FIELD AND THEORETICAL ANALYSIS OF ACCELERATED CONSOLIDATION USING VERTICAL DRAINS

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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 by considering the case study of Bhandup Lagoon Works Embankment. Based on this ratio, 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'.

Terzaghi [10] (1943) defined consolidation as "Every process involving a decrease in water content of saturated soil without replacement of water by air is called a process of consolidation". In general it is the process in which reduction in volume takes place by expulsion of water under long term static loads. It occurs when stress is applied to a soil that causes the soil particles to pack together more tightly, therefore reducing its bulk volume. When this occurs in a soil that is saturated with water, water will be squeezed out of the soil.

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.

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) [10], 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 [10], 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 'c_{vz}' is coefficient of vertical consolidation, 'k' is the coefficient of permeability, 'γ_w' is the unit weight of water and 'm_v' is coefficient of volume change:

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

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) [1], 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,

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

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:

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

In which,

$$\mathrm{v} = \mathrm{F(n, S, kh, ks)} \tag{14}$$

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

And,

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

In which,

$$\xi = \frac{-8T_h}{m} \tag{17}$$

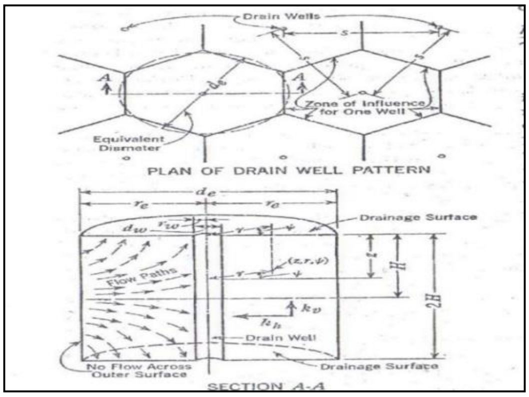


Figure 1. Plan of drain well pattern and fundamental concepts of flow within zone of influence of each well

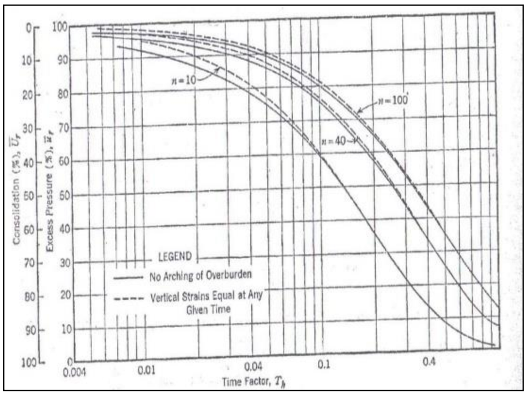


Figure 2. Average degree of consolidation for various values of 'n' under 'equal strain' condition at any given time

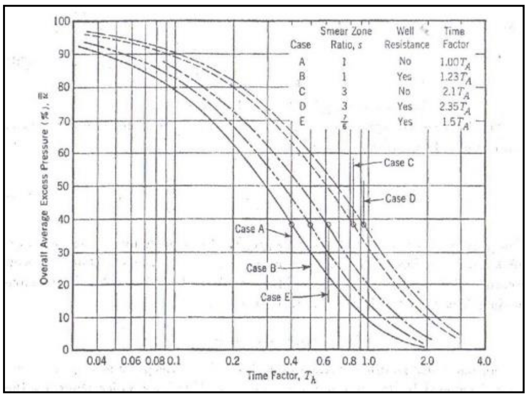


Figure 3. Effect of smear and well resistance on 'equal strain' consolidation by radial flow to drain wells

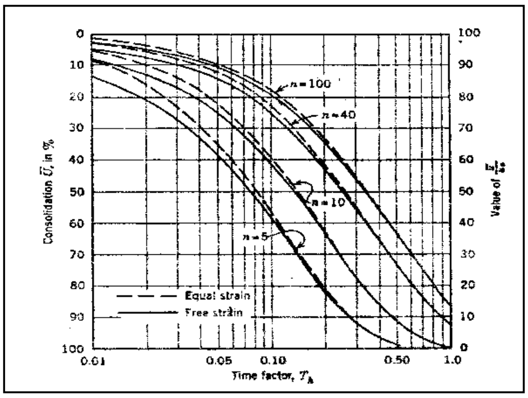


Figure 4. Comparison of equal strain and free strain

Biot (1941) [2], extended the classical reviews of Terzaghi's [10] 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) [7], gave the detailed use of vertical drains as a pre-compression technique for improving the properties of compressible soils. Richart (1959) [9], 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) [5], 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.

Various case records for 'c_{vz} (field)/c_{vz} (lab)' ratio have also been recorded for vertical drains by different methods. Bergado (1991) [3], studied the effectiveness of Mebra prefabricated drains inside the AIT campus by constructing 4m high embankment. Bergado (1991) [3], analysed time-settlement data for Bangna-Bangpakong highway and the coefficient of consolidation 'c_{vz}' was back-figured from the field performance of the highway embankment and the following correlations was found 'c_{vz} (field)/c_{vz} (lab)' = 26. Leroueil (1987) [8], showcased the 'c_{vz} (field)/c_{vz} (lab)' ratio for more than 15 sites.

2.1. Analysis

As per Terzaghi's [10] 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:

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

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

$$(1-U)=(1-U_z)\,(1-U_r) \tag{19}$$

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.

2.2. Methods to determine the laboratory c_{vz}

Two methods, namely the logarithm of time (Casagrande) and the square root of time (Taylor), is used for evaluating coefficients of consolidation of clayey soils are adopted.

Casagrande's logarithm of time fitting method

In this method, the determination of the coefficient of consolidation normally requires that compression readings be carried out at least for 24 hours so that the slope of the compression curve attributed to the secondary compression of the soil can accurately be evaluated on a curve of compression versus logarithm of time. The procedure for determination of c_{vz} is as follows:

$$c_{vz}=\frac{0.197*H^2}{t_{50}} \tag{20}$$

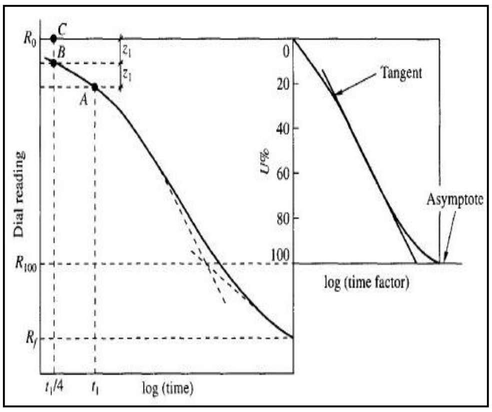


Figure 5. Log of time fitting method

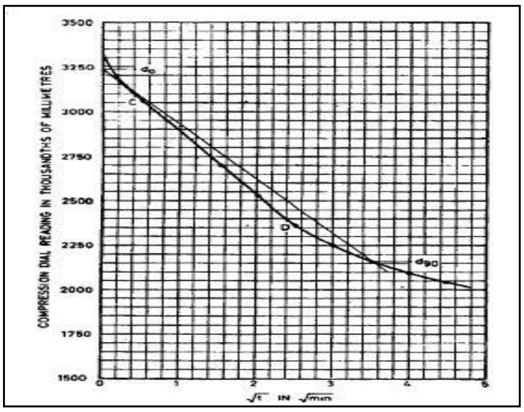


Figure 6. Square root of time fitting method

Taylor's method of time fitting

The procedure for determination of c_{vz} is as follows:

$$c_{vz}=\frac{0.848*H^2}{t_{90}} \tag{21}$$

2.3. Instrumentation

Instrumentation can be defined as the set of techniques employed which gives the behaviour of soil/structure under the applied load/stress. In our case we will be adopting deep settlement markers to measure settlement of soft marine clay with time under the construction load. Pore pressure measurement devices such as piezometers are used to measure the development and dissipation of pore water pressure with time.

Importance of Instrumentation

Instrumentation for marine clay with ground improvement is intended in following aspects of design and construction.

i) In the design for stability analysis, factor of safety can be adopted just near to unity, for economy in embankment cross section by providing instrumentation, which helps in monitoring of embankment during construction.

ii) The sequence of construction and time gaps particularly during surcharge laying operation can be monitored with instrumentation with reference to stability of embankment.

iii) The pavement construction can be done after ensuring that no appreciable settlement will take place further.

iv) Construction period is expected to practically reduce by use of settlement data, since there maybe vast difference between estimated and observed settlement time. Further it may be possible to reduce the estimated settlement time in further projects with the experience that double drainage condition is prevailing or not.

v) The instrumentation process provides a valuable experience and a reliable and vast data bank which can be used for guiding into subsequent designs.

2.4. Programme developed for evaluation of consolidation

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.

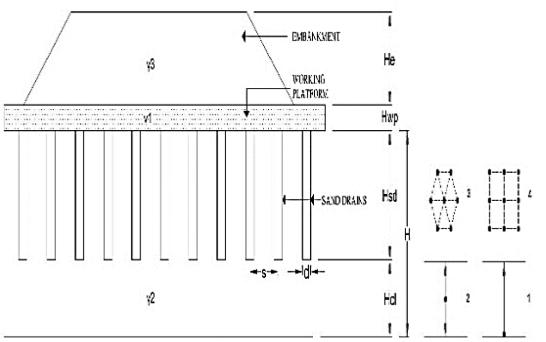


Figure 7. Schematic Description of Legends

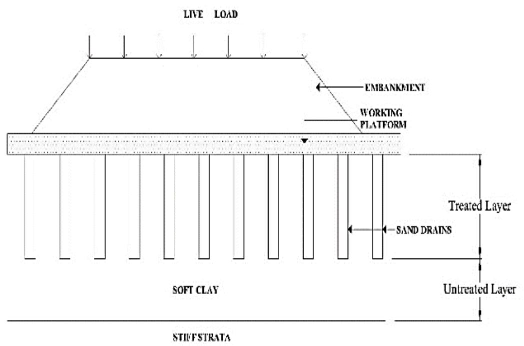


Figure 8. Description of treated and untreated layer

Table 1. Various Input Parameters for the Programme

Description	Legends	Units	Value
Depth of clay layer	H	m	11.00
Bulk Density of clay layer	γ_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	γ_1	g/cm^3	1.80
Height of embankment	H_e	m	2.00
Density of embankment material	γ_3	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

Based on the above input parameters, typical output from the programme will be as under:

After executing the programme using equal strain condition the output is presented pictorially in Figure 9 and Figure 10. Figure 9 presents the variation of pore water pressure with respect to time for varying spacing of vertical drain varying from 0.25 m to 3.0 m. The variation of spacing with respect to time for different degrees of consolidation is presented in Figure 10.

From Figure 9 it is observed for spacing of 2.0 m, the percent consolidation varies from 30% at time around 1 month and reaches to 100% by the time it reaches 15 month. Similar variations are observed for spacing varying between 3.0 m to 0.25 m. From Figure 10, it is seen that for 90% consolidation time required is less than a month when spacing is 0.25 m and it takes 10 months when the spacing increases to 2.0 m.

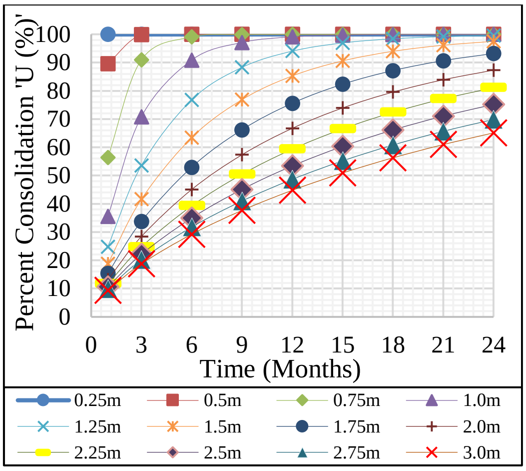


Figure 9. Schematic Variation of Percent Consolidation with Time for varying Spacing (c_{vz}=4x10^{-04} cm^2/sec, c_{vr}=1.0 cvz)

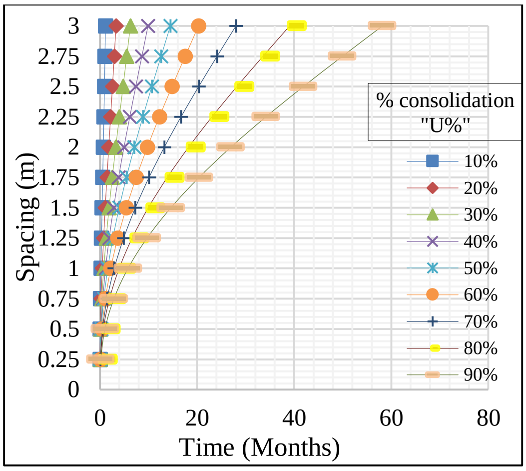
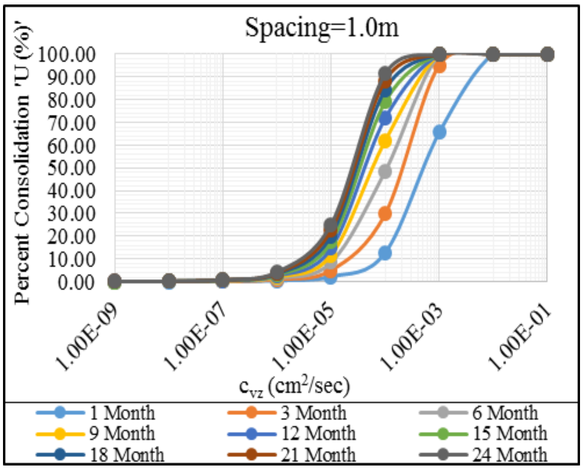


Figure 10. Schematic Variation of Spacing with Time for Varying Percent Consolidation (U%) (c_{vz}=4x10^{-04} cm^2/sec, c_{vr}=1.0 c_{vz})

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 11. 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 12. Analysis is in progress to understand this phenomenon.



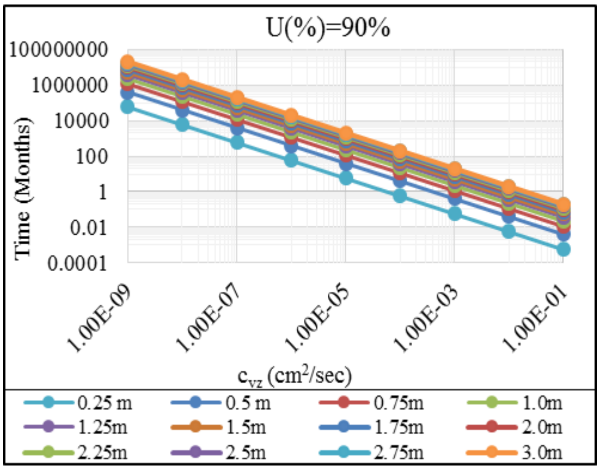


Figure 11. Variation of coefficient of consolidation with percent consolidation for varying time, constant spacing (S=1.0m)

Figure 12. Variation of coefficient of consolidation with time for varying spacing, constant percent consolidation (U%=90%)

It is proposed to compare the theoretical calculation with the field observations, and to understand the behaviour of soft saturated clay when under the application of the applied stress. For this purpose we are proposing to compare theoretical results with the field observation. To understand this behaviour of vertical band drain in the field, a case studies have been considered namely:

i. Bhandup Lagoon Works Embankment.

2.5. Case Study: Bhandup Lagoon Works Embankment

Figure 13. Bhandup Lagoon Works Embankement Location

The entry to the BMC lagoons at the Bhandup end is located at the busy suburb of Mumbai which is approximately 25 kms from Mumbai down town on the North East end of Mumbai. The plant is located 1.5 kms from the junction of the Eastern Expressway Highway, and 3 kms from Bhandup Railway Station. The approach embankment stretched from the 9 chainages. This entire length is located on marine clay/ salt pan deposits on the banks of Thane creek.

Table 2. Typical soil properties adopted for design based on laboratory and field tests

Sr. no	Soil Properties	Value	Unit
1.	Bulk Density of clay	1550	kg/m^3
2.	Natural Moisture content	43-77	%
3.	Specific Gravity	2.6	
4.	Liquid Limit	59-115	%
5.	Plastic Limit	18-41	%
6.	Unconfined compressive strength	3000	kg/m^2
7.	Compression index	0.99	
8.	Coefficient of consolidation	2.79 x 10^{-04}	cm^2/sec

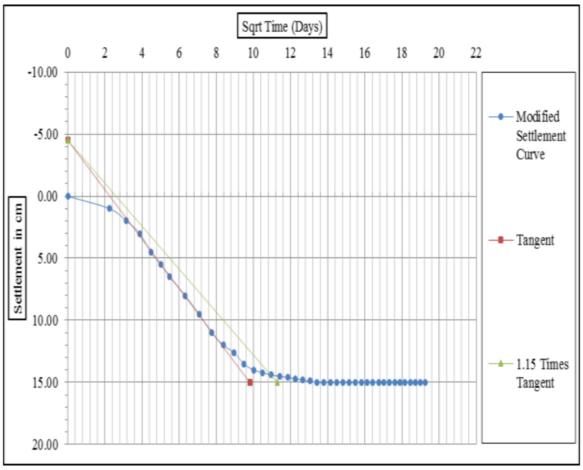


Figure 14. Variation Modified settlement curve/ Taylor's Method (Sett. marker) (A-1)

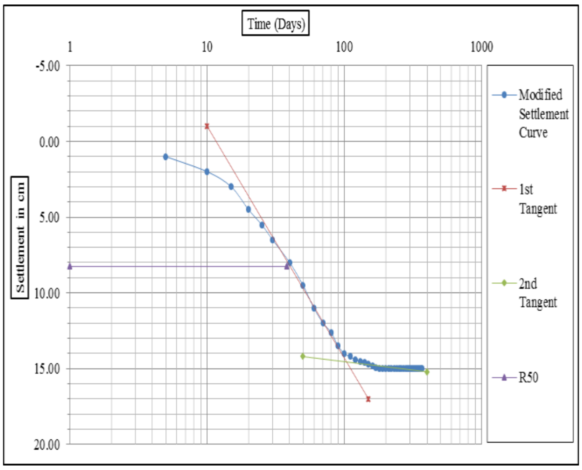


Figure 15. Variation Casagrande's Method (Settlement Marker) (A-1)

The field instrumentation was done with the help of settlement and piezometer markers and the analysis is done considering the time-settlement and time-pore pressure data for chainage A-1, A-2, A-3, A-4, A-2/A-3 Jn., B-1/B-2 Jn., N-W Curve, E-1 and E-V. The stage loading is calculated for given embankment height keeping in mind the bearing capacity aspect.

Figure 14 shows the modified time-settlement curve obtained as per IS code 2720-Part 15 [6] used for Taylor's Square Root of Time method. Figure 15 is modified time settlement curve on $\log_{10}$ of time scale used for Casagrande's Logarithm of Time Fitting method.

Taylor's Method

Here, H= 5.0 m = 500 cm, Tv = T_{90} = 0.848, t = t_{90} = 10454400 sec

$$c_{vz} = \frac{0.848 * (500)^2}{10454400}$$

Based on above parameters, $\boxed{c_{vz} \text{ (field)} = 2.03 \times 10^{-02} \text{ cm}^2\text{/sec}}$

• **Casagrande's Method**

Here, H= 5.0 m = 500 cm, Tv = T_{50} = 0.197, t = t_{50} = 3283200 sec

$$c_{vz} = \frac{0.197 * (500)^2}{3283200}$$

Based on above parameters, $\boxed{c_{vz} \text{ (field)} = 1.50 \times 10^{-02} \text{ cm}^2\text{/sec}}$

2.6. Summary

Based on the work carried out an attempt is made to determine rate of settlement which is likely to take place in field based on these ratios. The ratio of c_{vz}(field)/c_{vz}(lab) for various cases is presented in Table 4. This data can be useful to estimate the rate of consolidation and time required for consolidation in the field in this vicinity.

Table 3. Coefficient of Consolidation Field (c_{vz}) in cm^2/sec

Sr. No.	Marker	Chainage	Laboratory	Taylor Method (c_{vt})	Casagrande Method (c_{vc})
1	Settlement	A-1	2.79×10^{-04}	2.03×10^{-02}	1.50×10^{-02}
2	Settlement	A-2	2.79×10^{-04}	1.96×10^{-02}	1.58×10^{-02}
3	Settlement	A-3/L1	5.14×10^{-04}	1.70×10^{-02}	1.27×10^{-02}
4	Settlement	A-4/L1	5.14×10^{-04}	1.45×10^{-02}	1.04×10^{-02}
5	Settlement	A2/A3 JN	3.90×10^{-04}	2.14×10^{-02}	1.63×10^{-02}
6	Settlement	B1/B2 JN/L1	5.14×10^{-04}	2.03×10^{-02}	1.63×10^{-02}
7	Settlement	N-W CURVE	3.90×10^{-04}	2.03×10^{-02}	1.54×10^{-02}
8	Settlement	E-1	2.79×10^{-04}	1.70×10^{-02}	1.43×10^{-02}
9	Settlement	E-V/L1	5.14×10^{-04}	2.10×10^{-02}	1.63×10^{-02}
10	Piezometer	A-1	2.79×10^{-04}	1.65×10^{-02}	1.14×10^{-02}
11	Piezometer	A-2	2.79×10^{-04}	1.65×10^{-02}	1.14×10^{-02}
12	Piezometer	A-3/L1	5.14×10^{-04}	1.41×10^{-02}	1.08×10^{-02}
13	Piezometer	A-4/L1	5.14×10^{-04}	1.45×10^{-02}	1.21×10^{-02}
14	Piezometer	A2/A3 JN	3.90×10^{-04}	1.12×10^{-02}	8.38×10^{-03}
15	Piezometer	B1/B2 JN/L1	5.14×10^{-04}	1.57×10^{-02}	1.27×10^{-02}
16	Piezometer	N-W CURVE	3.90×10^{-04}	1.25×10^{-02}	1.04×10^{-02}
17	Piezometer	E-1	2.79×10^{-04}	1.25×10^{-02}	1.04×10^{-02}
18	Piezometer	E-V/L1	5.14×10^{-04}	1.70×10^{-02}	1.43×10^{-02}

Table 4. Ratio of Coefficient of Consolidation by Taylor's & Casagrande's Methods (c_{vt} , c_{vc}) to Coefficient of Consolidation of lab (c_{vz} lab)

Sr. No.	Marker	Chainage	Laboratory (c_{vlab})	Taylor Method (c_{vt}/c_{vlab})	Casagrande Method (c_{vc}/c_{vlab})
1	Settlement	A-1	2.79×10^{-04}	72.68	53.77
2	Settlement	A-2	2.79×10^{-04}	70.11	56.75

3	Settlement	A-3/L1	5.14×10^{-04}	33.15	24.64
4	Settlement	A-4/L1	5.14×10^{-04}	28.25	20.16
5	Settlement	A2/A3 JN	3.90×10^{-04}	54.95	41.76
6	Settlement	B1/B2 JN/L1	5.14×10^{-04}	39.45	31.69
7	Settlement	N-W CURVE	3.90×10^{-04}	52.00	39.50
8	Settlement	E-1	2.79×10^{-04}	61.07	51.08
9	Settlement	E-V/L1	5.14×10^{-04}	40.93	31.69
10	Piezometer	A-1	2.79×10^{-04}	59.09	40.86
11	Piezometer	A-2	2.79×10^{-04}	59.09	40.86
12	Piezometer	A-3/L1	5.14×10^{-04}	27.40	20.92
13	Piezometer	A-4/L1	5.14×10^{-04}	28.25	23.60
14	Piezometer	A2/A3 JN	3.90×10^{-04}	28.72	21.49
15	Piezometer	B1/B2 JN/L1	5.14×10^{-04}	30.55	24.64
16	Piezometer	N-W CURVE	3.90×10^{-04}	32.10	26.57
17	Piezometer	E-1	2.79×10^{-04}	44.87	37.15
18	Piezometer	E-V/L1	5.14×10^{-04}	33.15	27.72

So for the given property of soil, which are measured in laboratory multiplied by this ratio would give us the rate of consolidation which is likely to take place in the field. The same could be used as a multiplication factor with laboratory test data for all cases in this particular region to determine rate of consolidation, which is likely to occur thus giving us a brief idea of how the soil is going to be behaving under the stress conditions.

Thus, from the above ratio, knowing the laboratory coefficient of consolidation the field coefficient of consolidation can be found out for that region. Now from the programme developed for evaluation of Rate of Consolidation, with proper consolidation parameters from the case study, time required for 70% consolidation for the given spacing of 1.0 m can be obtained from Figure 9 as around 3 months. Similarly for time of 2.93 months with spacing 1.0 m the percent consolidation works out to 70% from Figure 10.

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_{vz} reduces (from 1×10^{-01} cm^2/sec to 1×10^{-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 $\log_{10} c_v$ and $\log_{10} t$, the graph obtained was a set of straight lines and hence the best fit curve to the obtained observations is t=A*Cv^B. 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.

For determining time for 90% consolidation of 11 m depth of clay layer, for $c_h = 1.0\ c_v$ and for double drainage condition we get the following equation,

$$Cv \cdot t = 2.45E^{-03}S^2 + 6.69E^{-04}S - 5.04E^{-04} \tag{22}$$

Now, if we know any of two parameters from 1) coefficient of consolidation 'c_v', 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.

For example, in the project report of Bhandup case study, they have mentioned $c_{vLaboratory}$ to be taken as 2.79×10^{-04} cm^2/sec, and Spacing taken for project is 1.25 m. By putting these values in the above equation, we get the time required for 90% consolidation is 137506.71 days.

III. CONCLUSIONS

Thus, this data will be useful in planning of the given project i.e.

- In deciding the various factors such as time required for the stage loading,
- Time when the future activities can be started when a considerable amount of consolidation has taken place.
- Time taken to complete the project.
- Spacing required for the project to complete the consolidation process in desired time.

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