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FIELD AND THEORETICAL ANALYSIS OF ACCELERATED SETTLEMENT USING VERTICAL DRAINS

Shyamal Kumar Mukherjee
Research Scholar,
Department of Civil Engineering,
Datta Meghe College of Engineering
Airoli, Navi Mumbai, India

Mehul Ramani
Post Graduate Student,
Department of Civil Engineering,
Datta Meghe College of Engineering,
Airoli, Navi Mumbai, India

Dr. Anand Katti
Professor,
Department of Civil Engineering,
Datta Meghe College of Engineering,
Airoli, 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 need to be carried out. Vertical drains is generally preferred technique as accelerated settlement is achieved during the construction phase itself. The concept of vertical drains is based on three dimensional consolidation as described by Terzaghi (1943). Based on this concept, a settlement programme is being developed and an attempt is made to determine the field to laboratory coefficient of vertical consolidation ratio by methods proposed by Taylor and Asaoka (1978) for this region by considering the case studies namely 1.) Mulund Airoli Bridge approach embankment 2.) Palm Beach Marg. Based on this ratio, the rate of consolidation and time required for consolidation in the field can be determined knowing the consolidation parameters.

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 day, 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*'.

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.

Construction problems on soft compressible saturated soils

Soft saturated marine clays are characterized by low shear strength and high compressibility. Such clays needs improvement of engineering properties of the soilbefore 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.

Necessity of vertical drains

Amongst the various ground improvement techniques the vertical drains is preferable in soft- cohesive soil to achieve accelerated settlement. This method is based on the concept of three dimensional consolidation.The law of consolidation suggests that shorter the drainage path, fasterthe rate of the consolidation ($t=T_v*d^2/c_{vz}$ i.e. $t \alpha d^2$) where‘t’ is time required to achieve degree of consolidation, ‘T_v’ is time factor, c_{vz} is co-efficient of vertical consolidation and referred ‘c_{vz}’ henceforth and ‘d’ is depth of drainage layer. This can be made possible by adopting vertical drain,where drainage path is reduced by four fold where in excess pore waterdissipates radially and vertically at faster rate. The installation of the vertical drains in the clay reduces the length of the drainage paths thereby reducing the time to complete the consolidation process. The purpose of vertical drain installation is thus achieved twofold firstly to accelerate the consolidation process of the clay subsoil, and, secondly, to gain rapid strength increase to improve the stability of structures on weak clay foundation.

Hence, by adopting vertical drains, accelerated settlement is achieved during the construction period itself. This ensures the longevity of the civil engineering structures.

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:

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

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

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

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

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

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 T_v where:

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

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:

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

For the values of U% between 0 and 52.6%, $T_v$can be represented as

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

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

$$T_v = 1.781 - 0.933\, log(100 - U\%)$$

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:

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

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

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

A solution for this second order expression is:

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

in which $\bar{u}=u_0e^{\lambda}$

wherein, e is the base of natural logarithm,

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

And

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

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

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

in which

$v=F(n, S,k_h,k_s)$

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

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

In which

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

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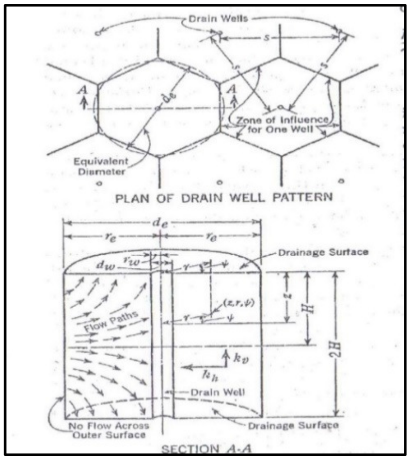

Figure 1: Plan of drain well pattern and fundamental concepts of flow within zone of influence of each well

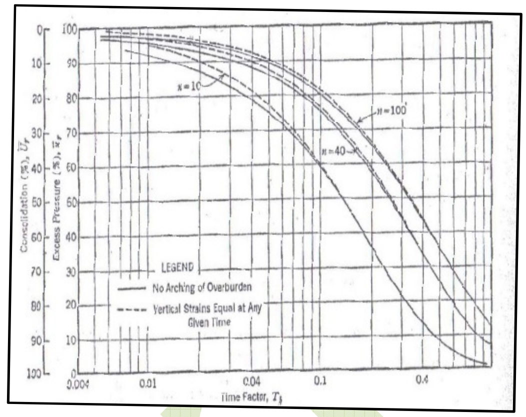

Figure 2: Average degree of consolidation for various values of 'n' under 'equal strain' condition at any given time

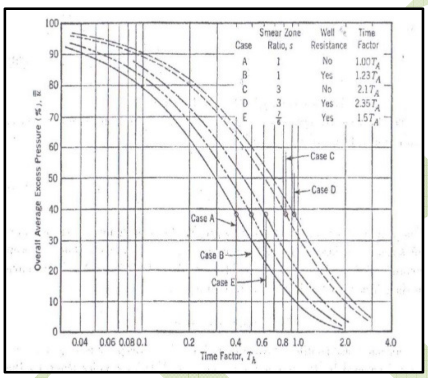

Figure 3: Effect of smear and well resistance on 'equal strain' consolidation by radial flow to drain wells

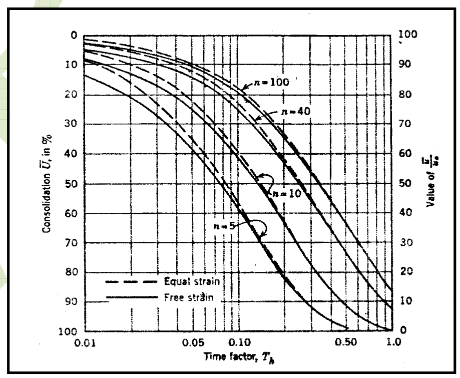

Figure 4: Comparison of equal strain and free strain

Biot (1941), 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 designconsiderations.

Various case records for '$c_{vz\ (field)}/c_{vz(lab)}$'ratio have also been recorded for vertical drains by different methods. Bergado (1991), studied the effectiveness of Mebra prefabricated drains inside the AIT campus by constructing 4m high embankment. Asaoka (1978), Skempton-Bjerrum (1957) and FEM methods, yielded good results in relation to predicted and observed settlements. Bergado (1991), 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), showcased the '$c_{vz\ (field)}/c_{vz\ (lab)}$'ratio for more than 15 sites. Dhowian,et. al. (1987), found the average ratio of field to laboratory 'c_{vz}' to be in order of 55 for the Sabkha sediments.Shukla (2009),reviewed the numerous methods for determining coefficient of vertical consolidation'c_{vz}', which is required for predicting the rate of settlement of structures founded on cohesive soil deposits in order to check the settlement criteria of foundation design.

ANALYSIS

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:

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

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

$$(1-U)=(1-U_z)(1-U_r)$$

Wherein,U = degree of consolidation for three dimensional flow
U_z = degree of consolidation for one dimensional flow (in vertical direction)
U_r = degree of consolidation for radial flow.

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:

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