AN ANALYTICA STUDY OF SAND DRAIN

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ABSTRACT

In the present parametric study, time required for consolidation of clay layer is estimated with different configurations of sand drains. Diameter and spacing of sand drains are varied. Sand drains are arranged in triangular and rectangular pattern. Three ratios of coefficient of consolidation for vertical drainage to that of radial drainage are considered in the analyses. Analyses are carried out for the condition of with smear and without smear. A FORTRAN computer program is developed to compute the average degree of consolidation for specified time intervals, and then results are interpolated to calculate time required for a given degree of consolidation. Results indicate that time required for 90% consolidation decrease with increase in diameter and increases with increase in spacing. It can be also concluded from study that smear effect has considerable effect on the consolidation process, hence requires proper investigation. The conductivity of remoulded zone and its size are key parameters in the analysis for smear effect.
ABSTRAK

Dalam kajian ini, pelbagai konfigurasi parit tegak 'sand drain' dipertimbangkan untuk menentukan masa pengukuhan tanah liat. Diameter dan jarak di antara 'sand drain' (tengah ke tengah) yang berlainan dicadangkan. 'Sand drain' boleh disusun dalam bentuk segi-tiga ataupun segi-empat. Tiga nisbah koeficient pengukuhan tegak dengan melintang diambil kira dalam kajian ini. Analisis ini juga mengambil kira tindakan 'smear'. Satu program komputer, FORTRAN telah diterokai untuk mengira purata darjah pengukuhan menerusi selang masa yang ditetapkan, kemudian interpolasi keputusan yang diperolehi untuk mendapatkan masa semula yang diperlukan bagi darjah pengukuhan tertentu. Keputusan kajian menunjukkan bahawa masa yang diperlukan untuk mancapai darjah pengukuhan 90% berkurangan dengan penambahan diameter 'sand drain'. Walau bagaimanapun, masa pengukuhan 90% akan bertambah jika jarak di antara 'sand drain' bertambah. Menerusi penyelidikan teliti, didapat proses pengukuhan juga dipengaruhi oleh tindakan 'smear'. Konduktiviti dan saiz 'remoulded zone' merupakan parameter yang penting dalam manganalisis tindakan 'smear'
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CHAPTER 1

INTRODUCTION

1.1 General

The consolidation settlement of soft clay subsoil creates a lot of problems in foundation engineering. Because of the very low clay permeability, the primary consolidation takes a long time to complete. To shorten this consolidation time, vertical drains are installed together with preloading by surcharge embankment or vacuum pressure. Vertical drains are artificially created drainage paths which can be installed by one of several methods and which can have a variety of physical characteristics. Pore water squeezed out during the consolidation of the clay due to the hydraulic gradients created by the preloading, can flow a lot faster in the horizontal direction towards the drain and then flow freely along the drains vertically towards the permeable drainage layers. Thus, the installation of the vertical drains in the clay reduces the length of the drainage paths and, thereby, reduces the time to complete the consolidation process. Consequently, the higher horizontal permeability of the clay is also taken advantage. Therefore, the purpose of vertical drain installation is 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. Vertical drain can be classified into 3 general types, namely: sand drains, fabric encased sand drains, and prefabricated sand drains.

Application of sand drain for improvement of soft ground in the Southeast Asian region have been reported by Tominaga et al. (1979) in Manila Bay Reclamation Area, Philippines; by Choa et al. (1979) in Changi Airport, Singapore; by Chou et al. (1980) in Taiwan; by Akagi (1981), Balasubramaniam et al. (1980), Brenner & Prebaharan (1983), Moh & Woo (1987), and Woo et al. (1989) in Bangkok, Thailand. Recent sand drain applications in Japan were reported by Takai et al. (1989) and Suzuki & Yamada (1990) in the Kansai International Airport Project and by Tanimoto et al. (1979) in Kobe, Japan.

In Southeast Asia, various applications have been recently reported with regards to prefabricated vertical drain by Choa et al. (1981), Lee et al. (1989), and Woo et al. (1988) in Singapore; by Nicholls (1981) in Indonesia; by Volders (1984) and Raman et al. (1990) in Malaysia; and by Belloni et al. (1979) in the Philippines. In the soft Bangkok clay in Thailand, prefabricated vertical band drain have been successfully applied and tested by full scale test embankments by Bergado et al. (1991).
1.2 Other Methods Available

1.2.1 Surface Compaction

One of the most widely used and oldest techniques of soil densification is compaction. Construction of embankment, runway on any soft or loose foundation site needs a compact base for laying the structure. The usual surface compaction devices are rollers, tampers, and rammers.

1.2.2 Vibroflotation

Vibroflotation is a technique for densifying in-situ non-cohesive soils, with simultaneous vibration and saturation. The equipment required for vibroflotation involves a vibroflot probe, accompanying power supply, water pump, crane and front end loader. Most vibroflotation applications have been depths less than 20m, although depths of 30m have been attained successfully. The factors contributing to successful densification are equipment capacity, probe spacing and pattern, in-situ soils, vibroflot withdrawal procedure, workmanship etc. This technique is best suited for densifying very loose sand below the water table.

1.2.3 Soil Reinforcement

The scientific basis for the modern concept of soil reinforcement lies in the idealization of the problem of soil reinforcement in the form of a weak soil reinforced by high strength thin horizontal membranes. A wide variety of materials has been in use as
reinforcing material. Early structures were formed using organic materials such as timber, straw for reinforcement. As these materials are less durable, new materials such as steel, concrete, glass fibre, rubber and thermoplastic has been successfully used.

1.2.4 Geotextile and Geomembranes

Geotextile are porous fabrics manufactured from materials which are primarily petroleum products, and other materials such as polyester, polyethylene, nylon, fibre glass and various mixtures of these. They are manufactured in different thickness ranging from 10-30 mils (1mil=1/1000 inch); they are also in variety of patterns, the most common methods being woven, non-woven, grid, hybrid etc.

Geotextile are good in tensile strength and hence can contribute to the load bearing capacity of the soil. Thus, geotextile perform the function of reinforcement in soils. This application has solved many construction problems on soft and compressible soil. They are also used in reinforcement’s wall and embankments.

Geomembranes are thin materials with very low permeability. They are flexible and are manufactured from synthetic or bituminous products. These geomembranes are strengthened, if necessary, with a fabric or film. For all practical purposes, geomembrane may be considered to be impermeable to both gases and fluids.
1.3 Project Objective

Historically, the design of structures on soft compressible soils (clays) has created problems for civil engineers. Construction without some sort of soil treatment is usually impractical due to unpredictable long-term settlement. Simple surcharging as a soil consolidation method can take many years. Although surcharging increases water pore pressure, settlement can take considerable time, as the water lacks easy path to leave the soil.

The objective of present study is to develop a computer program to compute the time-average degree of consolidation relationship for different configurations of sand drains. Diameter and spacing of sand drains are varied. Sand drains are arranged in triangular and rectangular pattern. Three ratios of coefficient of consolidation for vertical drainage to that of radial drainage are considered in the analyses. Analyses are carried out for the condition of with smear and without smear.
CHAPTER 2

LITERATURE REVIEW

2.1 General

Over the past few decades, it has become necessary to utilize more and more of the geotechnically less desirable building sites for civil engineering projects. Thick deposits of soft cohesive soil underlie many of these sites. In such conditions, some method of soil improvement is generally required to provide adequate soil-bearing capacity and to reduce total and differential post-construction settlements to tolerable levels.

Preloading, or surcharge, is probably the most cost-effective and widely used technique to accelerate the consolidation process and to strengthen the weak clayey soil in situ. However, the primary consolidation process may take quite a long time because of the low permeability of clay soils. In such a case, the vertical drain can be used to shorten the consolidation time, leading to increased subsoil bearing capacity and shear strength. The use of vertical drains reduces the length of drainage paths and takes advantage of usually higher permeability of soils in the horizontal direction, thus resulting in shorter consolidation time. The technique has been employed successfully to accelerate settlement and gain strength in soft clayey soils and marine sediments for construction of highway
embankments, industrial and residential structures, and airport runways (Hansbo et al. 1981; Rixner et al. 1986).

The degree of consolidation achieved via vertical drains in a time interval is controlled by the soil parameters and properties of the VD. Some of the parameters of the soil and vertical drain are uncertain, because of the inherent variability of soil deposits and measurement errors. It has been suggested that the horizontal coefficient of consolidation is the most important random variable affecting the degree of consolidation via vertical drain.

Figure 2.1: Typical Vertical Drain Installation for A High Way Embankment (after Rixner et. al. 1986)
2.2 Vertical Sand Drain

The time taken to consolidate relatively thick compressible strata can be too long. Input for most situations where thickness exceeds twenty feet and coefficients of consolidation value are less then approximately 0.001 cm²/sec.

Any technique which decrease the drainage path length and takes advantage of higher coefficient of consolidation would be helpful in decreasing the time required for settlement to occur. If such a method was available and used before permanent construction work began, the site would be stabilized and past construction settlement limited to acceptable limit. Such a method exists in which radial drainage takes place and is basic principle of sand drain. The drainage path length is now the distance between sand columns and quite often a coefficient of consolidation higher horizontally then vertically can be taken advantage of equation analogous to vertical flow for radial flow is:

\[ t = \frac{T_h \times d_e^2}{C_h} \]

where, \( t \) = time for consolidation
\( d_e \) = center to center spacing between sand drains
\( T_h \) = time factor for horizontal drainage
\( C_h \) = horizontal coefficient of consolidation for horizontal drainage as mobilized by vertical compression

Value of \( t \) has been solved for a wide variety of sand drain, spacing \( d_e \) and sand drain diameter \( d_e \). \( C_h \) is sometimes considerably larger than \( C_v \), but not always.
If no direct data is available, the value of $C_v$ determined from standard consolidation tests should be maximum value used. As sand drain becomes larger in diameter and placed too close to one another the time needed for consolidation decreases.

Table 2.1: Common Types of Vertical Drain (after Rixner et al. 1986)

<table>
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<tr>
<th>General types</th>
<th>Sub-types</th>
<th>Remarks</th>
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<tr>
<td>Sand drains</td>
<td>Closed end mandrel</td>
<td>Maximum displacement</td>
</tr>
<tr>
<td></td>
<td>Screw type auger</td>
<td>Limited experience</td>
</tr>
<tr>
<td></td>
<td>Continuous flight hollow stem auger</td>
<td>Limited displacement</td>
</tr>
<tr>
<td></td>
<td>Internal jetting</td>
<td>Difficult to control</td>
</tr>
<tr>
<td></td>
<td>Rotary jet</td>
<td>Can be non-displacement</td>
</tr>
<tr>
<td></td>
<td>Dutch jet-bailer</td>
<td>Can be non-displacement</td>
</tr>
<tr>
<td></td>
<td>Sandwich, Pack Drain, Fabridrain</td>
<td>Full displacement of relative small volume</td>
</tr>
<tr>
<td>Fabric encased sand drains</td>
<td>Cardboard drain</td>
<td>Full displacement of small volume</td>
</tr>
<tr>
<td>Prefabricated vertical drain</td>
<td>Fabric covered</td>
<td>Full displacement of small volume</td>
</tr>
<tr>
<td></td>
<td>Plastic drain without jacket</td>
<td>Full displacement of small volume</td>
</tr>
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Figure 2.2: Layout of Sand Drain
2.3 Techniques Available for Sand Drain

Three different techniques are common although many other are available.

1. Mandrel drive: In this method a closed end pipe (mandrel) is driven to the bottom of the soil to be consolidated, it is filled with sand which is placed under approximately 100 lb/in² of air pressure and then it is gradually lifted out of ground. The closed end, being a hinged valve, opens and the sand under pressure rushes out. The pipe continues to be lifted until it reaches the ground surface. The entire process is then repeated for next sand drain. The cycle takes 2 to 10 minute, depending upon local conditions.

2. Hollow stem continuous flight auger: Here a continuous flight auger of the diameter as the intended sand drains is rotated into the soil to the specified depth. Since the auger is formed around a hollow pipe, sand under pressure can be introduced into it. Auger is back rotated out of the hole; the sand drain is left behind and forms the sand drain. Cycle time for this installation method is 5 to 20 minutes.

3. Jetted hollow or closed end pipes: The driving into the soil of either hollow or closed end hinged pipes via water jetting is also used for sand drain installation. After pipe placement, the sand is introduced under pressure as the pipe withdrawn. Cycle time is 5 to 20 minutes.
2.4 Smear and Disturbance Effect

Partial remolding decreases the coefficient of consolidation and increase soil compressibility. Drains installed by displacement method cause more disturbances than the drains installed by non-displacement method.

The term smear defines the whipping action provided by the casing as sand drain is driven into the soil and then pulled out after it has filled with sand.
To consider the effect of smear and remolding in the analytical sample solution, it is assumed that smear zone contains a homogeneous material with different properties from those in remaining material in the soil cylinder. It is also assumed that smear zone will consolidate very fast so its consolidation can be ignored, zone can be treated as an incompressible material.

2.5 Theoretical Basic of Design

2.5.1 Consolidation

When a compressive load is applied to soil mass a decrease in volume of soil mass takes place. The decrease in the volume of soil mass under stress is known as compression and the property of the soil due to which a decrease in volume occurs under compressive forces is known as compressibility of soil.

The compressibility of soil can occur due to following cases.

1. Compression of solid particles and water in the voids.
2. Compression and expulsion of air in the voids.
3. Expulsion of water in the voids.

Compression of solid particles is negligibly small and compression of water in the voids is also extremely small as water is incompressible. Air exists in partially saturated soils and dry soils. The compression of air is rapid as it is highly compressive, but it is not relevant for saturated soils. In fully saturated soils compression is mainly due to expulsion of water.
Compression resulting from a long term static load and the consequent escape of pore water is termed as consolidation. It is due to expulsion of water from the voids. The compressions takes place due to shifting of solid particles from one position to the other by rolling and sliding and thus attain a closer packing.

2.5.2 Initial, Primary and Secondary Consolidation

Consolidation of a solid deposit can be divided into three stages.

1. Initial Consolidation:

When partially saturated soil is subjected to a load, a decrease in volume occurs due to expulsion and compression of air in the voids and small change in volume due to compression of solid particles. The reduction in volume of the soil just after the application of the load is known as initial consolidation. In saturated soil it is due to compression of soil particles.

2. Primary Consolidation:

After initial consolidation further reduction in volume occurs due to expulsion of water from voids. When saturated soil is subjected to pressure, initially all the applied pressure is taken up by water as excess pore water pressure due to which hydraulic gradient develops and water flows out decreasing the volume. The decrease depends upon the permeability of soil i.e. time dependent. This reduction in volume is primarily consolidation. In fine grained soils it takes longer time, while in coarse grained soil it occurs quickly due to high permeability. It also increases effective stress by transferring pressure from water to solid particles.
3. Secondary Consolidation:

The reduction in volume continues in vary slow rate even after the excess hydrostatic pressure developed by the applied pressure is fully dissipated and the primary consolidation complete. The additional reduction in the volume is called secondary consolidation. It is attributed to the plastic readjustment of solid particles and absorbed water to new stress system.

2.5.3 Radial Consolidation

Terzaghi’s theory of one dimensional consolidation is based on assumption that the soil is laterally confined and consolidation takes place only in one direction. But in special cases like sand, consolidation takes place in radial direction as well as in vertical direction. The main application of the radial consolidation is in sand drains, used to increase the rate of drainage in the embankment.

The overall, average degree of consolidation $U$ under combined radial and vertical directions can be expressed as,

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

where, $U_v$ = average degree of consolidation in vertical direction

$U_r$ = average degree of consolidation in radial direction

$U_v = f(T_v)$ & $U_r = f(T_r)$

Where $T_v$ and $T_r$ are time factors in vertical and radial directions respectively, given by

$T_v = c_v t / d^2$

$T_r = c_r t / (4 R^2)$

$c_v = k_v / (m_v g)$

$c_r = k_r / (m_r g)$
where,

\[ R = \text{radius of the drainage area} \]
\[ d = \text{drainage length in the vertical direction} \]
\[ k_z = \text{coefficient of permeability in vertical direction} \]
\[ k_r = \text{coefficient of permeability in radial direction} \]
\[ m_v = \text{coefficient of volume change} \]

2.5.4 Derivation of One-dimensional Consolidation Theory

When a compressive load is applied to a laterally confined layer of sand, rapid vertical deformation occurs. The rate at which this deformation can take place depends upon the permeability of soil and upon the distance the water must travel to reach a drainage surface. The compressibility of clays may also be caused by three factors:

(i) the expulsion of double layer water from between the grains
(ii) slipping of the particles to new positions of greater density, and
(iii) bending of particle as elastic sheets. The permeability of clay being very small, time is an important factor in the consolidation of clays.

Figure 2.4: One-dimension Consolidations
Figure 2.4 (a) shows a clay layer, of thickness H, sandwiched between two layers of sand which serves as drainage faces. When the layer is subjected to a pressure increment Δσ, excess hydrostatic pressure is set up in the clay layer. At the time \( t_0 \), the instant of pressure application, whole of the consolidating pressure Δσ is carried by the pore water so that the initial excess hydrostatic pressure \( \bar{u}_0 \) is equal to Δσ, and is represented by a straight line \( \bar{u} = \Delta\sigma \) on the pressure distribution diagram. The straight line CED joining the water levels in the piezometric tubes represents this distribution. As water starts escaping into the sand, the excess hydrostatic pressure at the pervious boundaries drops to zero and remains so at all times. After a very great time \( t_f \), the consolidating pressure Δσ is partly carried by water and partly by soil, and the following relationship is obtained: \( \Delta\sigma = \Delta\sigma' + \bar{u} \). The distribution of excess hydrostatic pressure \( \bar{u} \) at any time \( t \) is indicated by the curve AFB, joining water levels, in the piezometric tubes; this curve is known as isochrone, and number of such isochrones can be drawn at various time intervals, \( t_1, t_2, t_3 \) etc. The slope of isochrones at any point at a given time indicates the rate of change of \( \bar{u} \) with depth.

Thus, the rate of change of \( \bar{u} \) along the depth of the layer represents the hydraulic gradient. The velocity with which the excess pore water flow at the depth \( z \) is given by Darcy's law

$$ v = k_i = \frac{k}{\gamma_w} \frac{\partial u}{\partial z} \quad \ldots(i) $$

The rate of change of velocity along the depth of the layer is then given by

$$ \frac{\partial v}{\partial z} = \frac{k}{\gamma_w} \frac{\partial^2 u}{\partial z} \quad \ldots(ii) $$