50	0.081	0.137	0.255
60	0.107	0.180	0.337
70	0.137	0.231	0.431
80	0.188	0.317	0.592
90	0.270	0.455	0.847
95	0.351	0.590	1.102
99	0.539	0.907	1.693

It may be observed that the curves for free strain are not much different and they give approximately the same results. Equal strains case is generally preferred as it is more convenient. Fig.12.28 also gives the value of T_r in a tabular form for the equal strain case.

3 Scope and Objective

The hydraulically pressurized Oedometer (Rowe Type) with central geodrain is employed in present investigation and Cvr value is determined for both settlement and pore pressure readings. Measurements of pore pressures are planned to carry out by conventional Bishop's pore pressure setup and extensometer.
It is intended to conduct a series of Consolidation tests with radial drainage through vertical geodrain centrally placed and measurement of Settlement and pore water pressure at 3 radial distances will be taken so as to prove efficacy against various physical factors namely type of drain material, shape, aspect ratio , various sapes of drain , 'n' value (ie. Different diameters of drain related to influence zone)
In present investigation it is intended to use Sand, Saw dust, Saw dust wick, Jute, Polyamide Polyster Geosynthetics to fabricate the vertical geodrains of different diameters in relation to diameter of hydraulically pressurized oedometer (Rowe Type) is used which has special facility for measuring pore pressure and settlement during consolidation due to radial flow of water. The present investigation will simulate the theoretical values of Degree of Consolidation with experimental values for all n values where n = Radius of Oedometer to Radius of the drain.

4 Labotatory Investigations

4.1 Materials Used

The soil used for this investigation was clay mineral Kaolinite obtained commeially in the form of powder. To ensure full saturation of the sample the clay was mixed to form slurry with twice the liquid limit using de-aired distilled water.

Table 2. Property of Kaolinite Soil

Type of clay	Kaolinite
Specific Gravity	2.456
Liquid Limit (LL)	59.6%
Plastic limit (PL)	33.33 %
Plasticity Index (PI)	26.27 %
Classification by A-line Casagrande Chart	CH
Co-efficient of Permeability	0.6 x 10-6 cm/sec

4.2. Properties of PVD drain material

In present investigation, Saw dust wrapped with Whatman filter paper (SD), Saw dust wrapped with Geosynthetics (SDW), Sand Drain and Jute wrapped with polyamide polyster (JPPG) is used for investigation. The properties of the drain material are shown in Table.2, Table.3, Table.4 and table.5. The Saw Dust is treated chemically and then used as a drain by encasing it with Whatman filter paper

Table 3. Property of Saw dust wrapped with Whatman Filter Paper

Sr. No.	Properties of saw dust	Value
1	D_{10}mm	0.29
2	D_{30}mm	0.52
3	D_{60}mm	1.05
4	Co-efficient of uniformity, c_u	3.620
5	Co-efficient of curvature, c_c	0.888
6	Maximum compressive stress, kg/cm^2	0.138
7	Coefficient of permeability, cm/sec	1.502×10^{-3}

Table 4 . Properties of Geotextile used in sawdust wick drain

Sr. No	Description	Value
1	Type of Geotextile	Non-woven
2	Mass per unit area	250gm/m2
3	Tensile strength	14 KN/m
4	Permeability by falling head	3.6x 10-3cm/sec

5	Opening size	85 microns
6	Puncture strength (CBR)	1940 N

Table.5. Properties of Sand Used in Sand Drain

1	Specific Gravity	2.645
2	Co-efficient of Permeability	8.45 x 10-3 cm/sec
3	Co-efficient of uniformity, cu	2.023
4	Co-efficient of curvature, cc	1.295
5	Fineness Moduli	2.2-2.3
6	Sand classified	SW

Table.6 Properties of prefabricated vertical circular Jute wrapped with Polyamide Polyster Geosynthetics

Sr. No	**Properties of newly developed jute wrapped with Polyamide Polyster drain**	**unit**	**value**
1	Weight	gms	5
2	Diameter	Cm	2.1
3	Height	Cm	5.1
4	Peak unconfined stress for flexibility measurement	Kg/cm^2	0.8
5	A.O.S. (0_{95}) – Filter	µm	<75
6	Permeability – Filter	Cm/sec	1.1x10-1
7	Grab Tensile strength- Filter	KN	0.6
8	Elongation at break – filter	%	25

Table 7. Properties of Jute used in JPPG drain

Sr. No	Description	Value
1	Mass per unit area	388gm/m2
2	Tensile strength	250-350 N
3	Permeability by falling head	3 x 10-2cm/sec
4	Jute thickness single layer and double layer	1.08mm & 2.06
5	Grab tensile strength	800-900 N
6	Length of fibers in mm	10-200(highly variable)
7	Elongation percentage at break	5%

4.3 Experimental Set up

The Experimental setup used in the present investigation consists of:

(i) Hydraulic Pressure System
(ii) Oedometer
(iii) Pore pressure measurement system.
(iv) Settlement measurement system

The hydraulically pressurized Oedometer (Rowe Type) with central geodrain is employed in present investigation and Cvr value is determined for both settlement and pore pressure readings. Measurements of pore pressures are planned to carry out by conventional Bishop's pore pressure setup.

Fig.2. Rowe Type oedometer and self-compensating Mercury

4.4 Method of Soil Preparation

The soil used for this investigation was clay mineral Kaolinite obtained commercially in the form of powder. To ensure full maturation of the sample the clay was mixed to form slurry with twice the liquid limit using de-aired distilled water. Density was sufficiently low to allow the removal of entrapped air when the sample in the consolidation cell was vibrated. The slurry was transferred into the Oedometer after the cell body had been lightly coated with a thin layer of silicon grease to minimize side friction; the Oedometer was then placed on a handle operated vibrator and vibrated for

approximately one hour after which only occasional air bubbles could be seen on the surface. The clay was then scribed level. And a filter paper followed by a porous stone was placed at the top. The sample was then preconsolidated under gradually applied static dead load of 10KPa, with Δp/p = 1kPa, 2kPa, 4kPa, 8kPa, 10 kPa) so that the consolidation occurring is normal. (Where 1kPa = 0.01kg/cm^2)
These increments are given by means of dead load with porous stone on the top of the clay sample topped by filter paper so that sample during consolidation water gets removed through porous stone. These increments of Dead loads are to be kept for a longer period of time (at least 48 hours). Representative sample for determination of water content was taken and measured. Initial strength was measured by Vane shear in separate crucible of vane shear apparatus by dead loading in same fashion by small weights. To avoid the soil structure disturbance of soil cake prepared. Initial Height was measured with pointer arrangement with stand and the extra soil was trimmed.
Filter paper is kept on the surface of the trimmed soil and rigid Perspex plate was laid on it to create the equal strain condition while loading.

4.5 Installation stages of Vertical Drain

The axial hole was formed with a thin walled mandrel, having area ratio of 0.8 to 1.6 attached with template and guide frame. Circular Filter paper of size PVD is lowered in the bore hole. A drain hole was then flooded with water from the central connection to the reservoir. The drain was filled with de-aired saturated PVD drain material with the aid of small diameter flexible tubing by syphoning action without any smear and without any intrusion of clay in PVD to avoid blockage. The top cover is then seated into position.

4.6 Test Procedure

After the cell is sealed, settlement dial gauge and Bishop Pore pressure measuring apparatus were connected at their respective location. The first pressure increment is applied through the flexible convoluted jacket after closing the drainage control valve and settlement gauge reading is recorded. After completion of consolidation process drainage control valve was closed then the next increment of load is applied and the same process is repeated for a series of various pressure increments, with P/P = 1.0. The loading was done in the increment of 20, 40, 80, 160 and 320 kPa keeping ΔP/P = 1.

After the completion of the test, vane shear test was performed at 3 locations to determine the gain in strength due to dissipation of water. The value of settlement and pore water pressure is measured with respect to time and co-efficient of radial consolidation is calculated.

5 Tests and Result Analysis

Experimental curves will be compared with Barron's Theoretical curve.

Settlement

- Degree of Consolidation (Ur) % Vs Theoretical Time factor
- Degree of Consolidation (Ur) % (as obtained from experimental results) Vs Theoretical Time factor (as obtained from Experimental results)

5 (A) Settlement

(i) Degree of Consolidation (Ur) % Vs Theoretical Time factor

Calculation of theoretical Time factor for Barron's theory 254mm diameter oedometer

Keeping n = 10 for Settlement

R_e = Radius of Oedometer = 254/2 = 127 mm

R_w = Radius of Drain = 25.4/2 = 12.7 mm

$n = R_e/R_w = 10$

$$\mathbf{F(n) = (n^2/n^2-1)\ln(n) - \frac{3n^2-1}{4n^2}} \quad \ldots\ldots\ldots..(13)$$

F (n) = 1.5783

$\mathbf{U_r = 1\text{-}e^{(-8Tr/F(n))}}$

$\mathbf{Tvr = \ln(1\text{-}U_r)*F(n)/\text{-}8}$ ………..(14)

$$Tvr = \frac{\ln(1\text{-}U_r)}{-5.068}$$

By substituting the value of Ur we can get the theoretical value of time factor Tvr.

Calculation of experimental Time factor using Barron's theory 254mm diameter oedometer keeping n = 10 for Settlement

R_e = Radius of Oedometer = 254/2 = 127 mm

R_w = Radius of Drain = 25.4/2 = 12.7 mm

$n = R_e/R_w = 10$

$$F(n) = (n^2/n^2-1)\ln(n) - \frac{3n^2-1}{4n^2}$$

F (n) = 1.5783

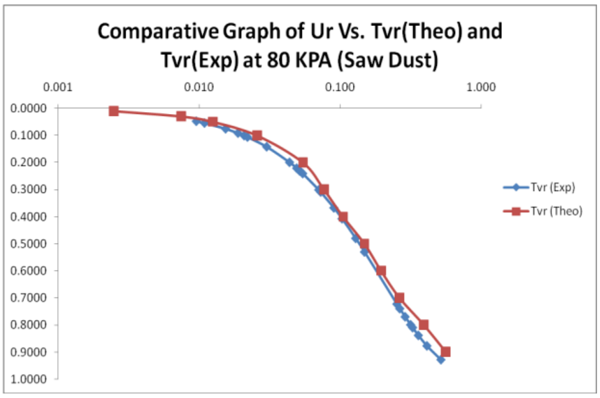
$U_r = 1\text{-}e^{(-8Tr/F(n))}$

$Tvr = \ln(1\text{-}U_r)*F(n)/\text{-}8$

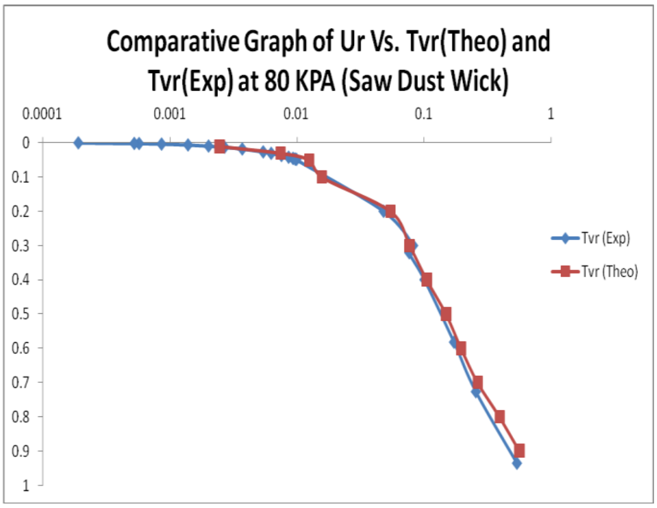
$$Tvr = \frac{\ln(1\text{-}U_r)}{-5.068}$$

By substituting the value of Ur calculated from log fitting method from the graph of DGR vs Log t we get experimental values of Tvr from equation 1.

Values of Tvr for different values of U_r are calculated as shown in Table for n = 10. Typical fitting of experimental and theoretical curve is as shown in figure.

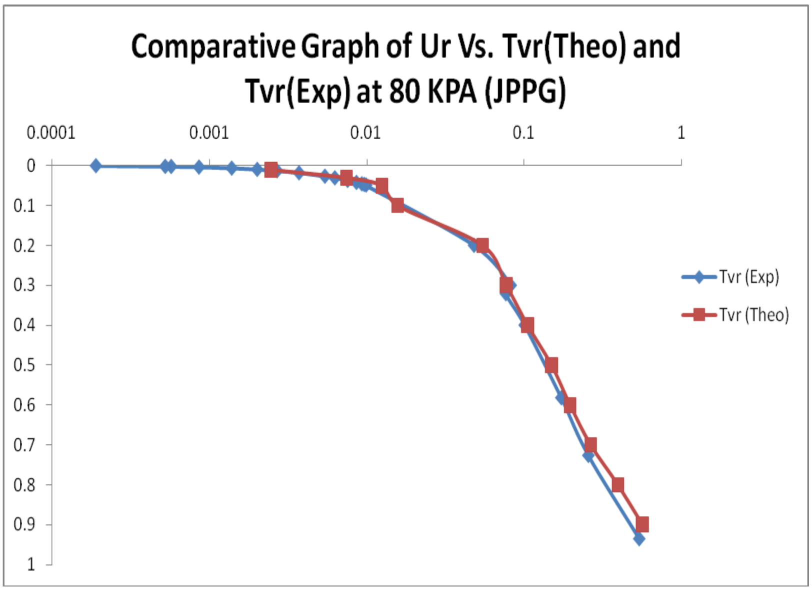


- The theoretical Ur% and Tvr for settlement for SD circular drain is plotted.
- It is compared with experimental values at 80 KPa and it is observed that up to 20% degree of consolidation slight variation is observed in experimental and theoretical value.
- Than from 20 % to 92% of degree of consolidation, the theoretical and experimental curve for settlement is coinciding and again a slight variation is observed after 92%.

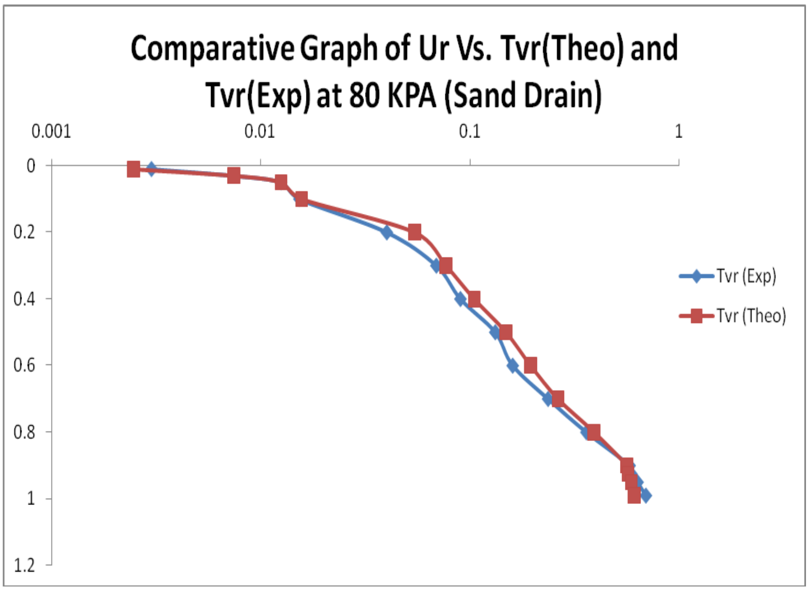


- The theoretical Ur% and Tvr for settlement for SD circular drain is plotted.

- It is compared with experimental values at 80 KPa and it is observed that up to 20% degree of consolidation 5% variation is observed in experimental and theoretical value.
- Than from 20 % to 94% of degree of consolidation, the theoretical and experimental curve for settlement is coinciding and again a 6% variation is observed after 99%.



- The theoretical Ur% Vs. Tvr graph for settlement for JPPG drain is plotted.
- It is compared with experimental values at 80 KPa and it is observed that upto 4% degree of consolidation slight variation is observed in experimental and theoretical value.
- Than from 4 % to 82% of degree of consolidation, the theoretical and experimental curve for settlement is coinciding and again a slight variation is observed after **90%.**



- The theoretical Ur% Vs. Tvr graph for settlement for sand drain for n=14.76 is plotted.
- It is compared with experimental values at 80 KPa and it is observed that up to 8% degree of consolidation slight variation is observed in experimental and theoretical value.
- From 8 % to 90% of degree of consolidation, the theoretical and experimental curve for settlement is coinciding and again a slight variation is observed after 90%.

6 Conclusions

(i) The theoretical Ur% and Tvr for settlement for SD circular drain is plotted. It is compared with experimental values at 80 KPa and it is observed that up to 20% degree of consolidation slight variation is observed in experimental and theoretical value. Than from 20 % to 92% of degree of consolidation, the theoretical and experimental curve for settlement is coinciding and again a slight variation is observed after 92%.
(ii) The theoretical Ur% and Tvr for settlement for SDW drain is plotted. It is compared with experimental values at 80 KPa and it is observed that up to 20% degree of consolidation 5% variation is observed in experimental and theoretical value. Than from 20 % to 94% of degree of consolidation, the theoretical and experimental curve for settlement is coinciding and again a 6% variation is observed after 99%.
(iii) The theoretical Ur% Vs. Tvr graph for settlement for JPPG drain is plotted. It is compared with experimental values at 80 KPa and it is observed that up to 4% degree of consolidation slight variation is observed in experimental and theoretical value. Than from 4 % to 82% of degree of consolidation, the theoretical and experimental

curve for settlement is coinciding and again a slight variation is observed after 90%.
(iv) The theoretical Ur% Vs. Tvr graph for settlement for sand drain for n=14.76 is plotted. It is compared with experimental values at 80 KPa and it is observed that up to 8% degree of consolidation slight variation is observed in experimental and theoretical value. From 8 % to 90% of degree of consolidation, the theoretical and experimental curve for settlement is coinciding and again a slight variation is observed after 90%.
Thus it is observed that for all drain material there is slight variation in Degree of consolidation upto 4 to 6 % in theoretical and experimental values for Ur% Vs Tvr. This is because of the Physiochemical effect of clay minerology.
It is also observed that variation in theoretical and experimental values is observed at 84 to 86% of Degree of Consolidation. This is due to the secondary compression in the soil structure. The depression of the adsorbed layer results in the secondary compression
Consolidation due to radial drainage using PVD is one of the ground improvement techniques in which the consolidation is accelerated by reducing drainage path.
Amongst various drain materials viz. sand, SD, SDW used in the investigation JPPG drain expedite the dissipation of water efficiently resulting in faster rate of consolidation and strength of treated mass. The hydraulically pressurized Rowe-type oedometer is employed in present investigation is found to be efficient to measure settlement and pore pressure.
It is observed that for all drain materials viz. SD, SDW and Sand, there is slight variation of 4% to 6%initially and 6 to 10 % at end of Primary consolidation in theoretical and experimental curve plotted for Degree of Consolidation (Ur%) and Theoretical and experimental Time Factor (Tvr). JPPG curve fits well compared to other drains.
Initial variation is due to Hydrodynamic lag in consolidation while end portion variation is because of secondary compression of soil due to depression of ad-sorbed water in clay water system.

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