Faculty of Engineering

EFFICIENCY OF VARIOUS PERFORATED PIPE CONFIGURATION IN SLOPE DRAINAGE SYSTEM

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LIST OF SYMBOLS

α	- Geometrical factor
A	- Clean water inlet area inside the pipe per slotted pipe meter
d	- Outside diameter
di	- Pipe inside diameter
d_e	- Equivalent depth that accounts for convergent flow toward the drain
DN	- Nominal diameter
h	- Difference in head
h_e	- Entry head loss
h_h	- Horizontal head los
h_v	- Vertical head loss
h_r	- Radial head loss
h_t	- Total head loss
Hm	- Height of the water table mid-way between drains
H_a	- Average height of the water table above drain level.
K	- Hydraulic conductivity
K_1	- Soil hydraulic conductivity above drain level
K_2	- Soil hydraulic conductivity below drain level
L	- Drain spacing
L_d	- Parallel drain spacing
Li	- Diameter of holes
n	- Number of holes per row
Q	- Steady recharge of water percolating to the water table equal to the drain discharge
q	- Specific discharge
R	- Recharge rate per unit area
W	- Resistance

LIST OF ABBREVIATIONS

PLM	– Pre-wrapped Loose Materials
PA	– Polyamide
PP	– Polypropylene
PE	– Polyethylene
PETP	– Polyester (Polyethylene Terephtalate)
PS	– Polystyrene
AOS	– Apparent Opening Size
ASTM	– American Society for Testing and Materials
BS	– British Standard
CDOH	– Colorado Division of Highways
RRL	– Road Research Laboratory
USBR	– US Bureau of Reclamation
HDPE	– High Density Polyethylene Pipe
HDB	– Horizontal Drainage Borehole
PVC	– Polyvinyl Chloride Pipe

To my beloved family and friends.

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ABSTRACT

Horizontal drains are defined as the holes that drilled into a cut slope or embankment and cased with a perforated metal or slotted plastic liner (Royster, 1980). The effectiveness of the horizontal drain is affected by several factors, such as the length of the pipe, location, spacing, perforation and others. However, there is not much research on the effect of different combinations between perforation pattern and types. Hence, the purpose of this study is to determine and study the effect of perforation patterns and perforation types on slope drainage system on the performance of the horizontal pipe. Several soil tests are conducted before the experiments as to determine the characteristics of the soil sample. There are four experiments conducted with different pipe perforation patterns and types, Experiment 1 (Pattern: Straight, Type: Partial); Experiment 2 (Pattern: Staggered, Type: Partial); Experiment 3 (Pattern: Straight, Type: Full); Experiment 4 (Pattern: Staggered, Type: Full). 25mm diameter with length 60cm HDPE pipes are used throughout all the experiments. The pipes are enveloped with a layer of non-woven geotextile and with quarry gravel acts as the filter material. Pipes are installed with a slope of 5^o from horizontal in the model box with dimensions of 0.25m (w) x 0.56m (l) x 0.25m (h). Rainfall simulator with full cone sprinkler is used to introduce the rainfall event. From the experiment conducted, it can be concluded that partially perforated pipe with straight perforation pattern has the highest discharge, which is 1.017×10^{-5} m^3/s. However, in term of the amount of sediments collected, the partially perforated pipe with staggered perforation pattern in Experiment 2 has the lowest amount of sediments collected, which is 0.049g. Throughout this study, in term of perforation pattern, straight perforation pattern and staggered perforation pattern prove to have their own pros and cons. Meanwhile, in term of perforation type, partially perforated pipe is more effective than fully perforated pipe in term of the discharge and the amount of sediments collected.

ABSTRAK

Parit mendatar biasanya ditakrifkan sebagai lubang-lubang yang ditebuk ke dalam lereng potong atau tambak dan diikat dengan pelapik logam atau plastik berlubang (Royster, 1980). Keberkesanan saliran mendatar dipengaruhi oleh beberapa faktor, seperti kepanjangan paip, lokasi, jarak, perforasi dan lain-lain. Walau bagaimanapun, tidak banyak penyelidikan yang dibuat mengenai kesan kombinasi yang berlainan antara corak dan jenis lubang. Oleh itu, tujuan kajian ini adalah untuk menentukan dan mengkaji kesan corak dan jenis lubang pada sistem perparitan cerun pada prestasi paip mendatar. Beberapa ujian tanah dilakukan sebelum percubaan untuk menentukan ciri-ciri sampel tanah. Terdapat empat eksperimen yang dijalankan dengan corak dan jenis perforasi paip yang berbeza - Eksperimen 1 (Corak: Lurus, Jenis: Separa); Eksperimen 2 (Corak: Staggered, Jenis: Separa); Eksperimen 3 (Corak: Lurus, Jenis: Penuh); Eksperimen 4 (Corak: Staggered, Jenis: Penuh). Paip HDPE dengan diameter 25mm dan panjang 60cm digunakan dalam semua eksperimen. Paip diliputi dengan lapisan geotekstil bukan tenunan dan dengan batu kerikil bertindak sebagai bahan penyaring. Paip dipasang dengan cerun 5° dalam kotak model dengan dimensi 0.25m (w) x 0.56m (l) x 0.25m (h). Simulator hujan dengan penyembur kon penuh digunakan untuk memperkenalkan peristiwa hujan. Daripada eksperimen yang dijalankan, dapat disimpulkan bahawa paip berliang dengan corak perforasi lurus mempunyai pelepasan tertinggi iaitu 1.017 x 10-5 m^3/s. Walau bagaimanapun, dari segi jumlah sedimen yang dikumpulkan, paip separuh berliang dengan corak penebalan berperingkat dalam Eksperimen 2 mempunyai jumlah sedimen terendah yang dikumpul, iaitu 0.049g. Sepanjang kajian ini, dari segi corak perforasi, corak penebalan lurus dan pola perforasi yang dibuktikan membuktikan mempunyai kebaikan dan keburukan mereka sendiri. Sementara itu, dari segi jenislubang, paip berliang separa lebih berkesan daripada paip berlubang penuh dari segi pelepasan dan jumlah sedimen yang dikumpulkan.

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Generally, landslide or slope failure happened due to some factors such as the slope steepness, drainage, vegetation, composition of soil and others. Rainfall considered as one of the cause which trigger the failure of the slope and this is normally happened to the tropical regions such as Malaysia which experiencing frequent and prolonged rainfall that mainly due to the monsoon rainfalls. Based on the study of Danish Kazmi et al. (2016), it stated that the main contributing factors of the landslides in Malaysia are due to the rainfall (**Figure 1.1**).

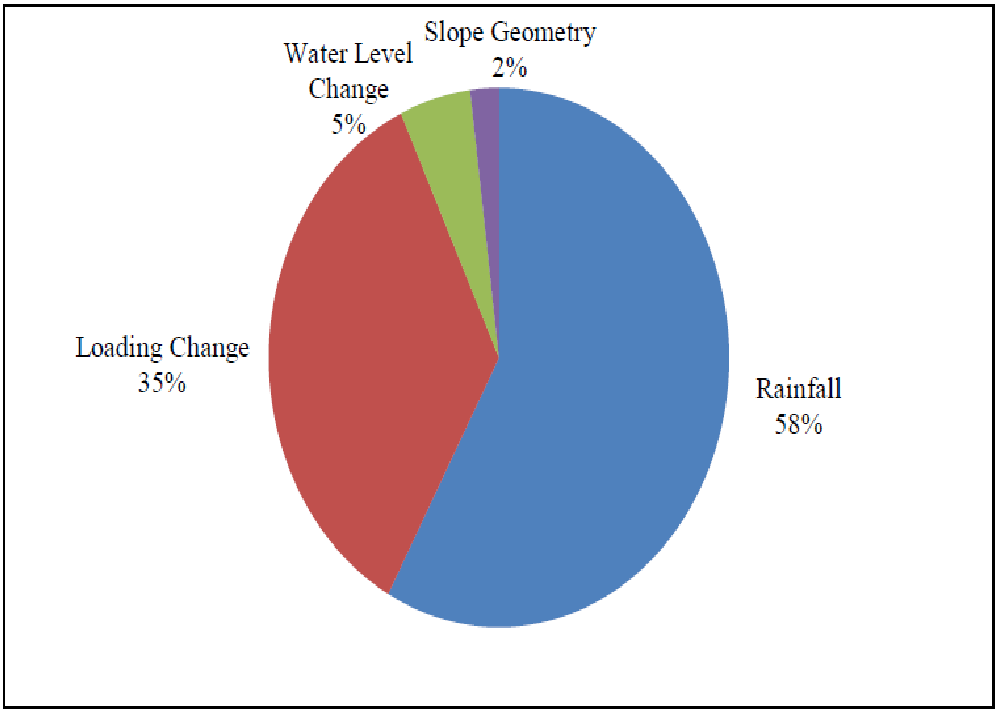

Figure 1.1: Contributing factors to Malaysia landslide
(Danish Kazmi et al, 2016)

There are numerous cases of landslide that happened in Malaysia due to the improper design or insufficient drainage slope system. The examples are the landslide at Precicnt 9 Putrajaya on March 22, 2007 and Puncak Setiawangsa on December 28, 2012. Landslide at Precicnt 9 Putrajaya causes twenty three vehicles buried and it was proved that the main causes of the landslide was due to the rise of the groundwater level and subsequently causes the rise in pressure in water level (Bernama newspaper, 2007 based on Muhamad Mukhlisin & Nurul Aini Abd Aziz, 2016). Meanwhile, for landslide at Puncak Setiawangsa, it was mainly caused by the application of unsuitable slope protection method, shotcrete wall with the purpose of preventing the water from seeping into the soil. However the water still able to seep into the uncovered area without flowing out from the slope and this causes the built up of groundwater pressure. Thus, this trigger the landslide at Puncak Setiawangsa (Danish Kazmi et. al, 2016). Hence, it is important to design a proper drainage system to minimise the possibility of the rise of groundwater level and pore water pressure.

During the intense rainfall periods, the infiltration of the rainwater will contribute to the rise of groundwater level and yet this will then resulted in the increment of the pore water pressure. With the pore water pressure increase, the shear strength of the soil will be reduced and subsequently causing the reduction of the slope stability (Ng & Shi, 1998). No doubt that, few remedial measures or actions have been taken to design, improve and maintain the slope stability and drainage will be one of the best method in improving the slope stability when the slope is subjected to the infiltration causes by the rainfall. Horizontal drain has been recognised as the more economical remedial method to lower the groundwater level by conveyed or transfer the groundwater away to keep to the soil dry (Mohd Ashraf Mohamad Ismail, Ng, and Ismail Abustan, 2017). According to Royster (1980), horizontal drain is able to reduce the excess pore water pressure and lowering the normal water table. Study of Rahardjo, Leong, Hritzuk and Rezaur (2003) has also proved that the water table after installation of horizontal drain are lower compared to the water table without any installation of horizontal drain (Refer to **Figure 1.2**).

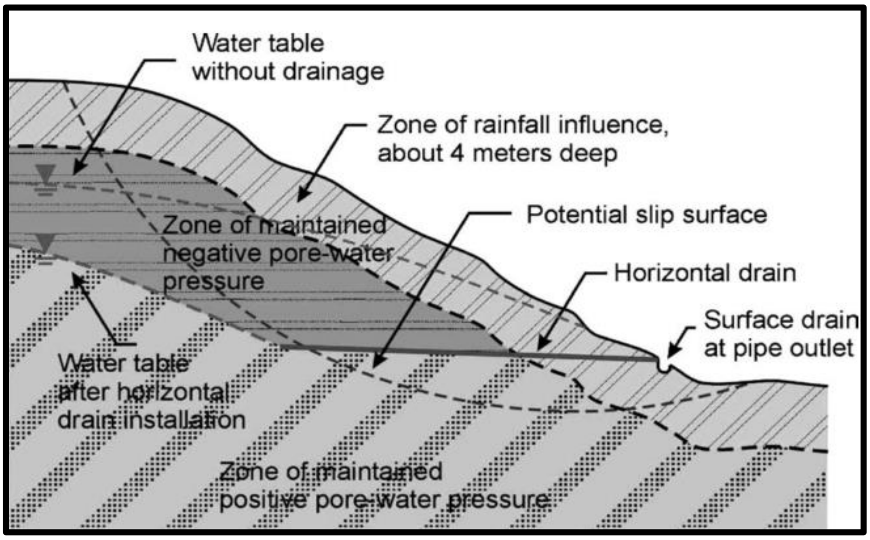

Figure 1.2: Slope model with and without horizontal drain
(Rahardjo, Leong, Hritzuk & Rezaur, 2003)

1.2 Problem Statement

Few studies have been carried out to determine the effectiveness of horizontal drain in enhancing the slope stability (Rahardjo et al., 2003; Pohll et al., 2013; Hassan Mohamed & Gamal Abouzeid 2005) and it is proved that the horizontal drain managed to lower the high groundwater level, yet increase the shear strength of the soil and improve the slope stability. Effectiveness of the horizontal drain is referring to the changes on the factor of safety of the slope in the presence or absence of the horizontal drain. Effectiveness of pipe depends on many factors including the drain location, spacing, length and also soil geometry (Mohamad Ismail et al., 2017).

Rahardjo et.al (2003) investigated the effectiveness of horizontal drains on residual soil slope stability and with outcome that the horizontal drain that located at the base of the slope is more effective in draining out the water and maintain the slope stability. Pohll et al (2013) focuses on effectiveness of drainage system design by considering the effect of drain elevation, spacing and length on the level of water table under steady state recharge using MODFLOW. The result concluded that water table level will drop with the increase in drain length, drain that located at the lowest elevation and shorter drain spacing. Hassan Mohamed and Gamal Abouzeid (2005) investigated the flow behaviour around perforated tile drainage pipes and the result showed that the increase in perforation ratio of pipe will result in the increase in seepage discharge.

Nearly similar theories obtained from the results of various studies by different researchers on several factors which affect the effectiveness of the pipe, such as pipe length (Pohll et al, 2013; Cai, Ugai, Wakai & Li, 1998 and Rahardjo, Satyanaga & Leong, 2012), pipe installation angle (Cornfoth, 2005; Cook, Santi & Higgins, 2012 and Rahardjo et al, 2012), pipe spacing (Cai et al, 1993 and Pohll et al, 2013), location of pipe (Rahardjo et.al, 2003 and Pohll et al, 2013) and perforation of the pipe (Jay, 1999; U.S. Corps of Engineers, 1941; Schwab, 1951; Hassan Mohamed & Gamal Abouzeid, 2005 and Stuyt, Dierickx & Martinez, 2005). Several studies have proved that the perforation of the pipe can affect the effectiveness of the horizontal drain either in size, ratio, shape and location. Based on Lane HDPE PERFORATION GUIDE (n.d.), partially perforated pipe is commonly been used for subsurface drainage. Generally, pipe with the combination of straight perforation pattern with partially perforation are used. However, the effectiveness and performance of the pipe with the combination of different perforation pattern such as staggered perforation pattern with different type of perforation such as partial perforation or fully perforation are still not been deeply investigated. The arrangement of perforation in staggered pattern might has the higher capability in capturing the water. Therefore, it is important to understand the effect of different combination of perforation pattern and perforation type on the effect of inflow and outflow of the drain.

1.3 Project Objectives

This study is focused on the effect of different perforation patterns and perforation types on pipe on the effectiveness of the slope drainage system. In this study, the effect on the inflow rate of water entering the perforated pipe and outflow rate of the water exit from perforated pipe and also the mass of sediments collected from the water discharged due to i) different perforation type (Partially and Fully) and ii) different perforation pattern on pipe (Straight and Staggered) will be investigate.

1.4 Scope of Study

This study is aimed to determine the effect of different perforations pattern on horizontal pipe on the effectiveness of the drainage system in the slope in term of the inflow and outflow rate. The results and the data are obtained based on the experiments which is conducted in Geotechnical Engineering Laboratory, UNIMAS. In this study, the focus on perforation pattern for both partially perforated and fully perforated pipe are made, however, the clear water inlet area inside the pipe (open area) is set to be constant for each partially and fully perforated pipe. This study is the continuous study of Yong, Taib and Selaman (2017) and Edwin (2016).

1.5 Significance of Study

This study provides the understanding on the relationships between the slope drainage system and the stability of the slope. As Malaysia is a tropical country with seasonal rainfall that prone for the occurrence of the landslide which subsequently resulted in the rise of groundwater level and water pore pressure, hence some slope stabilisation method like the installation of horizontal drain need to be taken into consideration. Cases such as the landslide at Precicnt 9 Putrajaya and also Puncak Setiawangsa are mainly occurred due to the insufficient or improper slope drainage system which resulted in the loss of life and property. Thus, it is important to design a drainage system which can lower the groundwater level and pore water pressure efficiently through the efficient in discharging the infiltrated water.

1.6 Organization of Study

This study consists of five chapters. Chapter 1 will be related to the background of the study, problem statement, project's aim and objectives, scope of study and also significance of study.

Second chapter is reviewing the previous studies on the horizontal drains. Besides that, it also review the subsurface drainage design formulas applied in designing the drainage. It also reviews the parameters that affect the efficiency of the drainage in slope such as length, angle, spacing and also drain envelope.

Aside from that, Chapter 3 discusses the methodology, materials and data collection of the experiment for this study. All the parameters such as the location, length and angle of the drain are stated in this chapter. Furthermore, the flow chart of this study is presented in order to show the exact flow or sequence of work in conducting the experiment.

Chapter 4 discusses all the collected data and results based on the experiments carried out for the five different soil tests and also the test of horizontal drain in different perforation patterns and perforation types. The different discharge rate that cause by different combination between perforation patterns and types are discussed in this chapter.

Chapter 5 provides the conclusion and suggestions for future works and improvement to be made for the horizontal slope drainage system

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Planning and designing of an effective horizontal drain required the consideration of various parameters such as the drain location, size, spacing, depth, soil types, slope angle of the drains and others. In this chapter, more focus will be placed on the length, angle, size, arrangement of the pipe, pipe perforation, drain envelope, filter and spacing between drains in order to design an effective horizontal slope drain.

2.2 Background of Horizontal Slope Drain

Rainfall is recognised as one of the major contributors to the failure of slope. Hence, it is essential to remove the infiltrated rainwater or groundwater from the slope to keep the soil in the dry state as well as to improve the slope stability. Installation of the horizontal drains are normally been used by most of the engineers to perform the task of lowering the water table level and drain out the groundwater from slope due to its efficient and more economical dewatering option.

Horizontal drains are defined as the holes that been drilled into slope and is then cased with the perforated metal or slotted plastic liner (Royster, 1980). In Hong Kong, the earliest drain type that been used was the slotted PVC pipe with an impermeable invert and wrapped with typically 1mm plastic mesh or nylon 'fly screen' filter as shown in **Figure 2.1**. The liner with a diameter of 75mm diameter PVC pipe was then installed within the casing and the casing was removed once installation of liner was done. For the perforated section, generally the options were either be the 6mm wide slots at about 25mm centres, or 20mm holes diameter at about 75mm centres on top surface of the PVC pipe.