International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 6 Issue 5|| May 2017 || PP. 01-08

Field and Theoretical Analysis of Accelerated Consolidation Using Vertical Drains

Chinmay Joshi[1], Dr. A. R. Katti[2]
[1](*Department of Civil Engineering, Datta Meghe College of Engineering, Navi Mumbai, India*)
[2](*Department of Civil Engineering, Datta Meghe College of Engineering, Navi Mumbai, India*)

Abstract : *Mumbai is the region consisting of soft compressible marine clay deposits. There are several construction problems on such soils and thus ground improvement is need to be carried out. Vertical drains is generally preferred technique as accelerated settlement is achieved during the construction phase itself if planned accordingly. The concept of vertical drains is based on the theory of three dimensional consolidation as described by Terzaghi (1943). Based on this concept, a consolidation programme is developed and an attempt is made to determine the field to laboratory coefficient of vertical consolidation ratio by Taylor's Square Root of Time Method and Casagrande's Logarithm of Time Fitting Method for this region. Based on this, the rate of consolidation and time required for consolidation in the field can be determined knowing the consolidation parameters. Equations are developed by using output of the programme and it is explained.*
***Keywords*:** *Soft Compressible Clay, Vertical Drains, Consolidation.*

I. INTRODUCTION

In the early times before the advancement in the geotechnical engineering, the only alternate for the foundation engineers was to design the foundation matching to the sub-soil conditions at the provided site. But now a days, due to the advancement in geotechnical techniques and with the help of latest technology it is possible for us to alter the engineering characteristics of weak founding soil to suit the foundation of our choice. This geotechnical processes of improving the quality of the founding soil to our desired requirements are called as 'Ground Improving'.

Soft saturated marine clays are characterized by low shear strength and high compressibility. Such clays needs improvement of engineering properties of the soil before constructing any civil engineering structure on this marine clays. Because of low permeability and poor drainage characteristics of this soft soil, it becomes essential to drain out pore water before construction begins, otherwise the added weight of new structure will cause development of pore pressure and subsequently water will squeeze out over a long period of time. Moreover, due to high compressibility of these soils, the consolidation settlements are of a very high magnitude from safety point of view, it would be better if major portion of this consolidation settlement takes place before/during construction phase itself.

In case of highly compressible saturated soft clay, imposition of load generates excess pore water pressure in soft layer. This excess pore water pressure may trigger both shear and settlement failures if not monitored and altered. This paper presents analysis and monitoring of ground improvement of soft saturated marine clays using equations.

II. LITERATURE REVIEW

To address settlement issues, literature review has been carried out for the theories related to three dimensional consolidation, and methods related to evaluation of consolidation parameters.

Terzaghi (1943), proposed one dimensional consolidation model and developed the corresponding analytical solution to explain, its mechanism and the phenomenon of the settlement of soil under surcharge, which triggered the study of the consolidation theory. Terzaghi, proposed piston and spring analogy for understanding the process of consolidation.

The basic differential equation proposed by Terzaghi is:

$$\frac{\partial u}{\partial t} = \frac{k}{\gamma_w m_v \partial z^2} = c_{vz}\frac{\partial^2 u}{\partial z^2} \tag{1}$$

Where, 'k' is the coefficient of permeability, 'γ_w' is the unit weight of water, 'mv' is coefficient of volume change, '∂t' is the change in time, '∂u' is the change in pore water pressure, '∂z' is the change in depth and 'c_{vz}' is coefficient of vertical consolidation:

$$c_{vz} = \frac{k}{\gamma_w m_v} \tag{2}$$

The solution for the above differential equation can be obtained by considering proper boundary conditions and by solving Fourier series as:

$$u = \sum_{N=0}^{N=\infty} \frac{2\Delta p}{m} [\sin \frac{mz}{H}]\, e^{(-m^2 c_{vz} t)/H^2} \tag{3}$$

Wherein, 'm' is an integer,'t' is time, 'H' is the thickness of the clay layer, 'Δp' is increment in pressure and z gives the variation in depth.

To arrive at a solution, use of two non-dimensional parameters are introduced. The first non-dimensional group is the time factor Tv where:

$$T_v = \frac{c_{vz} * t}{H^2} \tag{4}$$

The second non-dimensional group is the degree of consolidation 'U'. The term 'U' is expressed as the ratio of the amount of consolidation which has already taken place to the total amount which is to take place under the load increment and is represented as:

$$U\% = 100\ (1 - \sum_{N=0}^{N=\infty} \frac{2}{m^2} e^{-m^2 T_v}) \tag{5}$$

For the values of U% between 0 and 52.6%, Tv can be represented as:

$$T_v = \frac{\pi}{4} (\frac{U\%}{100})^2 \tag{6}$$

For the values of U% greater than 52.6%, Tv can be represented as:

$$T_v = 1.781 - 0.933\ log(100 - U\%) \tag{7}$$

Barron (1948), presented an analytical solution for combined vertical and radial drainage by decoupling the radial and vertical drainage at first and then attaining a product of the contribution from the radial and vertical drainage. Formulas for consolidation by vertical and radial flow to wells, for free strain and equal strain with or without peripheral smear and drain well resistance were also analyzed.

The differential equation for consolidation for equal strain case without smear and well resistance is given as:

$$\frac{\partial \bar{u}}{\partial t} = c_h \left(\frac{1}{r}\frac{\partial u}{\partial r} + \frac{\partial^2 u}{\partial r^2} \right) + c_{vz} \frac{\partial^2 u}{\partial z^2} \tag{8}$$

Wherein, 'c_h' is the co-efficient of consolidation for horizontal flow, '$\bar{u}$' is excess pore water pressure and 'r' is radial distance.

For radial flow only, 'c_{vz}' will be zero

A solution for this second order expression is:

$$u_r = \frac{4\bar{u}}{de^2 * \mathrm{F(n)}} \left[re^2 * Ln\left(\frac{r}{r_w}\right) - \frac{r^2 - r^2{}_w}{2} \right] \tag{9}$$

In which:

$$\bar{u} = u_0 e^{\lambda} \tag{10}$$

Wherein, 'e' is the base of natural logarithm:

$$\lambda = \frac{-8T_{\square}}{F(n)} \tag{11}$$

And,

$$F(n) = \frac{n^2}{n^2 - 1} ln(n) - \frac{3n^2 - 1}{4n^2} \tag{12}$$

Whereas the solution for same differential equation for equal strain case with smear zone at periphery is:

$$u_r = \bar{u}_r \frac{\left[ln\left(\frac{r}{r_s}\right) - \frac{r^2 - r_s^2}{2r_s^2} + \frac{k_{\square}}{k_s}\left(\frac{n^2 - s^2}{n^2}\right) \ln(s) \right]}{v} \tag{13}$$

In which:

$$v = F(n, S, k_h, k_s) \tag{14}$$

$$m = \frac{k_{\square}}{k_s}\left(\frac{n^2 - S^2}{n^2}\right) \ln(S) - \frac{3}{4} + \frac{S^2}{4n^2} + \frac{n^2}{n^2 - S^2} \ln\left(\frac{n}{S}\right) \tag{15}$$

And:

$$\bar{u}_r = u_0 \varepsilon^{\xi} \tag{16}$$

In which:

$$\xi = \frac{-8T_{\square}}{m} \qquad (17)$$

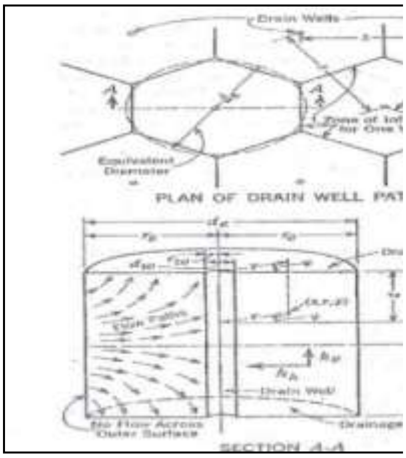

Fig. 1 Plan of drain well pattern and fundamental concepts of flow within zone of influence of each well

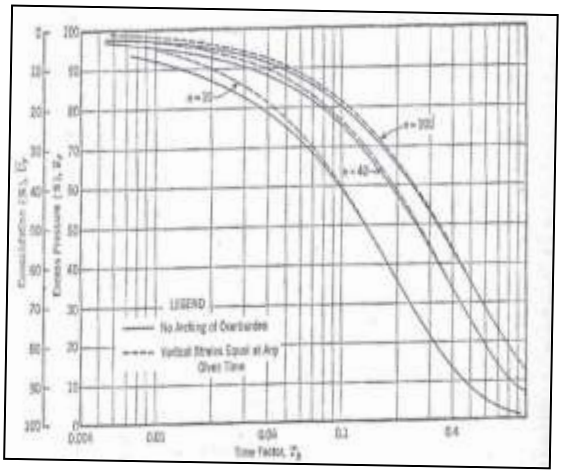

Fig. 2 Average degree of consolidation for various values of 'n' under 'equal strain' condition at any given time

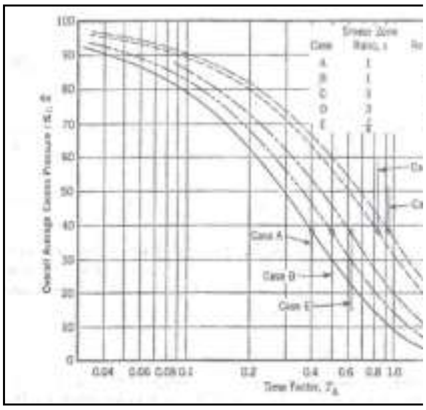

Fig.3 Effect of smear and well resistance on 'equal strain' consolidation by radial flow to drain wells

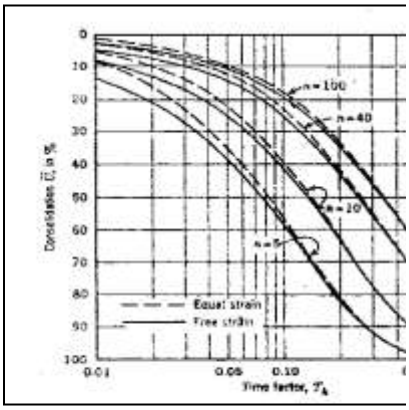

Fig. 4 Comparison of equal strain and free strain

Biot (1941), extended the classical reviews of Terzaghi's one dimensional problem of column under a constant load to three dimensional case and established equations valid for any arbitrary load variable with time. In this theory, Biot interpreted the mathematical formulation of the physical properties of soil and number of constants used to describe this property. Johnson (1970), gave the detailed use of vertical drains as a pre-compression technique for improving the properties of compressible soils. Richart (1959), presented diagrams for quantitative evaluation of equivalent "ideal well" of reduced diameter. The theories for consolidation due to vertical flow and radial flow of water to drain well was also reviewed. Hansbo (1979), made extensive sand drain study involving large scale field tests and observations of sand drain in soft clays. The consolidation process of clay by band shaped prefabricated drains was also studied and considered the design considerations.

III. ANALYSISOF PROGRAMME DEVELOPED FOR EVALUATION OF CONSOLIDATION

As per Terzaghi's theory of one dimensional consolidation, it was assumed that the soil is laterally confined and the strains are in vertical direction only. In most of the actual problems surface loadings cause excess pore pressure which will vary both radially and vertically. The resulting consolidation will involve radial as well as vertical flow. Such a process is called 'Three Dimensional Consolidation'.

The basic differential three dimensional consolidation equation in polar coordinates can be expressed as:

$$c_{vr}\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)+c_{vz}\frac{\partial^2 u}{\partial z^2}=\frac{\partial u}{\partial t} \quad (18)$$

The general solution for the above equation can be given by the combination of the one dimensional flow and radial flow as:

$$(1-U)=(1-U_z)(1-U_r) \quad (29)$$

Wherein, U = degree of consolidation for three dimensional flow

Uz = degree of consolidation for one dimensional flow (in vertical direction)

Ur = degree of consolidation for radial flow.

Based on the procedures suggested by Barron (1948), rigorous analysis has been carried out to understand the behaviour of coefficient of consolidation with time for different k_v (coefficient of permeability in vertical direction) and k_h (coefficient of permeability in horizontal direction) parameters. For evaluation of consolidation, a programme is developed in which, basic parameters which are obtained from soil exploration programme, field and laboratory tests are used as input parameters.

In short, for analysis of 11 m Depth of clay layer; by keeping depth of clay layer constant and using each 'c_h to c_v' ratio for analysis of 4 different ratios, we get the results for different centre to centre spacing of Vertical Drains, and for varying Percent Consolidation and Time. This procedure is carried out for any depth of clay layer.

Table I: Various Input Parameters fortheProgramme

Description	Legends	Units	Value
Depth of clay layer	H	m	11.00
Bulk Density of clay layer	$\square_2$	g/cm^3	1.40
Coefficient of consolidation in Vertical Direction	C_{vz}	cm^2/sec	4.00E-04
Relation between Cvz and Cvr			1
Coefficient of consolidation in Horizontal Direction	C_{vr}	cm^2/sec	4.00E-04
Height of working platform	H_{wp}	m	1.00
Density of working platform	$\square_{\square}$	g/cm^3	1.80
Height of embankment	H_e	m	2.00
Density of embankment material	$\square_{\square}$	g/cm^3	1.80
INPUT FOR TREATED LAYER			
Height of band drain	H_{sd}	m	10.50
Value of C_{VZ}	C_{vz}	cm^2/sec	4.00E-04
Value of CVR	C_{vr}	cm^2/sec	4.00E-04
Drainage condition			Double as SD
Sand Drain Diameter	d	cm	6.50
Spacing of Sand Drain	s	m	0.50
		cm	50.00
Drain Layout			
Triangular	3		
Square	4		
Pattern of sand drain			3
INPUT FOR SMEAR ZONE			
Radius of Drain well	r_w	cm	3.25
Relation between rw and rs			1
Radius of Smear Zone	r_s	cm	3.25
Permeability of soil in horizontal direction	K_h		1.00
Relation between Kh and Ks			1
Permeability of smear zone	K_s		1.00
INPUT FOR UNTREATED LAYER			
Thickness of Untreated Clay Layer	H_{cl}	m	0.50
CV of Untreated clay layer	C_v	cm^2/sec	4.00E-04
Drainage Condition			
Single	1		
Double	2		
Drainage Condition			1

After executing the programme using equal strain condition the output is presented pictorially in Figure 5 and Figure 6. Figure 5 presents the variation of pore water pressure with respect to time for varying spacing of vertical drain varying from 0.25m to 3.0m. The variation of spacing with respect to time for different degrees of consolidation is presented in Figure 6.

From Figure 5 it is observed for spacing of 2.0m, the percent consolidation varies from 30% at time around 1month and reaches to 100% by the time it reaches 15 month. Similar variations are observed for spacing varying between 3.0m to 0.25m. From Figure 6, it is seen that for 90% consolidation time required is less than a month when spacing is 0.25m and it takes 10 months when the spacing increases to 2.0m.

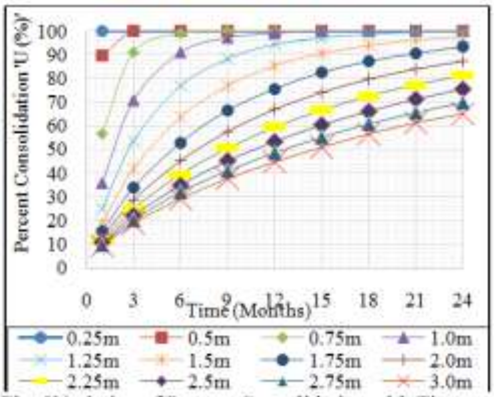

Fig. 5Variation of Percent Consolidation with Time for varying Spacing (c_{vz}=4x10^{-04}cm^2/sec, c_{vr}=1.0 c_{vz})

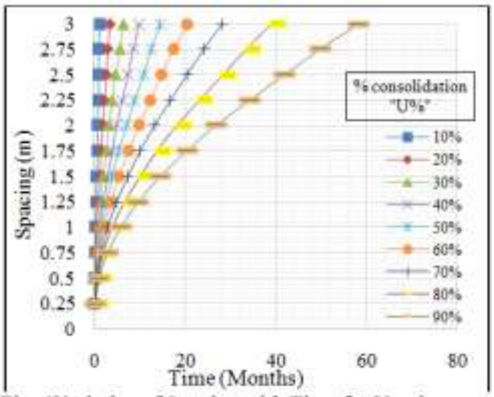

Fig. 6Variation of Spacing with Time for Varying Percent Consolidation (U%) (c_{vz}=4x10^{-04} cm^2/sec, c_{vr}=1.0 c_{vz})

The c_{vz} values proposed here is based on the field values observed in Mumbai region. Hence, the c_{vz} values considered are 1x10^{-01}cm^2/sec to 1x10^{-09}cm^2/sec. The ratio between the vertical and horizontal consolidation considered is for 0.5, 1.0, 1.5 and 2.0. From the plot of U% versus 'c_{vz}' it is seen that the U% falls from 100% to 0% where the c_{vz} varies from 1 x 10^{-02} cm^2/sec to 1 x 10^{-06} cm^2/sec as can be seen in Figure 7. Hence, it can also be seen that as the time increases the gradient of the drop also decreases, i.e. the curve flattens out.

To understand this behaviour in depth it was decided to plot time vs c_{vz} (cm^2/sec) on $\log_{10}$-$\log_{10}$ scale. Here a unique relation is observed where the relation between time and c_{vz} is straight line for all the cases and these lines are parallel to one another as seen in Figure 8.

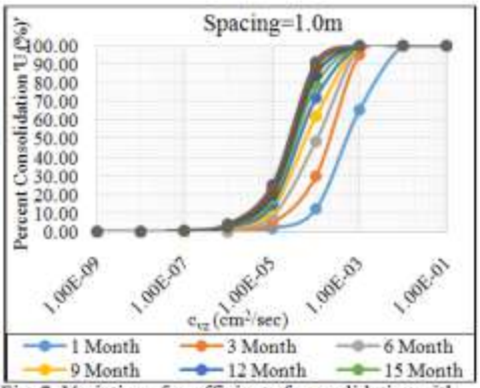

Fig. 7 Variation of coefficient of consolidation with percent consolidation for varying time, constant spacing (S=1.0m)

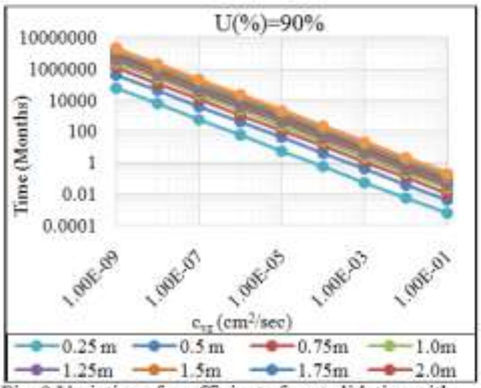

Fig. 8 Variation of coefficient of consolidation with time for varying spacing, constant percent consolidation (U%=90%)

IV. DERIVATION OF EQUATIONS

Based on the output generated after running the programme, relation is plotted on a $\log_{10} - \log_{10}$ scale between coefficient of consolidation and time for 50%, 70% and 90% consolidation. On the $\log_{10}/\log_{10}$ scale, it is seen that for different spacing (S), these relations are all straight lines and parallel to one another. It is observed that, as c_v reduces (from 1 x 10^{-01} cm^2/sec to 1 x 10^{-09} cm^2/sec) the time increases at higher rate. As per the study of Curve Fitting/ Regression Analysis, the best fit curve by least square method is attempted.

On taking $\log_{10}$ coefficient of consolidation and $\log_{10}$ time, the graph obtained was a set of straight lines and hence the best fit curve to the obtained observations is Time(t)=A*(Cv)^B. Where 'A' and 'B' are constant.

After detailed analysis and studying the data for 50%, 70% and 90% consolidation for thickness of soft clay layer of 4 m, 5 m, 7 m, 9 m, 11 m and 13 m, it is observed that the value of 'B' is constantly about -1.

Hence the equation t=A*(Cv)^B reduces to t=A*(Cv)^(-1) or in other words t=A/Cv

It is observed that the data is increasing at higher rate, as per the study of curve fitting (or regression analysis), the best fit curve by least square method is exponential curve. On taking log10 c_v and log10 t, the graph obtained was a set of straight lines and hence the best fit curve to the obtained observations is t=A*(Cv)^B.

Based on the above, constant parameters A and B are determined. After detailed analysis and studying the data for 50%, 70% and 90% consolidation for thickness of soft clay layers of 4 m, 5 m, 7 m, 9 m, 11 m and

13 m the constant parameters A and B are derived for $c_h = 0.5\ c_v$, $c_h = 1.0\ c_v$, $c_h = 1.5\ c_v$ and $c_h = 2.0\ c_v$. The same is tabulated below for depth of 11 m and $c_h = 1.0\ c_v$.

TABLE II:Values for Constant 'A' and 'B' with respect to Different Centre to Centre Spacing of Vertical Drains for 50% Consolidation, 70% Consolidation and 90% Consolidation, for Thickness of Clay Layer of 11 m, ratio of $c_h = 1.0\ c_v$ and for Double Drainage Condition

For 50% Consolidation	
Spacing "S" in m	**Value for constant 'A'**
0.25	1.93391E-05
0.5	1.08007E-04
1	8.08321E-04
1.5	1.76429E-03
2	2.89456E-03
2.5	4.15949E-03
2.75	5.00869E-03
3	5.88830E-03
For 70% Consolidation	
Spacing "S" in m	**Value for constant 'A'**
0.25	3.01261E-05
0.5	2.04184E-04
1	1.10100E-03
1.5	2.94523E-03
2	5.16319E-03
2.5	8.06192E-03
2.75	9.82638E-03
3	1.11139E-02
For 90% Consolidation	
Spacing "S" in m	**Value for constant 'A'**
0.25	8.10222E-05
0.5	4.04308E-04
1	2.16117E-03
1.5	5.89294E-03
2	1.08819E-02
2.5	1.68753E-02
2.75	2.00000E-02
3	2.31632E-02

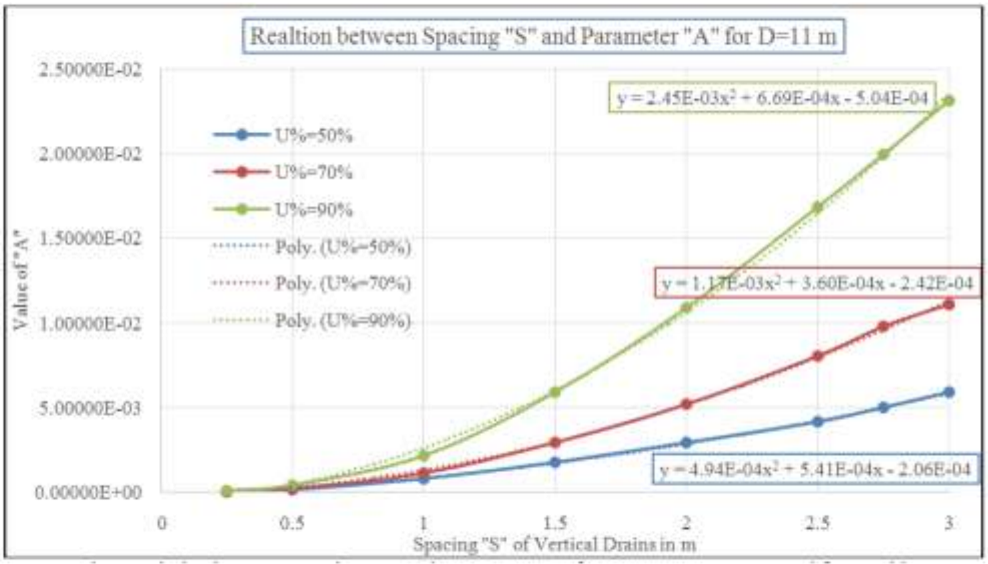

Fig. 9 Relation between Spacing "S" and Parameter "A" for D=11 m, $c_h = 1.0\ c_v$ and for Double Drainage Condition

TABLE III: Relation of Constant 'A' and Centre to Centre Spacing of Vertical Drains for $c_h = 1.0\ c_v$; For Double Drainage Condition

Depth in m "D"	**Percent Consolidation U% = 50%**	**Percent Consolidation U% = 70%**	**Percent Consolidation U% = 90%**
13 m	A = 5.66E-04S^2 + 5.31E-04S – 2.36E-04	A = 1.27E-03S^2 + 3.76E-04S – 2.88E-04	A = 2.90E-03S^2 – 1.77E-04S – 2.26E-04
11 m	A = 4.94E-04S^2 + 5.41E-04S – 2.06E-04	A = 1.17E-03S^2 + 3.60E-04S – 2.42E-04	A = 2.45E-03S^2 + 6.69E-04S – 5.04E-04
9 m	A = 2.79E-04S^2 + 9.43E-04S – 3.42E-04	A = 8.95E-04S^2 + 7.94E-04S – 3.68E-04	A = 1.85E-03S^2 + 1.59E-03S – 7.59E-04
7 m	A = 1.80E-04S^2 + 9.07E-04S – 3.00E-04	A = 5.23E-04S^2 + 1.27E-03S – 4.79E-04	A = 1.08E-03S^2 + 2.68E-03S – 1.08E-03
5 m	A = -1.06E-04S^2 + 1.38E-03S – 4.71E-04	A = 1.24E-04S^2 + 1.56E-03S – 5.24E-04	A = 1.53E-04S^2 + 3.38E-03S – 1.15E-03
4 m	A = -1.87E-04S^2 + 1.41E-03S – 4.94E-04	A = -1.63E-04S^2 + 1.97E-03S – 6.45E-04	A = -3.56E-04S^2 + 3.77E-03S – 1.18E-03

The basic equation is t=A*(Cv) ^B. But from our analysis it is observed that, the 'B' value works out to -1. Hence the equation reduces to, t=A/Cv. So it can be written as, A=Cv*t.

If we replace 'A' with 'Cv*t', we get the following set of equations,

TA**BLE IV:** Relation of Constant 'A' and Centre to Centre Spacing of Vertical Drains for $c_h = 1.0\ c_v$; For Double Drainage Condition

Depth in m "D"	**Percent Consolidation U% = 50%**	**Percent Consolidation U% = 70%**	**Percent Consolidation U% = 90%**
13 m	$Cv \cdot t$ = 5.66E-04S^2 + 5.31E-04S – 2.36E-04	$Cv \cdot t$ = 1.27E-03S^2 + 3.76E-04S – 2.88E-04	$Cv \cdot t$ = 2.90E-03S^2 –1.77E-04S – 2.26E-04
11 m	$Cv \cdot t$ = 4.94E-04S^2 + 5.41E-04S – 2.06E-04	$Cv \cdot t$ = 1.17E-03S^2 + 3.60E-04S – 2.42E-04	$Cv \cdot t$ = 2.45E-03S^2 + 6.69E-04S – 5.04E-04
9 m	$Cv \cdot t$ = 2.79E-04S^2 + 9.43E-04S – 3.42E-04	$Cv \cdot t$ = 8.95E-04S^2 + 7.94E-04S – 3.68E-04	$Cv \cdot t$ = 1.85E-03S^2 + 1.59E-03S – 7.59E-04
7 m	$Cv \cdot t$ = 1.80E-04S^2 + 9.07E-04S – 3.00E-04	$Cv \cdot t$ = 5.23E-04S^2 + 1.27E-03S – 4.79E-04	$Cv \cdot t$ = 1.08E-03S^2 + 2.68E-03S – 1.08E-03
5 m	$Cv \cdot t$ = -1.06E-04S^2 + 1.38E-03S – 4.71E-04	$Cv \cdot t$ = 1.24E-04S^2 + 1.56E-03S – 5.24E-04	$Cv \cdot t$ = 1.53E-04S^2 + 3.38E-03S – 1.15E-03
4 m	$Cv \cdot t$ = -1.87E-04S^2 + 1.41E-03S – 4.94E-04	$Cv \cdot t$ = -1.63E-04S^2 + 1.97E-03S – 6.45E-04	$Cv \cdot t$ = -3.56E-04S^2 + 3.77E-03S – 1.18E-03

V. CONCLUSION

Use of equations in the field:

As a field engineer, one is interested to know:

1. What should be the spacing of the vertical drains to be adopted based on the time allotted for the ground improvement activity provided in tender document, and the coefficient of consolidation likely to occur in the field.
2. If the spacing of the vertical drains is specified in the tender document, in that case the coefficient of consolidation in the field what exactly will be the time required for waiting period for the activity of the ground improvement to occur.

For this, engineer need to select the data as per the steps listed as under:

Step 1: Determine the Laboratory c_v value in cm^2/sec.

Step 2: From the field permeability test data in vertical and horizontal direction, establish the relation between the permeability in vertical direction and permeability in horizontal direction (whereas we can establish and choose the relation between $c_h = 0.5\ c_v$,$c_h = 1.0\ c_v$, $c_h = 1.5\ c_v$ and $c_h = 2.0\ c_v$)and whether it is single drainage condition or double drainage condition. (i.e. D=H/2 or D=H)

Step 3: Based on bore log, establish the thickness of clay layer, to establish the length of vertical drains.

Step 4: Based on the unconfined compression strength of the clay or the vane shear strength of the clay, evaluate the safe bearing capacity of the clay. Based on this value and the height of the proposed embankment (loading), evaluate the number of stages in which the consolidation has to be carried out. If it is more than one stage loading, in that case adopt the relation for 70% consolidation for all stages other than for the final stage, and adopt the curves for 90% consolidation for the final stage of loading.

Once the steps are finalized and depending upon the spacing required for the consolidations we could determine the value of 'A' from the appropriate Table presented above. Based on the parameter 'A', we can determine magnitude of time required for 50% consolidation, 70% consolidation and/ or 90% consolidation as per the case.

The c_v value obtained from the laboratory will be multiplied by appropriate factor, which will give the coefficient of consolidation which will likely to occur in the field.

Now, if we know any of two parameters from 1) coefficient of consolidation 'cv', 2) time 't' required for 50% consolidation, 70% consolidation or 90% consolidation or 3) spacing of vertical drain 'S', we'll be able to determine the remaining parameter.

ACKNOWLEDGEMENTS

This journal was made possible by the contribution of my supervisor Dr. A. R. Katti, Professor, Department of Civil Engineering. I am deeply indebted to him for his outstanding supervision, encouragement and guidance throughout the period of my candidature.

REFERENCES

Journal Papers

[1] Biot M.A. (1941), "General Theory of Three Dimensional Consolidation," Journal of Applied Physics, Volume 12, pp.155-164.
[2] Terzaghi K., (1943), "Theoretical Soil Mechanics" Published By John Wiley and Sons Inclusive, New York.
[3] Barron R.A., (1948), "Consolidation of Fine Grained Soils by Drain Wells," Transactions of American Society of Civil Engineers, Volume 113, pp.718-742.
[4] Richart F.E., (1959), "Review of the Theories for Sand Drains," Transactions of ASCE, pp.709-736.
[5] Johnson S. J., (1970), "Pre-compression for Improving Foundation Soils," Journal of Soil Mechanics and Foundation Division, American Society of Civil Engineers, Volume 96, No. 1, pp.111-144.
[6] Johnson S. J., (1970), "Foundation Pre-compression with Vertical Sand Drains," Journal of Soil Mechanics and Foundation Division, American Society of Civil Engineers, Volume 96, No. 1, pp.145-175.
[7] IS: 2720-Part 15-1986, "Determination of Consolidation Properties".
[8] Leroueil, S. (1987). "Tenth Canadian geotechnical colloquium: recent developments in consolidation of natural clays." Canadian Geotechnical Journal, 25, 85-107.
[9] Chinmay Joshi, (2017), M. Tech thesis titled "Critically Study the Load-Settlement and Load-Pore Pressure Characteristics of Soft Saturated Clays in the Field to Arrive at Equations for Spacing/Time Required for Accelerated Consolidation" submitted to University of Mumbai in Partial fulfilment of Master's Degree in Civil Engineering. (Unpublished)