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Landslide on a Deeply Landfilled Slope: A Case Study of Tembalang, Indonesia

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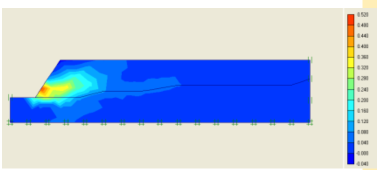
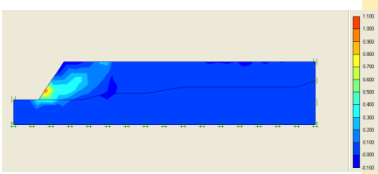
Graphical abstract





Abstract

This paper reports on the failure of a deeply landfilled area where a three-storey building was under construction on it. The soil used for landfill adheres to the safety needs as the material used was the commonly used mountainous soil. The soil has sufficient high shear stress even for a steep slope. When heavy and persistent rain came, some area suffered catastrophic landslide causing part of the ground floor in the three-storey building damaged. Since the rainy season is still undergoing, fast reinforcement acts were needed so that the construction works may proceed without any subsequent landslide events. A grouting technique using cement mixed into the soil was proposed at site and proved successful where no event of landslide occurred. This paper also presented the reasons for choosing grouting cement compared to the other common soil reinforcement methods. An increase in soil shear strength due to cement grouting will also be discussed. This paper also presents the cases of landslide caused by torrential rain and provides recommendation of reinforcement methods for such cases.

Keywords: Landfill; steep slope; landslide; cement grouting

Abstrak

Kajian ini melaporkan tentang kegagalan timbunan tinggi yang di atasnya sedang dibina bangunan tiga tingkat. Tanah yang digunakan untuk timbunan ini mematuhi keperluan keselamatan kerana bahan ini adalah dari tanah pergunungan. Tanah ini mempunyai kekuatan ricih yang tinggi walaupun untuk cerun yang curam. Ketika hujan lebat dan berterusan, sebahagian lereng mengalami gelongsoran yang menyebabkan sebahagian bangunan di tingkat dasar mengalami kerosakan. Oleh kerana musim hujan masih panjang, tindakan yang cepat perlu diambil supaya kerja-kerja pembinaan dapat diteruskan tanpa berlaku kerosakan cerun susulan. Kaedah penurapan menggunakan simen yang dicampurkan bersama tanah di tapak dipilih dan didapati kaedah ini berjaya mengelakkan berlakunya gelongsoran tanah. Kertas ini juga membincangkan keputusan pemilihan kaedah penurapan simen berbanding dengan kaedah-kaedah lain yang biasa digunakan dalam menguatkan tanah. Peningkatan di dalam kekuatan ricih tanah menggunakan kaedah penurapan simen juga akan dibincangkan. Kertas ini juga akan menyajikan tentang kes-kes gelongsoran tanah yang berlaku akibat hujan lebat dan cara-cara untuk mengatasinya.

Kata kunci: Timbunan tinggi; lereng curam; gelongsoran; penurapan simen

1.0 INTRODUCTION

This study was conducted to investigate the occurrence of landslide at a construction site located on a deeply landfilled slope in Tembalang, Semarang, Indonesia in 2008. The variety of elevation of the land surface meant that the site had to be cut and filled to obtain a level surface for building. Due to inaccuracies in the geodetic survey, deep landfill was required to adjust the fixed elevation. Such deep landfill with an adequate slope had not been included in the design. As a result, the elevation of the slope reached seven metres, as shown on the contour map in Figure 1.[1]

A three-storey building was planned to be built using foundation piles; however, the retaining wall was added to the construction plan only after the requirement for such deep landfill was detected.

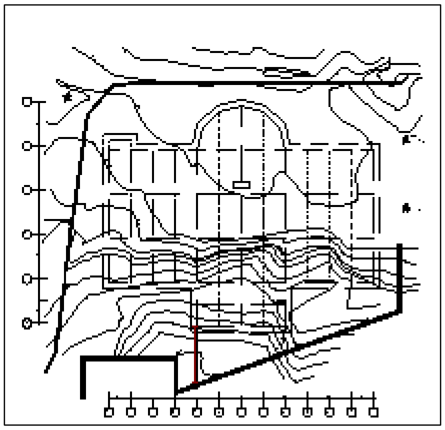


Figure 1 Contour map at the construction location[1]

The front of the building was sited at a higher elevation than the back, and most of the first floor was situated in the filled area. The soil materials used for landfill were taken from the land in front of the building, as shown in Figure 2. The slope of the embankment was set to follow the fall of soils in order to make it stable. As a consequence, the ground was not properly compacted and in some parts had a horizontal to vertical ratio of 1:4.

Figure 2 Landfill construction

The sequence of the construction was as follows. First, foundation piles were driven into the ground and a pile cap was constructed. Foundation beams were added the ground was then levelled. The first floor of the building was constructed first and after this was completed, the surface of the ground floor was further levelled until it reached the required elevation. The landfill work was still on-going when the retaining wall and septic tank construction started, as shown in the Figure 3.

Figure 3 Landfill construction after the start of building construction

The properties of the landfill are shown in Table 1 and Table 2. The properties and shear strength of the filled material were categorized as good for use as landfill. It was found that the soil used for landfill was suitable and almost similar to the existing soils in Tembalang, Semarang.

Table 1 Property of soil used as landfill material

Properties	Sample Code			
	1	2	3	4
Depth (m)	-01.00	-02.00	-03.00	-04.00
Water Content (w) %	36.2	33.45	31.86	30.01
Specific Gravity	2.6914	2.6851	2.6840	2.6928
Unit weight γ (gr/cm^3)	1.6712	1.6655	1.6668	1.6718
Dry unit weight γ_d (gr/cm^3)	1.2270	1.2480	1.2641	1.2859
Porosity (n)	54.41	53.52	52.90	52.25
Void Ratio (e)	1.1934	1.1515	1.1233	1.0941

Table 2 Shear strength parameters of the landfill material

Sample Code	Depth (m)	c (kg/cm^2)	ϕ (°)
1	-01.00	-	-
2	-02.00	-	-
3	-03.00	0.14	19
4	-04.00	0.13	21

The construction was done continuously from the dry season until the arrival of the rainy season. Heavy rain fell for a long time and this resulted in the landslide. However, as the staircase had a shallow foundation and the structures were free standing, this increased the weight of the load. The landslide caused significant deformation of the foundation of the stair structure and the ground floor. The damage that occurred to the ground floor included the work floor, the edge of the brick wall, the newly constructed septic tank and the canopy columns at the edge of the building. Therefore, prompt action was required immediately to address the landslide problem caused by the persistent heavy rain. A grouting technique using cement was proposed to overcome the problem of landslide in this area. Also, the evidence of the landslide will be discussed in greater detail in the following section.

■2.0 CASE STUDIES

Deposits of sandy soils in slopes always possess the potential to be put into conditions where movement is activated and continues to progress largely in one direction once triggered by an external agitation. This external force could be heavy rainfall, earthquakes, accidental local slides, or artificial agitations such as pile driving or vibration. No matter what the generic cause may be, once the flow-state is initiated, the soil tends to move downhill, with serious consequences. This type of flow-failure could occur even over gentle slopes, which are not conceived to be of serious concern. Thus, flow failure should be envisioned as a possibility even where movement is deigned to be limited. The problem of slope stability may be classified into two types: a limited deformation type and an unlimited deformation or flow type. The difference between unlimited and limited deformation is schematically illustrated in Figure 4.

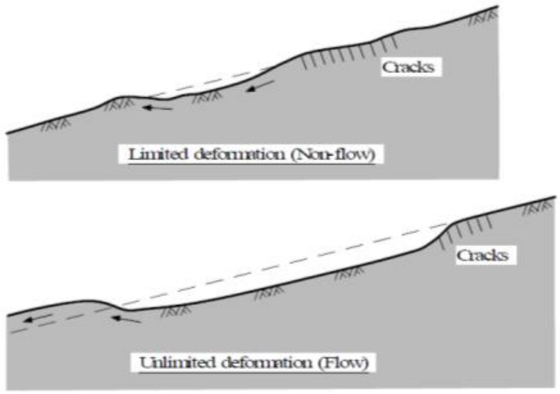


Figure 4 Flow and non-flow deformation of sandy soil[2]

When instability is triggered by some external agency a certain amount of deformation will take place in the soil, accompanied by cracking or displacement in the range of 50 cm to a few meters. However, such a minor displacement is not of much concern because the consequent damage would be minor and remedied at low cost. However, if a flow-type displacement is triggered, the consequences would be truly catastrophic as the moving soil mass would destroy a wide area as it flowed downhill.[2]

A numerical model for analysing the effect of rainfall infiltration on the stability of slopes was established using the finite element method and the limit equilibrium method. A comprehensive investigation was then undertaken in order to understand the hydraulic conditions that may contribute to a deep landslide. A landslide located in Chongqing was used to investigate the effect of rainfall infiltration on the seepage field and the deep slope stability. Rainfall records collected by Fengjie monitoring station in 1988 are used as the weather conditions. The accumulated precipitation in 1982 was 1396.4 mm, and ranks first in the 40.7 years return period. Based on numerical simulations, some conclusions are drawn, as follows. (1) When the soil is homogenous, only a shallow depth is affected by rainfall. The pore pressures at the slip plane vary slightly during the rainy season. In this case study, the initial factor of safety decreases from 1.052 to 1.037. Therefore, deep landslides are seldom triggered and are normally shallow. (2) Macro-pores in the soil may form a preferential path for water flow and make the pore pressure waves following rainfall. As compared with a homogeneous soil slope, the safety factor is lower. (3) The presence of fissure has to be taken into consideration in the analysis of the hydrological triggering systems of deep landslides. The overland flow supplies water to the deep layers through fissure, which results in the groundwater level rising. This may reasonably account for the occurrence of deep landslides.[3]

During the second half of 2011, heavy rainfall caused a dramatic damage to the railway foundations in Southern Norway. Most of the railway foundations affected were old, generally constructed between 1850 and 1950 at a time when construction work was done manually, and soil materials from cuts in local natural deposits were utilized for the construction of nearby embankments. The quality of the culverts and embankments, therefore, does not correspond to modern construction standards. As a consequence, the embankments do not perform well during intense and prolonged rainfall, as demonstrated in 2011. In some cases, the low capacity of old culverts caused the water levels to rise upstream of the embankments, followed by internal erosion and ended in the complete destruction of the embankments. Slope failures may occur in old embankments constructed of clay, silt, sand, and gravel without clear precursors to the failures. Analyses indicate that slope stability may also be critical without unusual weather conditions. There seems to be a need for improved research into the geotechnical behaviour of such embankments.[4]

A slope covered with various depths of colluvium soil was studied with the use of a monitoring system. The results from hundreds of settlement and displacement observation marks were taken into account. It was found that the maximum settlement and displacement were concentrated around the buildings of Hui-tsui, Zhian and Wu-Ming, and coincided with rainfall records for the area. The direction and distribution of displacement and surface cracks supports the previous study of a sliding block. According to the aforementioned stability analysis results, the rise of ground water in rainstorm conditions significantly impacts slope stability. Consequently, slope stability will be improved with the addition of drainage and drawdown systems and retaining structures. With the budget and effectiveness in mind, the first step should focus on the area around the Wu-Ming building where the ground water and geological condition is least favorable.[5]

2.1 Types of Cement Grouting Techniques

Grouting techniques can be classified into four groups, namely permeation grouting, compaction grouting, hydro-fracturing grouting and jet grouting.[6]

2.2 Permeation Grouting

In permeation grouting (Figure 5a), low-viscosity grout material is injected into the ground using relatively low pressure and stress. The relatively low pressure and stress is intended to minimize disturbance to the structure as much as possible. In this technique, the grout material flows through the pores of the soil. This technique is suitable for soil which has a permeability of less than 10^{-5} m/second, such as sandy soil.

2.3 Compaction Grouting

Figure 5b shows the compaction grouting technique. This technique uses high-viscosity material which is injected using relatively high pressure and stress. By using relatively high pressure and stress, the material remains in one piece and can cause stress to the soil surrounding the injection location. Stress will push and compact the soil surrounding it. The compaction grouting technique is used for poorly permeable soil like clay.

2.4 Hydro-Fracturing Grouting

In hydro-fracture grouting (Figure 5c) the grout material is injected by using higher stress and soil tensile strength in such a way that the soil will crack and the material will infiltrate into it and become solid in the voids of the soil. This technique is suitable for clay and sandy soil, but it is difficult to control and runs the risk of disturbing the surrounding soil.

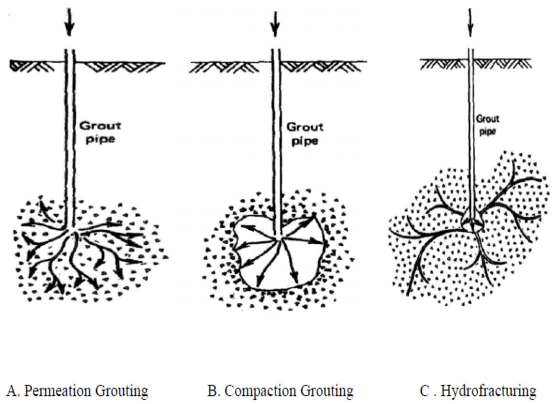


Figure 5 Types of grouting system[6]

2.5 Jet Grouting

In this technique, grouting materials are injected into the soil by using a jetting technique at pressures between 100 and 800 kg per square meter. This technique includes fracturing and mixing the existing soil with grout material. If necessary, soil can be pushed out and replaced partly or fully with grouting material. In this way, cement columns with high shear or compressive strength will form.

■3.0 METHODOLOY

To calculate the factor of safety (FOS) and occurrence of deformation during the dry and rainy seasons, the soil parameters and slope conditions are required. The soil parameters were taken from Tables 1 and 2. Meanwhile, the slope condition was taken from detailed engineering design drawings and the final project report. A computer program, Plaxis 7.2, was used to simulate the conditions during the dry and rainy seasons.

■4.0 RESULTS AND DISCUSSION

4.1 Finite Element Analysis

Figure 6 shows a model of the landfill and slope in land-sliding analysis using the Plaxis 7.2 program. As shown in this figure, the upper dark grey part is landfill and the bottom layer is the native soil.

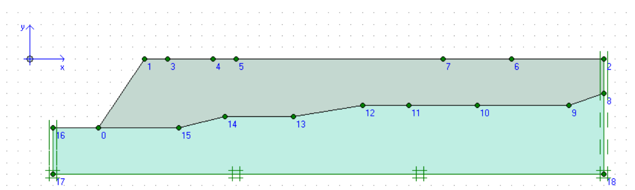


Figure 6 Plaxis 7.2 model for fill and slope[1]

As long as the weather remains dry, the slope is safe and no sliding occurs. Maximum strain in the fill was only 0.52%, as shown in Figure 7. The FOS was calculated to be 1.29.

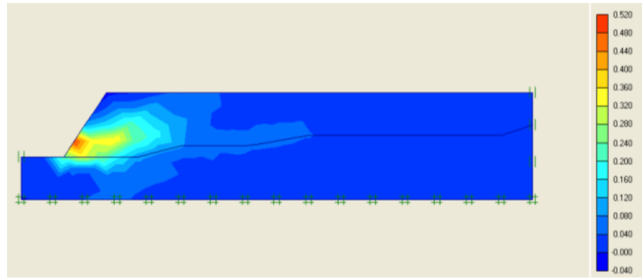


Figure 7 Strain in the slope when soil is dry[1]

However, after heavy and prolonged rain, the overflow of water from the front flowed into the lower part of the landfill in the building, causing the water level there to rise, as shown in Figure 8.

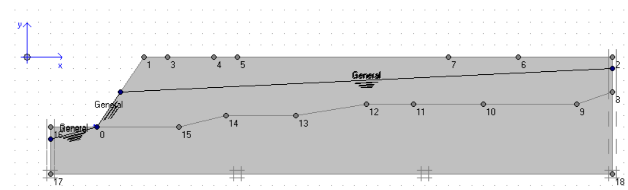


Figure 8 Water levels after heavy rain[1]

When the water level rose, the soil under the ground water level was the highest. This condition increases the stress on the slope and decreases the shear strength resistance. Figure 9 shows how sliding occurs when the slope collapses. It can be seen in Figure 6 that sliding occurs at the side of the slope, and the strain increases to 1.1%. The FOS was calculated to be below than 1.0.

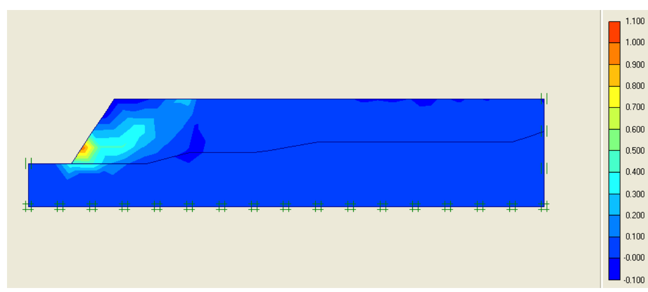


Figure 9 Incremental strains after heavy rain[1]

4.2 Slope Strengthening: Grouting Cement

In the case of the landslide at the highly landfilled site in the Tembalang area, several methods can be used to make the slope more stable, namely (i) by reducing the angle of tilt of the slope (this method called the "unloading" method), (ii) by adding drainage to direct the rain water away from the fill in order to reduce the saturation (this method is known as the "drainage" method), (iii) by placing geotextiles across the direction of landslide (this method is also called the "reinforcement" method), and (iv) by constructing a retaining wall.[7]

However, solving the problem using the first method is not possible due to the limitation of the area and the architecture requirements. The second method (by drainage) can be conducted after finishing the building work. Reinforcement was not an option due to budget constraints, while the construction of a retaining wall can only be started after the rainy season. These situations mean that slope stabilisation work is incomplete when landslides are likely to occur and thus immediate action is required to prevent them before construction damage to buildings worsens.

Therefore, permeation grouting was used to rectify the problem, as the landfill material is granular with high permeability. Grouting was applied where the landslide had caused deformation of the foundations. The equipment used in cement grouting includes a silo, mixer, a 800 kg per square metre high-pressure pump, a compressor with a capacity of 2400 litres per minute and 12 kg per cubic centimetre pressure, a hydraulic plastic pipe, a drilling machine, and a swivel. The process involves ground drilling by penetrating the drilling pipe at 2, 3 and 5 meters deep. After reaching the required depth, grouting cement is forced through the grout pipe. Grouting cement can spread widely at low pressure. Although 1600 kg of cement was injected, there was no indication that the entire void in the soil had been filled.

Even though the increase in shear strength in the cement grouting cannot be properly measured, cement grouting is effective enough to solve the sliding problem. No more slopes have slipped in the same or other locations at the site after grouting. Figure 10 shows the reanalysis of the problems conducted by increasing the strength-strain parameter c (cohesion), since the grouting cement tends to be cohesive. Modeling in this analysis was conducted by continuously modeling after the ground had moved when flooding occurred and modifying the c (cohesion) value gradually until the safety value of the highly landfilled site reached 1, indicating no landslide. The analysis shows that the landfill will be stable when $c = 0.2$ kg/cm^2. This means an increase in strength-strain after a minimum cement-grouting of 33% has been applied and the deformation value is 29.40×10^{-3} m.

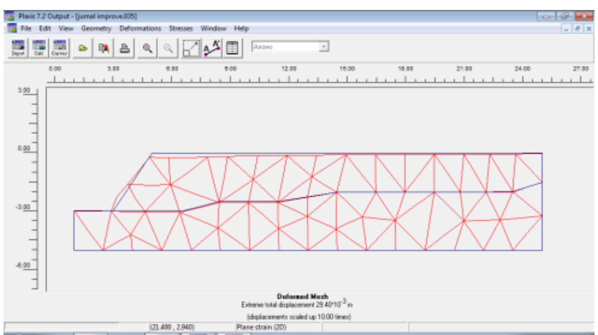


Figure 10 Deformation after cement grouting[1]

The sliding pattern of the occurrence has not reached the upper part of the fill, as shown in Figure 11.

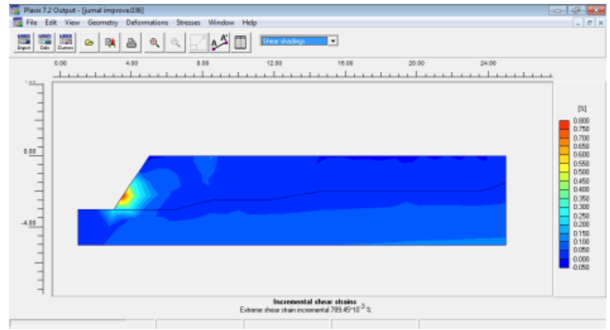


Figure 11 Sliding pattern[1]

Finally, geosynthetic soil reinforcement is another technique used to stabilise slopes, particularly after a failure has occurred or if a steeper than safe un-reinforcement slope is desirable. In addition, it can improve the edge of a slope, thus decreasing the tendency for surface sloughing (Figure 11).

■4.0 CONCLUSIONS

The following conclusions are drawn from this study:

a. Buildings located in hilly areas must be thoroughly and properly planned and designed.
b. Geotechnical and geodetic surveys must be carefully conducted, both at construction and quarrying locations.
c. By surveying adequately, foundations and other structures can be planned and designed without error.
d. Adequate surveys at the quarry will result in suitable soil properties and volume of soil for designing deep landfill.
e. Cement grouting can be considered in landfill slope design if the cement can be mixed with the soil to improve the shear strength.

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