SETTLEMENT OF EMBANKMENT TREATED WITH PRELOADING AND PREFABRICATED VERTICAL DRAIN (A CASE STUDY)

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ABSTRACT

Structures built on soft soil such as clay are generally subject to excessive settlement and it may continue for a long time. It depends on the ability of the soil to dissipate excess pore pressure due to construction load. In order to construct any structure on that soft soil, soil improvement is needed. Combination of preloading and Prefabricated Vertical Drain is very effective to be use as soil improvement. This soil improvement is related to the objectives of the study which are to predict settlement of an embankment based on Terzaghi One-Dimensional Consolidation analysis. Besides that, Asoaka's method were used to determine the actual settlement based on monitoring data and to compare the soil properties from the laboratory data with back calculated value. In this study, the predicted settlement is 1.54 meter and the actual settlement of the soil which calculated using Asoaka's Method is 0.51 meter. Back calculated value was determined in order to verify the soil properties from the laboratory. The differences between laboratory soil properties and back calculated value are been shown in the correlation form. From the analysis, it shows that the correlation for the Compression Index, $C_{c\ field} = 0.40\ C_{c\ lab}$ while the correlation of Recompression Index, $C_{r\ field} = 0.36\ C_{r\ lab}$, the correlation of Coefficient of vertical consolidation, $c_{v\ field} = 1.02\ c_{v\ lab}$, and Coefficient of horizontal consolidation, $c_{h\ field} = 1.02\ c_{h\ lab}$,. The correlations will be used as a reference for next project. From this case study, it shows that the ground improvement of preloading and PVD was a good agreement as it successfully reduces the time for the soil to consolidate.

ABSTRAK

Struktur yang dibina di atas tanah lembut seperti tanah liat umumnya mengalami enapan yang berlebihan dan ia boleh berterusan untuk masa yang panjang. Ia bergantung kepada keupayaan tanah untuk menghilangkan ruang ruang udara yang disebabkan oleh pembinaan. Oleh itu, untuk membina apa-apa struktur di atas tanah yang lembut, penambahbaikan tanah diperlukan. Gabungan pra-pembebanan dan penggunaan Parit pasang siap menegak sangat berkesan untuk digunakan sebagai penambahbaikan tanah. Penggunaan penambahbaikan ini sangat berkaitan dengan objektif-objektif kajian ini yang mana, untuk meramalkan pemendapan tambakan berdasarkan Analisis Pengukuhan Satu Dimensi Terzaghi. Selain itu, kaedah Asoaka telah digunakan untuk menentukan penyelesaian yang sebenar berdasarkan data pemantauan dan untuk membandingkan sifat-sifat tanah dari data makmal dengan nilai yang kembali dikira. Dalam kajian ini, enapan ramalan adalah 1.54 meter dan enapan sebenar tanah yang dikira menggunakan Kaedah Asoaka adalah 0.51 meter. Nilai yang dikira kembali telah ditentukan untuk mengesahkan sifat-sifat tanah dari makmal. Perbezaan antara sifat tanah makmal dan nilai yang dikira kembali telah ditunjukkan dalam bentuk hubung kait. Setelah analisis dilakukan, keputusan menunjukkan bahawa hubung kait Indeks mampatan, $C_{c\ lapangan} = 0.40\ C_{c\ makmal}$ manakala hubung kait Indeks pemampatan semula, $C_{r\ lapangan} = 0.36\ C_{r\ makmal}$, hubung kait Pekali penyatuan menegak, $c_{v\ lapangan} = 1.02\ c_{v\ makmal}$, dan Pekali pengukuhan mendatar, $c_{h\ lapangan} = 1.02\ c_{h\ makmal}$,. Hubung kait ini akan digunakan sebagai rujukan untuk projek seterusnya. Daripada kajian kes ini, ia menunjukkan bahawa penambahbaikan tanah pra-pembebanan dan Parit pasang siap menegak (PVD) adalah satu penggunaan yang baik kerana ia berjaya mengurangkan masa untuk menyatukan tanah.

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γ	Unit weight
C_c	Compression Index
C_r	Recompression Index
e_o	Initial void ratio
c_v	Coefficient of vertical consolidation
c_h	Coefficient of horizontal consolidation
σ'_o	Initial effective stress
CR	Compression Ratio
H	Thickness of soft soil
p_c	Pre-consolidation pressure
σ'_o	Initial effective stress
$\Delta\sigma'$	Change in effective stress
S_f	Final settlement
U	Degree of consolidation
T_v	Time Factor
t_{90}	Time to reach 90% consolidation
b	Width of drain (PVD)
t	Thickness of drain (PVD)
n	Spacing ratio
β	Slope/ gradient of graph
Δt	Time interval
k_h	Coefficient of horizontal permeability
k_s	Coefficient of vertical permeability
$F(n)$	Spacing factor
$F(s)$	Smear factor
$F(r)$	Well resistance factor

CHAPTER 1

INTRODUCTION

1.1 Background

Rapid development of an area will add to some construction such as building and highway have to build on a problematic soil like soft clay. Soft clay is known to have low shear strength and high compressibility that can affect infrastructure including buildings, roads and rail tracks. Therefore, the load from the construction may results in bearing capacity failure and excessive settlement. Vertical drain has been used to speed up the consolidation process by increasing the permeability and the distance for consolidation. A very common type of vertical drain used is prefabricated vertical drain because of the easier installation.

A common type of construction placed on soft soil is embankment. An embankment refers to a volume of earthen material that is placed and compacted for the purpose of raising the grade of roadway. Construction of high embankment of soft ground is usually susceptible to bearing capacity failure, intolerable total and different settlement, large lateral pressure and movement and slope instability.

Field monitoring is the only way to provide a continuous records of the ground behavior from the point of the instrument installation. There are many types of instruments that have been use at the construction field such as piezometer and inclinometer. Settlement plate and settlement gauge are commonly used to measure settlement. Field observation is the other method to indicate that a certain percentage of settlement has taken place and therefore the residual settlement will be negligible or will not cause disruption to the construction.

1.2 Problem Statement

Structures built on soft clay are subjected to excessive settlement. The large proportion of settlement is dependent on consolidation process which may continue for a long time depending on the ability of soil to dissipate excess pore water pressure due to construction load. Besides that, engineering characteristic of soft clay soil should be studied into consideration as deep understanding of the analysis could help people in this field to understand how crucial and critical the soil could become the structure.

Soft clay has the lowest value of permeability which water hard to get through the particles and it will cause the high moisture content. It is known that water could be the main agent that makes the soil become unstable because of the high ability of the soil to trap huge amount of water within its particles. By the weak conditions of the soil, it is dangerous when structures like road and railway to be built on the soft clay soil without having proper design and analysis to the soil.

In order to construct any structure on that soft soil, the soil improvement is needed. The design of the soil improvement needs the soil properties such as void ratio and coefficient of consolidation. However, there are soil properties cannot be obtained from Site Investigation Data and an assumption has to be made based on the previous study. If the assumption inaccurate, this will give impact to the PVD and embankment design.

1.3 Objectives

Generally, the main objective of this study is to determine the predicted settlement and actual settlement. However, the more specific objectives of the study may as follows;

1.3.1 To predict the magnitude of settlement of embankment based on Terzaghi One Dimensional Consolidation analysis

1.3.2 To determine the actual settlement of the embankment using Asaoka's method based on monitoring data

1.3.3 To determine the differences of soil properties that obtain from Site Investigation and back calculated value.

1.4 Scope and limitation

The settlement will be design based on the site investigation data that collected from Jalan Morak to Cabang 4 Tok Mek Ngoh, Tumpat, Kelantan. The case studies are based on the construction of embankment of Jalan Morak to Cabang 4 Tok Mek Ngoh. This study is based to the site investigation data (One Dimensional Laboratory test) and settlement monitoring data that collected from Ministry of Works. The soil parameter and soil profile are based on two selected boreholes. In analysis, the thickness of compressible layer, pre-consolidation pressure, initial effective stress, initial void ratio and change in stress is assumed to be constant. However, the case study is focusing on the settlement criteria only predicted by using the conventional one dimensional consolidation theory which developed by Terzaghi in 1925.

In order to accelerate the time rate of settlement and magnitude of the settlement, vertical drain was used in the soil. Preloading is the most successful ground improvement technique that can be used in low- lying areas. It involved loading of the ground surface to induce a greater part of the ultimate settlement that the ground is expected to experience after construction. Installation of vertical drain will shorten the time required for the process by reducing the length of the drainage path.

There are various types of vertical drains including sand drains, prefabricated vertical drains (geosynthetic) have been used in the past. Apart of increasing cost of sand, prefabricated vertical drains is more effective since the system is easy to install. The settlement marker and settlement gauge was used to monitor the actual settlement occurred in the field. Besides that, the geotextile are used for embankment stabilization because it can improve the bearing capacity of soft soil foundations. Furthermore, it can increase safety against underground failure and reduce the settlement of subsoil foundation.

2.2 Subsoil Exploration

Subsoil exploration is the process by which geological, geo- technical and other relevant information which might affect any other type of engineering project are acquired. The soil exploration is very important in order to select the type and depth of foundation, determine the bearing capacity and determine the maximum and differential settlement. Besides that, the subsoil exploration is important to predict lateral earth pressure against retaining wall, select suitable construction technique and construction material and also to investigate the safety of existing foundation and suggest the remedial measures [11].

Generally for subsoil exploration in any project, they performed three steps which are boring, sampling and testing. A boring activities is defined as a cylindrical hole drilled into the ground for the purposes of investigating subsurface conditions, performing field test, and obtaining soil, rock, or ground water specimen for testing[11]. From boring activities, the sample can be obtained for soil sampling.

There are three types of soil samples that recovered from boring which are altered soil, disturbed sample and undisturbed sample. The third step is field test. Field test is divided into several types of test such as Standard Penetration Test (SPT) and Cone Penetration Test (CPT)

The Standard Penetration Test and Cone Penetration Test are important to determine the soil profile. The measured SPT 'N-value' is defined as the penetration resistance of the sand which equals to summation number of blows required to drive the SPT sampler over the depth interval of 15cm to 45cm[11]. SPT is very important in order to determine the soil profile that can be a factor of settlement.

If the SPT value only takes four blows or less to drive SPT sampler, then the sand should be considered to be very loose and could be subjected to significant settlement due to the weight of structure or due to earthquake shaking. On the other hand, if it takes over 50 blows to drive the SPT sampler, then the sand is considered to be in very dense condition and would be able to support high bearing loads and would be resistance to settlement from earthquake shaking.

2.3 Soil Profile

Standard Penetration Test can be used to generate soil profile. Soil profile is referred to layer of the soil. The number of blow of each sample taken from the test will determine the group of soil whether it is soft or hard. Different places or site will gives different soil profile. Boring log will used to give description and detailing of soil in term of color, consistency, relative density grain size and texture.

The upper layer of soil which nearest to the surface is commonly called top soil. The other sample of boring test is taken as 0.45 m depth for each of sample. The 'N-value' of each sample will be used to classify the soil. The classification of the soil is tabulated as in Table 2.1.

Table 2.1 SPT values and its density

N- values	Relative Density
0-2	Very soft
2-4	Soft
4-8	Medium Stiff
8-15	Stiff
15-30	Very Stiff
>30	Hard

2.4 Soil Classification

Soils have different properties maybe similar in some aspect and can be classified into groups and subgroups according to their engineering behavior. The soil particle can be categorized as gravel if the size is 2mm to 75 mm. The size for sand is about 0.05mm to 2mm. The silt particle size is about 0.002mm to 0.05mm and clay particle size is less than 0.002 mm. According to the soil profile of a borehole, there are three types of soil which are clay, silt and sand.

According to BS5930, soft ground refers to ground with soils having shear strength or cohesion less than 40kPa and can be physically molded by light pressure using fingers. On the other hand, very soft ground such as typical coastal alluvium or commonly called 1- PSI soil has undrained shear strength of about 10kN/m^2 and when squeezed the very soft soils extrudes between the fingers[13].

The behavior of soft alluvial soils is influenced by the source of the parent material, depositional processes, erosion, redeposition, consolidation and fluctuations in groundwater levels [13]. Generally, alluvial deposits (materials transported and deposited by water action) consist of finest clay to very coarse gravel and boulders. Alluvial soils usually show pronounced stratification and sometime organic matter, seashell and decayed wood are present in alluvial clay.

2.5 Laboratory Testing of Soil

Laboratory testing should be as simple as possible. Tests using elaborate equipment are time- consuming and therefore costly, and are liable to serious error unless carefully and conscientiously carried out by highly experienced technician. In order to determine the settlement of soil, some soil properties need to be carried out. There are consolidation, collapse, organic content, fill compaction which is standard proctor and modified proctor

A general theory for consolidation, incorporating three- dimensional flow a vector is complicated and only applicable to a very limited range of problems in geotechnical engineering. One dimensional consolidation specifically occurs when there is no lateral strain for example in the oedometer test.

2.5.1 Oedometer test

Oedometer test is the primary laboratory equipment used to study the settlement or expansion behavior of soil. The oedometer test should only be performed on disturbed soil specimens, or in case of studies of fill behavior, on specimens compacted to anticipated field and moisture condition. The equipment can be varies but generally an oedometer test consist of a metal ring that laterally confines the soil specimen, porous plates placed on top and bottom of the soil specimen as shown in Figure 2.1.

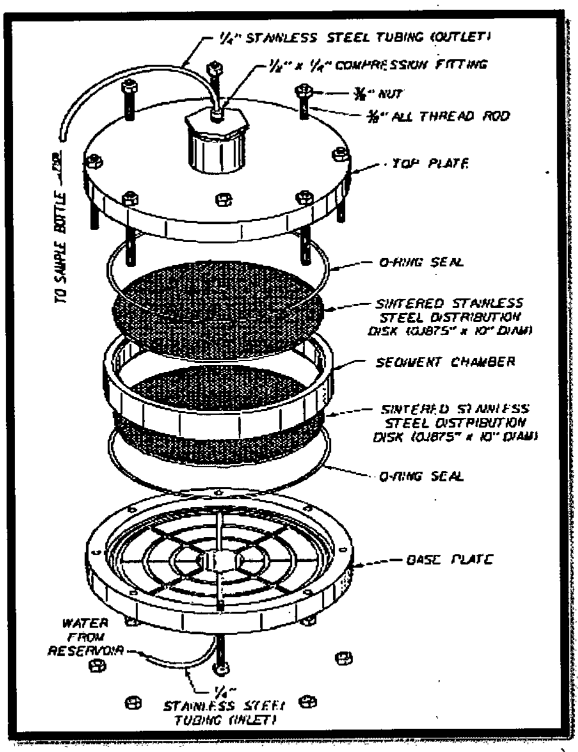

Figure 2.1 Apparatus used for Oedometer Test

Besides that, the other equipment is a loading device that applies a vertical stress to a soil specimen, a dial gauge to measure the vertical deformation of the soil specimen as it is loaded or unloaded and a surrounding container to allow the soil specimen to be submerged in distilled water [11].

There are two types of oedometer. The first oedometer is fixed- ring oedometer which is the soil specimen will be compressed from the top downward as the load is applied, while for floating- ring oedometer, the soil specimen is compressed inward from the top and bottom. The advantages of using the floating- ring oedometer is there is less friction between the confining ring and the soil. The disadvantages of the floating-ring is that it is more difficult to set up and soil may squeeze or fall out of the junction of the bottom porous plate and ring. Because of the disadvantages, the fixed- ring oedometer is always be used for testing.

In order to determine the consolidation from this oedometer test, there are three importance variables which are the excess pore water pressure, the depth of the element in the layer and the time elapsed since application of the loading. However, the assumption has to be made for this experiment. The total stress on the element is assumed to remain constant. The coefficient of volume compressibility is also assumed to be constant and the coefficient of permeability for vertical flow is assumed to be constant.

2.6 Soil Improvement

As the soft soil is having low permeability and very high compressibility, it is very important for the soil to be improved. Soil improvement is the technique involves changing soil characteristics by a physical action, such as vibration or by the inclusion or mixing in the soil or a stronger material. It is important to reduce both absolute and differential settlement or in certain cases, accelerate them.

Soil improvement can be divided into two categories. The first category includes techniques which require foreign materials and utilisation of reinforcements. They are based on stiffening columns either by the use of a granular fill which is called stone columns, by piling elements which are not reaching a still soil stratum or by in situ mixing of the soil with chemical agents which is known as deep stabilization.

The second category includes methods which are strengthening the soil by dewatering, for example the preloading techniques often combined with vertical drains[3]. In this project, the soil improvement that was used is preloading and prefabricated vertical drain (PVD). Figure 2.2 show the suitable ground treatment that can be used for different types of soil.

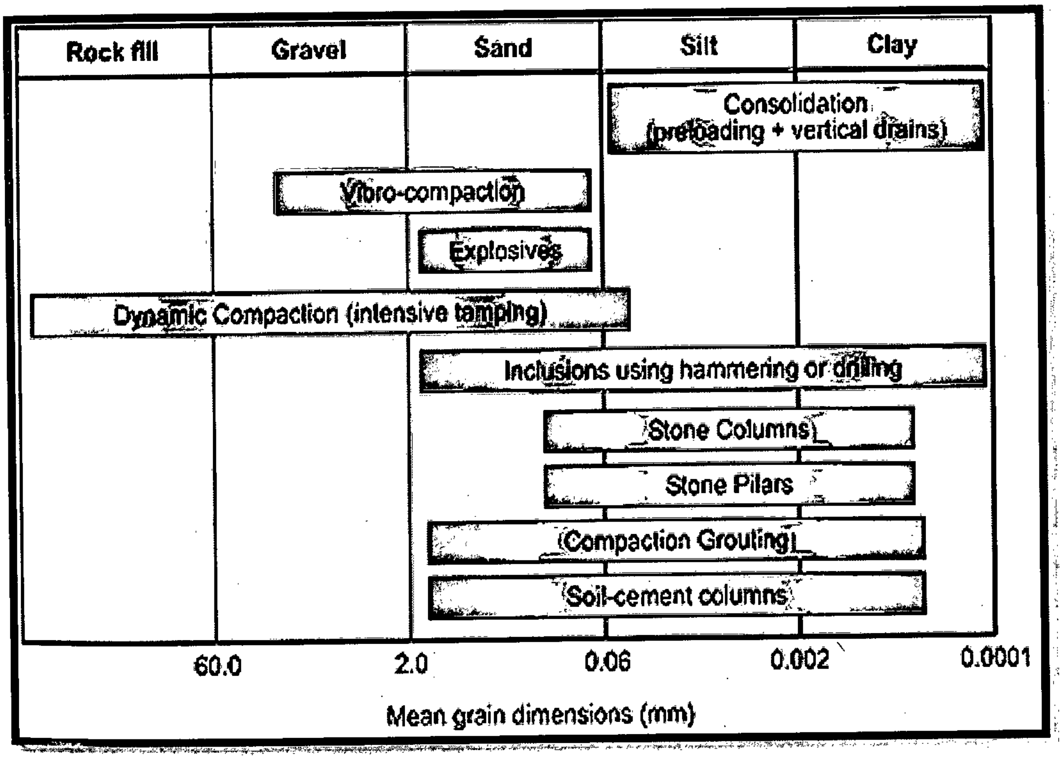

Figure 2.2 Suitable ground treatment for different types of soil

2.6.1 Cement deep mixing method

The cement deep mixing method is a soil stabilization method which mixes cement slurry with soft soil in situ to attain a required strength. By using this method, soft soil is stabilized by two phase chemical reaction. There are some advantages by using this cement deep mixing method which it will give higher strength and lower compressibility than the native soil. This method also can give minimum impact to environment. This is because the drilling and mixing operation is low noise and low vibration and does not generate dust.

2.6.2 Vibro compaction

The other methods that use to improve the soft ground is vibro- compaction. Vibro compaction is also known as 'vibro- flotation' which refers to deep compaction of soil. This method is also used to increase the density and load- carrying capacity of loose partially and fully saturated soil by the vibration and displacement of the particles by the vibrator. The improved inter-granular friction reduces settlement under applied load.

In order to use this method, ground investigation need to be done. This is because in order to determine the particle size distribution, void ratio, soil stratification, groundwater conditions and relatively density. This method of compaction need to have layout of compaction which is based on a radius of compaction of around 1.5m in granular soil and a grid pattern selected to suit loading requirement such as rows of compaction points under strip foundations at 1-2m centres and overlapping 2-3m triangular grid for areal treatment. The depth of compaction can be 35m in special cases but 10-15m is typical. The illustration of vibro compaction method can be seen in figure 2.3.

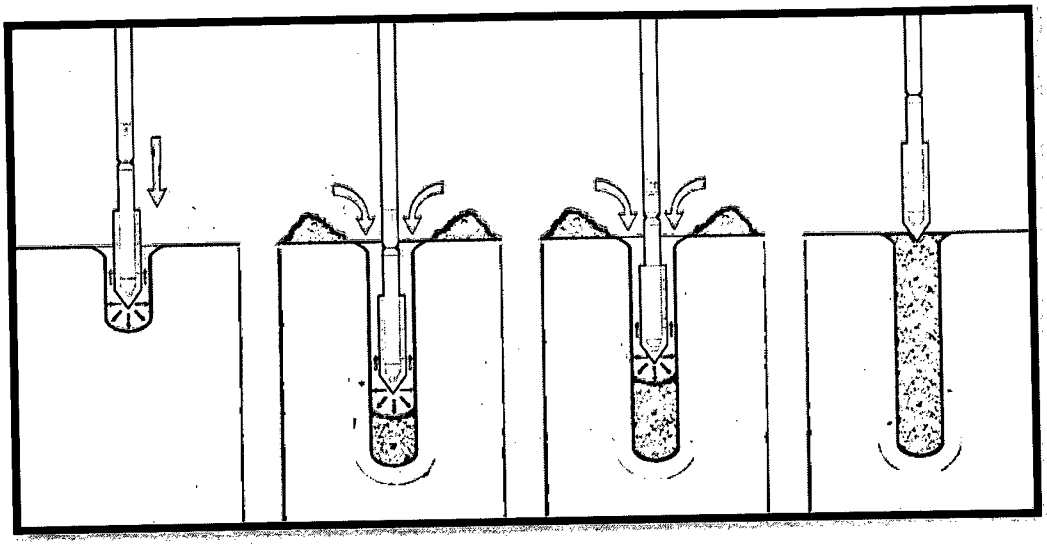

Figure 2.3 Vibro compaction method used for soil improvement

Construction in granular soils requires the use of high pressure water jets from the tip of the vibrator to flush out fine soil and to assist in forming the hole as vibrating poker is slowly lowered under its own weight. When the poker reaches the required depth it is surged up and down to remove fines.

2.6.3 Vibro- replacement-stone column

The other method used for ground treatment is vibro- replacement-stone columns. The vibro- replacement technique uses the vibrator or poker to displace and compact the in-situ ground as in vibro-compaction. This method is suitable for reinforcing most loose granular soils, fills, weak and cohesive soils. The shear strength to be treated should be less than 20 kN/m^2. Figure 2.4 shows the technical illustration of how vibro-replacement-stone columns method was conducted.

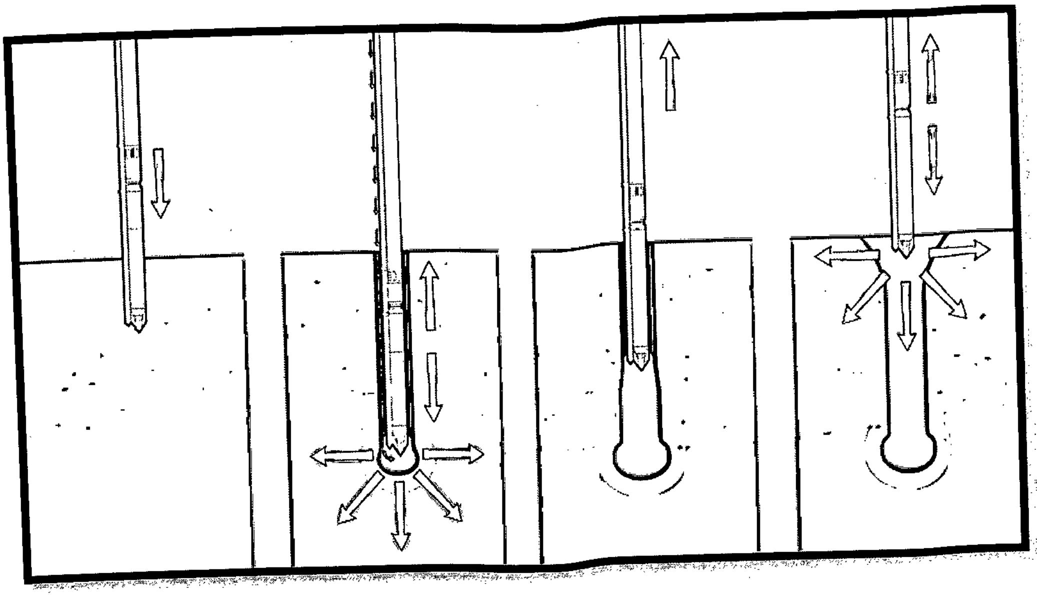

Figure 2.4 Vibro- replacement stone column method

By using this method of vibro- replacement- stone columns, the engineers have to design the ultimate bearing capacity, settlement, depth of treatment and layout of columns. The construction uses similar plant with the vibro- compaction, but for this method the stone used is immobile, and compressed

2.6.3.1 Top feed system

There are five methods for stone column using vibro- replacement. The top feed system is used in dry conditions in stiff soils, where the poker penetrates the ground under its own weight using compressed air and vibration. At the required depth the poker is withdrawn and a small charge of the stone is introduced and compacted by the vibrating poker to interlock with the ground.

2.6.3.2 Wet system

The other method is the wet system which is used with top feed of the stone in cohesionless soils below the water table and in weak silts and clays. The vibrating poker is then penetrates the depth under its own weight, with water jets removing fines. At required depth, the water pressure is reduced to ensure that the holes formed remains open with water circulation and stone is introduced down the annulus and compacted in short lifts to build up the column to the surface.

2.6.3.3 Bottom feed system

Besides that, system used for stone column is bottom- feed system, plant and equipment and cased and rammed stone columns. The bottom- feed system can be used below the water table without water jetting, thereby avoiding the problems of disposal of the surplus water. In addition to penetration under its self weight, compress air and vibration, the rig may provide additional pull down force on the poker. The poker has a stone supply tube and hopper attached to deliver stone to the tip of the poker assisted by compressed air.

At the required depth the poker is withdrawn 1m, and a designed amount of stone is discharged at the tip and then compacted by the surging action of the vibrator. Plant and equipment required is similar to that for vibro-compaction which a 300-400 mm diameter poker weighing 3-5 tonnes. The other method is cased and rammed stone columns which are used in high- sensitivity clays where vibro- techniques are likely to weaken the surrounding soil.