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Soft Soil Stabilisation Via Vertical Drainage with Minimal Site Disturbance: A Case Study at Cameron Highlands

Wei-An Chong[1], Chee-Ming Chan[2]*, Poi-Cheong Tan[3], Salina Sani[2], Nur Faezah Yahya[2], Noor Khazanah A. Rahman[2]

[1] *Pakatan Runding Yusoff Sdn Bhd, 50470 Kuala Lumpur, MALAYSIA*
[2] *Department of Civil Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, 84600 Pagoh, Johor, MALAYSIA*
[3] *Reinforce Soil Engineering Sdn Bhd, 81100 Johor Bahru, Johor, MALAYSIA*

*Corresponding Author: chan@uthm.edu.my
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Abstract

Vertical drains are often adopted to improve poor ground conditions by accelerating the consolidation process of soils. This paper describes a case study utilising this technique to stabilise soft soils in Cameron Highlands. This method involves the installation of vertical drains with embankment and the permeable characteristic of the prefabricated vertical drains. The details of the vertical drain design and the construction of the project were also studied. In addition, site disturbance control measures and on-site monitoring methods should be implemented to manage the impact of the construction. In summary, this paper indicates the application of the vertical drain to stabilise high-rise soft soils and recommends the construction process to provide a reference for sites with similar locations or height.

1. Introduction

Cameron Highlands is located in the state of Pahang, Malaysia. It is known as a highland resort covered by thick tropical rainforest in Malaysia. Tourists are attracted by its cool climate and charming plantation agriculture. The coordinates and altitude of Cameron Highlands determine that its temperature is relatively low, with temperatures of approximately 24°C during the day and 14°C at night [1]. The frequent rainfall and the dense forest in the area are responsible for the formation of soft and compressible peat or clay deposits. The soft soils typically have weak shear strength and low bearing capacity, which may cause severe settlement damage to the structure built on top of them. Therefore, ground improvement works are always required to stabilise the soils.

Soft ground improvement for construction purposes is a widespread phenomenon in the field of geotechnical engineering. Geotechnical engineers are committed to treating soft soils by applying their professional knowledge. It requires conscious consideration to address soft soil problems, particularly in areas with high rainfall and elevated terrains such as Cameron Highlands. These types of soils often exhibit the characteristics of low strength, high compressibility and poor drainage, which may lead to extreme settlement, instability and damage to structures on top of them. Most ground improvement techniques involve injection, extensive excavation and replacement, which can result in significant site disturbance and environmental impact [2]. Therefore, the necessity for an alternative method that could minimise site disturbance and environmental impact arises.

Vertical drains, also known as prefabricated vertical drains (PVD) with surcharge, are a popular ground improvement technique due to their efficiency in accelerating the consolidation process of soft soils. They play a critical role in shortening pore water distance, reducing pore water pressures and accelerating the consolidation process. The drains are typically composed of synthetic materials or prefabricated geotextiles. The drains are designed to have high permeability, which provides pathways for excess pore water to escape from the ground.

They are penetrated and installed into the compressible soil layers. This ground improvement technique is highly effective for treating cohesive soils for soil depth up to 50 m using a dedicated PVD rig. They are usually involved in various civil engineering projects, including infrastructure construction, land reclamation, landfills and slope stabilisation [3].

The purpose of this paper is to determine the feasibility of utilising the vertical drains with an embankment in the specific circumstances of Cameron Highlands. Besides that, this study aims to assess the possible site disturbance and provide appropriate controls and measures to reduce the possibility of slope failures. In addition, this paper intends to recommend appropriate field monitoring methods to assess the effectiveness of vertical drains in high-rise site improvement projects.

2. Methodology

2.1 Vertical Drain with Embankment

Vertical drains are usually used to dissipate the excess pore water pressure in cooperation with embankment or surcharge. The drains are efficient in providing artificial drainage paths in soils, while the embankment is used to apply an additional load to soils beneath. Fig. 1 illustrates a typical cross-section of vertical drains with embankment installed in a project. The consolidation mechanism can be defined by relating the functions of both drains and embankment. The embankment acts as a load applied to the soil, causing pore water to be squeezed out from the soil particles due to high pressure. The vertical drains provide a path for the pore water to flow towards them due to their permeable characteristics. The pore water is allowed to flow faster towards the upper soil layers in the shortest vertical path [4]. Hence, the construction of the drains with embankment can accelerate the consolidation and settlement process.

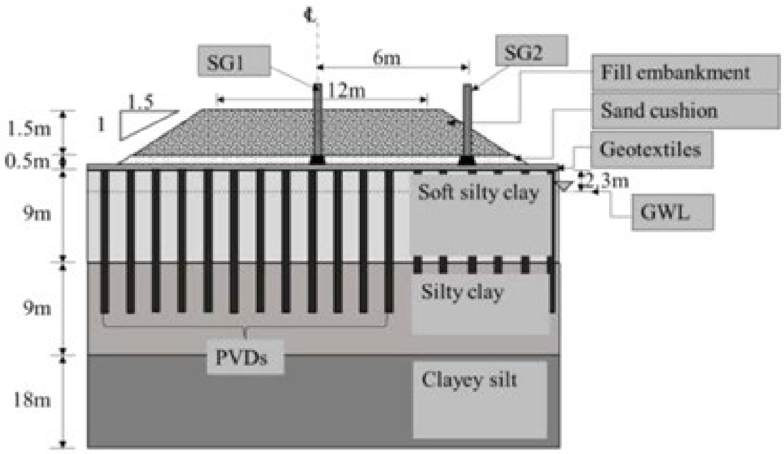

Fig. 1 *Typical vertical drains with embankment [5]*

2.2 Vertical Drain Materials

Vertical drains are prefabricated materials which comprise a double-sided ribbed polypropylene core wrapped with an external non-woven geotextile, as shown in Fig. 2. The core serves as a longitudinal flow path along the drain, while the geotextile acts as a filter jacket which provides excellent hydraulic flow discharge capacity [6].

The vertical drains are excellent for providing long-term durability and performance in soft soils. They can be present in the soils with good tensile strength, high resistance to biological degradation and water repellence [7]. Besides that, the unique properties of the geotextile only allow the movement of excess pore water entering it. Soil particles such as sand or gravel are retained from entering and clogging the drains.

3. Case Study

3.1 Site Details

The project site is situated in the District of Cameron Highlands, Pahang. The site is generally hilly with steep-sided cut slopes, surrounded by trees and bushes as shown in Fig. 3. It is adjacent to Tenaga National Berhad (TNB; Malaysia's largest electricity supplier company) dam. The site was planned with an improvement area of 4,872 square meters, as shown in Fig. 4. The ground elevation of the site varies from RL 1168.36 to RL 1190.00, which were measured from the mean sea level (MSL).

The area has historically been a former sediment dump caused by human activities. It was anticipated to be unsuitable for future infrastructure development. Therefore, the area was reserved for geotechnical investigations and ground improvement where necessary.

Fig. 2 *Typical prefabricated vertical drain*

Fig. 3 *Project site after site preparation*

Fig. 4 *Layout of the project area*

3.2 Ground Conditions

The geological information of the subsurface soils in the area was determined by conducting a Standard Penetration Test (SPT). From the results, the area was a sediment disposal area, and soft dumping sediment was found in the topsoil layer. The average thickness of the accumulated sediment and debris was 1.5 m below the 1173.0 original datum level. In addition, the area also consists of soft soil layers with an approximate depth of 10 m.

According to the geotechnical investigations of the areas, the soft ground had a low bearing capacity and low shear strength. It had the potential to induce ground settlement for future infrastructure development. Therefore, a ground improvement methodology should be proposed in order to minimise soil settlement and provide a stable platform for the infrastructure.

3.3 PVD Design

The soft soil stabilisation involved the ground improvement technique of implementing vertical drains with embankment in the area. The selected technique was appropriate to minimise and reduce infrastructure settlement during the construction and service stages. A total of 1903 points of vertical drains were designed to improve the soft ground conditions. The prefabricated vertical drains with a width of 100 mm were installed in a square pattern with a spacing of 1.5 m and a length of 12 m, as illustrated in Fig. 5.

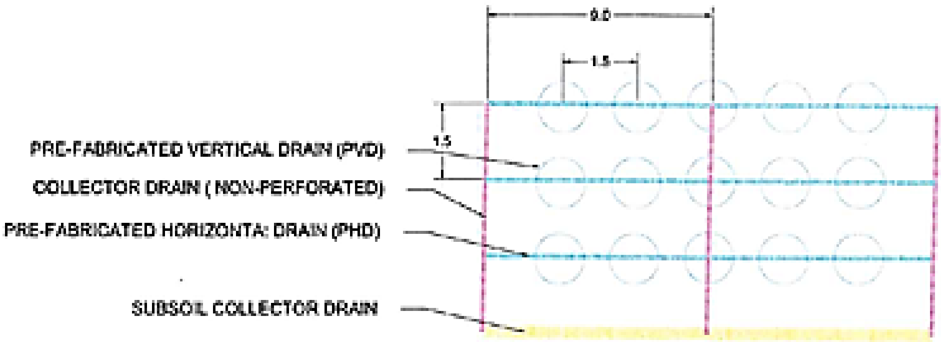

Fig. 5 *Layout plan for PVD at spacing 1.5 m*

3.4 PVD Installation

The PVD installation was started by setting up the reference points in the project area. A suitable hydraulic rig of 50 tonnes equipped with a PVD mast and mandrel was placed over the selected points. The vertical drain was threaded through the mast into the mandrel and held at the base of the mandrel by an anchor plate. The mandrel and the drain were driven into the ground to a depth of 12 m. The mandrel was extracted while the anchor plate and the drain remained in the soil. After the mandrel was fully extracted from the ground, the drain was cut off above 300 mm above the ground surface, as shown in Fig. 6. These steps were repeated at designed points by

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repositioning the rig and mast to suitable locations. Upon completion of the installation process, the tidiness and consistency of the vertical drains were left in the ground.

Fig. 6 *Installation of vertical drains*

The horizontal drain was easily installed by hand without the need for heavy equipment such as a static cable-pulled and hydraulic rig. The horizontal drain was placed at the first point of a row. Then it was pulled to the last point across the vertical drains on a straight line. When the designed length was reached, the drain was cut off. Then the horizontal drain was connected to all the extra parts of the vertical drains exposed outside of the ground. The placement and cutting process was repositioned to the designed rows next to it, and the cycle is repeated. Fig. 7 illustrates the complete installation of the horizontal drains.

The vertical drain method was typically designed with the construction of an embankment over the soft soil. After the installation of both vertical and horizontal drains on the site, an embankment with a 2 m depth of rockfill was placed on top of the project area. The objective of the placement of embankment was to accelerate the consolidation process with approximately 46 kPa of load applied. The soil stabilisation project can be handed over to the main contractor and consultant after at least 90% consolidation is achieved.

Fig. 7 *Horizontal drains setting out*

4. Site Disturbance Control Measures

It is important for the soil contractors to propose a specified design for the high-rise site project. The supervising engineers should have relevant knowledge and experience to identify the potential disturbances of the ground improvement works to the surrounding site. The disturbances may cause slope failure, poor drainage and even project failure in future.

The slopes cutting and tree removal activities shall be conducted before ground improvement works commence to prevent slope failure. The slope failure may occur when the slope is not designed with an appropriate angle. The gradient of the slope in the ground improvement area must be 2H:1V. The stability of the slope is safe if it is evaluated to have a minimum of 1.5 factors of safety (FOS) by GeoStudio software. During the process of slope cutting, the supervisor engineer should ensure there is no overcutting and loosening of the finished surface.

The frequent rainfall on the high-rise site will bring a significant increase in the water table in the project area. This phenomenon requires additional slope protection measures to remove the excessive water. One of the measures is to construct subsoil collector drains, which are connected to the horizontal drains. The drains are used to provide a path for the subsurface water flows from the site to the main drainage. Lowering the water content increases the shear strength of the soil, thereby decreasing the probability of slope failure at the site.

The construction of the embankment is a pivotal aspect of the project to accelerate the consolidation process. However, embankment over the soft soil may bring an increased risk of instability due to the surrounding terrain, soil condition and drainage systems. Therefore, the shear key must be proposed to control the embankment movement and deformation within the acceptable limits. The shear key typically consists of gabion and rockfill in this project. It helps to increase the sliding resistance of the embankment by transferring the horizontal forces acting on the wall to the soil.

5. Field Monitoring Methods

The soft soil stabilisation project should be monitored using a series of field monitoring methods after the completion of the stabilisation works. The application of field monitoring methods such as settlement plates, piezometers and inclinometers can identify the occurrence of errors or non-compliance with the design or technical standards [8]. An early action can be taken to solve the problems or mistakes made before they pose a huge loss to the involved parties.

5.1 Piezometers

Piezometers are geotechnical sensors that are utilised to measure the pore water pressure in the soil. After the placement of the embankment on top of the soil, the pore water pressure in the soil changes due to the additional load. The changes in the pore water pressure and static water level can be obtained by measuring the piezometric head. Hence, the geotechnical engineer can compute the degree of consolidation of the soils and track the progress of the consolidation. In this project, at least 90% of the degree of consolidation for the soils is designed to be achieved. It is not encouraged to construct a structure on top of the soil if less than 90% of the degree of consolidation is achieved to prevent damage to the structure in the future.

5.2 Inclinometer

Inclinometers are instruments that are typically used to measure angles of slope, the elevation of soils with respect to gravity's direction. They consist of an aluminium casing that allows them to be installed vertically in soil. In this project, the embankment pressure that is exerted on the soil may induce lateral displacement in the soil. The inclinometers should be installed in the sand working platform and at the edges of the embankment fill areas. The site supervisor can monitor the rate and magnitude of lateral displacement of the slope and embankment.

5.3 Settlement Plates

Settlement plates are a simple apparatus that measures the consolidation settlement beneath embankment fills. It specialises in monitoring the consolidation of ground improved by vertical drains and embankments. The apparatus consists of a base plate and a reference rod. A typical settlement base of a plate is 600 mm x 600 mm x 10 mm. Deep reference points are required to be established as a datum for the settlement gauges. In this project, the settlement of the ground must be at least 90% of the total settlement without treatment.

6. Conclusion

The transformation of geotechnical engineering from conception to construction on high-rise building sites requires deeper and more advanced considerations than those of low-rise buildings. Multiple perspectives should be considered during the engineering processes. The key processes involved in the project are typically divided into planning, design, construction and monitoring.

Site visits and surveys were critical to gathering the information needed and identifying the ground conditions as well as potential risks before a project begins. The vertical drain method was chosen and designed to stabilise the soft soil due to the simplicity and speed of the process. Construction on high-rise construction sites usually poses a greater risk to slope stability than low-rise construction. The main contractor shall cut and fill slopes to prevent slope failures and provide a stable working platform for construction activities. After the installation of the drains, several slope protection measures, such as subsoil collection drains and shear key, shall be taken to control the impact of the construction activities on the site. The utilisation of the PVD, shear key and collection drain must be matched to the designed parameters, including length, quality and quantity, so that the construction on site is suited to the proposed design. Proper construction can prevent failure and unnecessary costly remedial works upon completion of construction. After construction, site workers should conduct field monitoring measures such as piezometer, inclinometer and settlement plate tests to assess the effectiveness of vertical drains.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Chee-Ming Chan;* ***data collection:*** *Wei-An Chong;* ***data analysis and validation:*** *Chee-Ming Chan, Salina Sani and Poi-Cheong Tan;* ***draft manuscript preparation:*** *Wei-An Chong;* ***manuscript checking and correction:*** *Nur Faezah Yahya and Noor Khazanah A. Rahman. All authors reviewed the results and approved the final version of the manuscript.*

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