A STUDY ON THE CHARACTERISTIC AND PERFORMANCE OF CASCADE DRAIN IN MALAYSIA

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ABSTRACT

Cascade drain is one of the hydraulic structures that are widely used in slope condition area. The functions of cascade drain are to control and convey flows from surface runoff at upstream to downstream. The advantages of cascade drain are the simple, economic and rapid construction procedure plus the aforementioned economic savings. The aims of this study are to study the characteristic and performance of cascade drain for the working and the behaviour. There were three different types of cascade drain which are horizontal step, end sills step and inclined step. The dimensions of every cascade drain are recorded. The discharge values were calculated using Rational Method and been compared with the Manning's Equation. The drop length of water while raining was recorded and the Froude number were calculated to determine the hydraulic jump. From the comparison among three different types of cascade drain, the most sufficient cascade drain with the best jump is the horizontal step cascade drain. Horizontal step cascade drain provided a short length for each step that influence the distance of jump.

ABSTRAK

Longkang lata adalah salah satu daripada struktur hidraulik yang digunakan secara meluas di kawasan berbentuk cerun. Fungsi longkang lata adalah untuk mengawal dan memastikan aliran di permukaan hulu mengalir ke hilir dalam aliran yang terkawal. Kelebihan longkang lata adalah mudah dilaksanakan. Prosedur pembinaannya yang jimat dan memberikan penjimatan ekonom. Matlamat kajian ini adalah untuk mengkaji ciri-ciri dan prestasi longkang lata untuk kegunaan dan sifatnya. Terdapat tiga jenis longkang lata iaitu jenis rata melintang, panjang dan condong. Dimensi setiap longkang lata direkodkan. Nilai pelepasan telah dikira menggunakan Kaedah Rasional dan telah dibandingkan dengan Persamaan Manning. Panjang air yang jatuh antara satu anak mata longkang ketika hujan dicatatkan dan nombor Froude telah dikira untuk menentukan lompatan hidraulik. Dari perbandingan diantara ketiga-tiga jenis longkang lata, longkang lata jenis rata melintang paling mencukupi sifat sebagai longkang lata yang sesuai di Malaysia dengan lompatan hidraulik yang terbaik. Kepanjangan langkah mendatar longkang lata adalah pendek untuk setiap langkah dan ini mempengaruhi jarak lompatan.

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SYMBOLS	TITLE
LPT :	Lebuhraya Pantai Timur
FR :	Federal Road
FRL :	Finished road level
MSMA :	Urban Stormwater Management Manual for Malaysia
RCC :	Roller compacted concrete
Fr :	Froude number
t_c :	Time of concentration
m^3/s :	Meter cube per second
m :	Meter
cm :	Centimetre
SWD :	Storm Water Drainage
mm/hr :	Millimetre per hour
m^2 :	Meter square

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Generally, the cascade drain is formerly used in the dam structure as the stepped spillway. Then, the cascade drain design is developed and widely used in other hydraulic design. The cascade drain consists of a series of steps or drops that built into the spillway. The cascade drain is widely used at the slope areas which have the different level and height of soil. This situation allows the water flow from upstream to downstream. This is especially true at road constructed in sloping area in order to manage and divert the natural flow of water.

Basically, cascade drain can be classified as the spillway type because it has similar function. The main function of the cascade drain is to manage and control the flow of water on the earth surface from upstream to the downstream area. It effectiveness can be visualised during rainy day. The water from the precipitation process will flow in the cascading drain at a specific flow rate. This depends on the precipitation rate which is the rainfall and the area of cascade drain. In addition, the flow in the cascade drain allows the hydraulic jump, an abrupt change in depth from supercritical to subcritical flow.

1.2 Problems Statement

The cascade drain is used to manage the flow of water approximately from upstream to downstream area. The cascade drain is fully function at when the precipitation process occurs which is during the raining day. The main problems usually happen when the cascade drain cannot handle the high volume and flow rate of the water from the heavy rain. The heavy rain increase the flow rate of water in the cascade drain and thus, creating uncontrolled flow. Theoretically, the flow must follow the steps without surpasses. This high flow rate will eventually affect the hydraulic jump performance and increase the distance of the hydraulic jump in the cascade drain. The uncontrolled distance of hydraulic jump can surpass the flow over the steps.

In addition, the flood will occur when the flow is not contained within the cascade drain structure. The uncontrolled flow will decrease the ability of cascade drain to flow the water smoothly and decrease the storm water management system function. The storm water management is constructed beyond the structure in order to convey the flow downstream to the river. This over flow can disturb the road user. The water will splash to the finished road level (FRL) near the road side and creates water ponding. This water ponding is a non cohesive area that will reduce the friction of tyres on the road and make the vehicle becomes difficult to handle. These phenomena can cause accident to road user when driving in a high speed.

Hence, it is essential to ensure the design of cascade drain in Malaysia is follow the specification to avoid the cascade drain become uncontrolled and over flow that can make a flood. This study will identify the problems that occur at the cascading drain structure. It will also increase the road ability and road user safety.

1.3 Objectives

The objectives of this study are:

i. To determine the existing design and characteristics of cascade drain in Malaysia.

ii. To determine the suitable types of cascade drain to be used in Malaysia.

1.4 Scope of Study

The case studies of the project were selected from five different locations at the Kuantan district in Pahang state due to its convenience and easy access. The comparisons among the three different types of cascading drain at these six locations were taken in order to study their different performances.

The five locations of case study are:

- Cascade drain type A: Horizontal Step
  Case Study 1 - Kuantan RC 0.0 km Lebuhraya Pantai Timur (LPT) Kuantan-Gambang
  Case Study 2 - 1.2 Km from roundabout Taman Desa Aspa (FR 14)

- Cascade drain type B: End sills Step
  Case Study 3 – Km 232.4 Lebuhraya Pantai Timur (LPT) Kuantan-Gambang
  Case Study 4 – Batu 12, Kuantan-Gambang Road in front of Binaan Desjaya Sdn. Bhd

- Cascade drain type C: Inclined Step
  Case Study 5 - 9 Km from Kuantan-Kemaman Bypass junction at Gambang-Kuantan Road (FR03)

The surface runoff discharge were determine using the rational method while the drop length of cascading drain were calculated using drop length function that stated in Urban Stormwater Management Manual for Malaysia (MSMA, 2000).

The implementation of the study is to ensure that the jump is within the allowable distance in order to avoid surpassed. The allowable distance of jump reduced the water flow rate and work as the energy dissipater for the cascade drain. Moreover, it will control and manage the flow within the cascading area from upstream to downstream.

Besides that, the allowable distance will help to control the flood phenomena at the road side. The uncontrolled flow of water on the road is very dangerous and can cause an accident. Thus the cascade drains were built to control the flow and reduce the accident on the road downstream.

This study will enhance the development of the cascade drain structure in highway and other hydraulic design in the construction field.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Cascade drain is one of the hydraulic structures that commonly used to control the flow from upstream to downstream in a drainage system. Cascade drain is a drainage that consists of series of steps and can be in any shape. The existing of steps can contribute to a substantial flow resistance and the place where energy dissipation happen form drag process. The flow acceleration and boundary layer on the stepped also can affect the flow properties significantly (Peruginelli , 2000)

Open channel flow occurs when there is a free surface that exposed to atmospheric pressure (Larry, 2005). Open channel flow assumes that the pressure at the surface is constant and the hydraulic grade line is at the surface of the fluid. Examples of open channel flow include streams, rivers and culverts not flowing full. It is difficult to solve the problem from open channel because the flow conditions are complicated by the position of the free surface which will change with time and surface. Open channel can be in any shape (Blair, 1990).

2.2 Cascade drain

The cascade drain was formerly introduced as the stepped spillway that commonly use at the dam structure. Then, the stepped concept has been developed and widely use in many hydraulic design because it can function to discharge the water flow and works as the energy dissipater. An interesting feature of the cascading drain is a series of steps or drops system which is flexibility by allowing differential settlements of the embankment (Chanson, 2002).

2.2.1 Functions

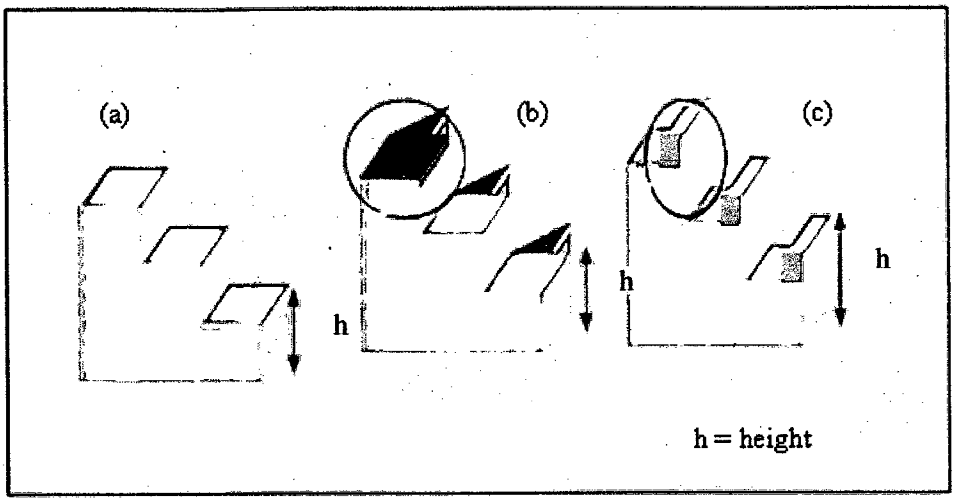
Generally, the function of the cascade drain is to control and manage the flow of water from the precipitation process. The cascade drain is fully functioning during the precipitation process where any form of water such as rain that falls from the sky to the earth surface. The water that fall to the ground surface will be channeled and controlled by the cascade drain from the upstream to downstream. This phenomenon usually occurs at the slope conditions where the different heights of soils are observed.

The other function of cascade drain is to discharge the water flow over dams or steep slopes and works as the energy dissipater. The steps produce considerable energy dissipation along the chute and reduce the size of the required downstream energy dissipation basin. The main influencing factors for the energy dissipation ratio in stepped spillways are unit discharge, slope condition and height of step. The energy dissipation ratio decreases with the increase in the unit discharge and increases as the slope becomes gentle.

2.2.2 Types of Cascade drain

Basically, the cascade drain was constructed with series of steps into the drain. The area on to which the water falls from each step is built to resist the force of the falling water. Cascade drains are practical if the slope exceeds 30%, but otherwise they become too expensive. There are various types of stepped chutes which were horizontal steps, inclined steps, and steps with end sills and were show in Figure 2.1.

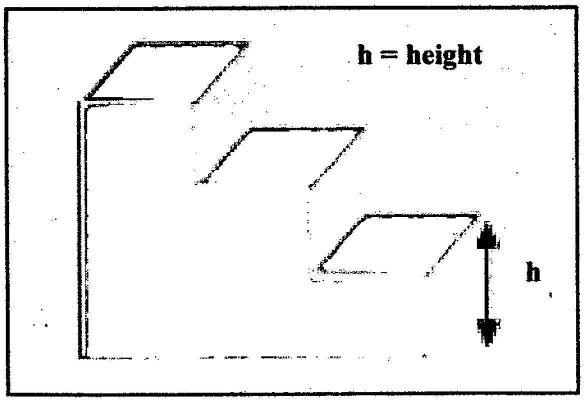
Figure 2.1 : The types of cascade drain (a) Horizontal Steps, (b) Inclined Steps and (c) End Sills steps



2.2.2.1 Horizontal steps

The horizontal steps drain were used to slow down the flow of water from the upstream before the flow reach the downstream area. This type of drain was built at the steep slope with the specific degree. The advantages of this drain are very easy to construct and economical. The cross section of horizontal cascade drain was depicted in Figure 2.2 where h is the height of step (Barani, et. al, 2000).

Figure 2.2 : The horizontal steps

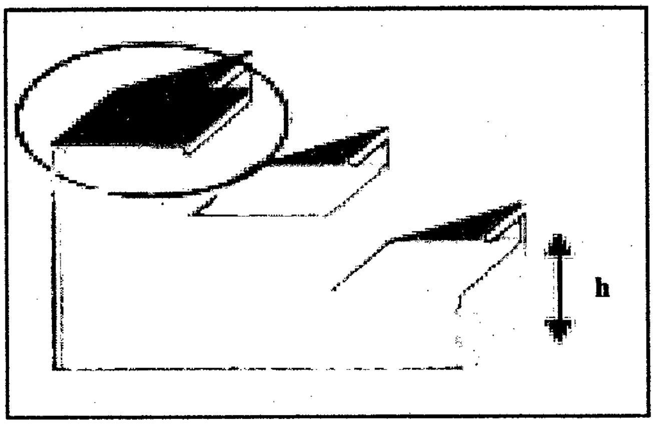


2.2.2.2 Inclined steps

The structures of step are all the same but the additional structure in shape of triangular was placed on top of the steps. The water flow from upstream will experience the inclined situation on the first step before flow to the next step and continuous flowing to the downstream area. This extra structure provided an extra height of step and will influence the discharge of water (Chinnarasri, et. al, 2004).

Figure 2.3 shows the examples of inclined, h is height of step.

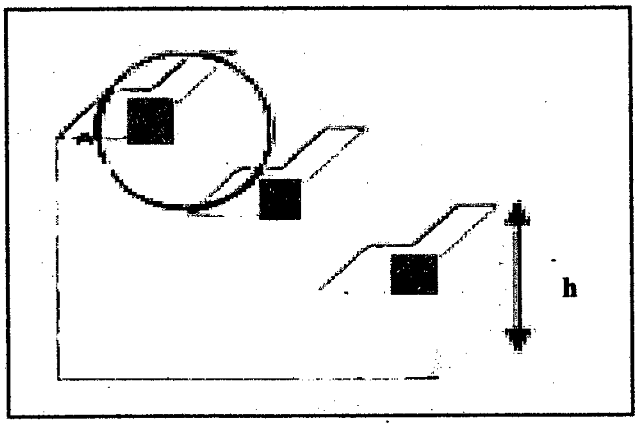
Figure 2.3 : The inclined steps



2.2.2.3 Steps with End Sills

The characteristic of steps with end sills is the additional of rectangular structure on top of each step provided. Those rectangular were function as the weir for the cascade drain by reducing the flow of water. The advantage of this step is it can prevent scouring of the channel bottom. The example of end sill step drain was shown in Figure 2.4 (Chaturabul, et. al, 2000).

Figure 2.4 : The End Sill steps



The steps with end sills seem to be the most efficient configuration in terms of relative energy dissipation. The effect of number of steps is evident since the relative energy loss increases with the number of steps. In addition, new correlations showing the relation between relative energy loss and relative critical flow depth are proposed for practical applications.

2.2.3 Design Considerations

There are several considerations that should be included in designing cascading drain and stilling basins.

i. Surface Runoff

   The high precipitation will cause a rise in the upstream water surface. The available of surface runoff will depend on the topography and rainfall at the area. The runoff will flow to the cascade drain which utilize all of the available runoff and create the design discharge, since the discharge increase with the value of intensity from the rainfall and surface runoff.

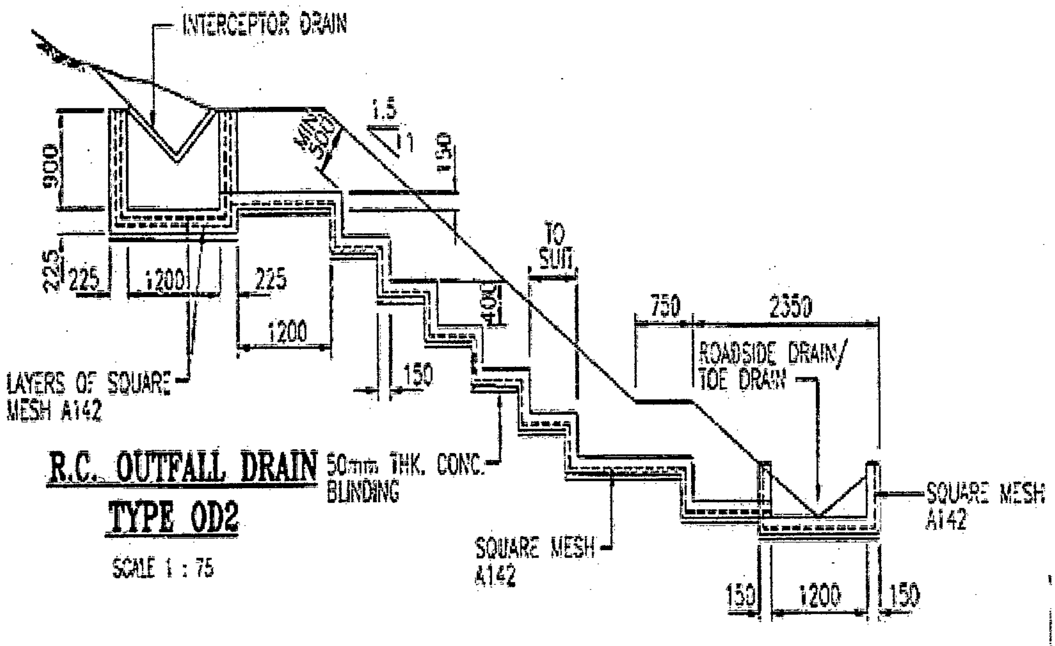
ii. The Hydraulic jump

   There are three positions or alternative patterns that allow a hydraulic jump to form downstream of the transition in the channel. These positions are controlled by tail water (MSMA, 2000).

For design purposes in roadside channels, hydraulic conditions are usually assumed to be uniform and steady. This means that the energy slope is approximately equal to average ditch slope, and that the flow rate changes gradually over time. This allows the flow conditions to be estimated using a flow resistance equation to determine the so-called normal flow depth.

The standard design of cascade drain in Malaysia with the dimension was shown in Figure 2.5.

Figure 2.5 : Standard design of cascade drain. (Public Work Department, 2000)



2.2.4 The Advantages of Cascade drain

In hydraulic engineering the energy dissipation capacity of spillways and energy dissipaters is a key element to minimize the erosion potential of the flow downstream of a dam and thus to ensure its stability against failure during floods.

Stepped spillways allow to continuously dissipating a considerable amount of the kinetic energy such that the downstream stilling basin where the residual energy is dissipated by hydraulic jump can be largely reduced in dimension compared to a basin at the toe of a conventional smooth chute.

Also, the cavitations risk along the spillway decreases significantly due to smaller flow velocities and the large air entrainment rate. Stepped spillways or cascades are thus a combination of spillway chute and energy dissipater.

They are preferably applied for dam spillways or combined sewer systems for the safe discharge of water over large drops. Basically, the cascade drain is often combined with the spillway of the dam. They are also used in parks and are suitable to the type of river course design improving natural surroundings.

The cascade drain will flow the water from level to level and the optimal dissipation is expected if a hydraulic jump occur. The skimming flow occurs for steeper stepped chutes and large discharges in which the step acts as roughness element and causes a strong mixing of the water with air.

Stepped spillways have regained popularity over the last two decades thanks to financial benefits resulting mainly from:

1. The simple, economic and rapid construction procedure, especially with the roller compacted concrete (RCC) construction method.
2. The aforementioned economic savings with the downstream energy dissipater due to the high amount of energy dissipation along the chute.

The roller compacted concrete (RCC) placement in layers enables a simultaneous and thus economic construction of the spillway steps on the downstream dam face. Another common application is the use of stepped overlays on the downstream face of hydraulically unsafe embankment dams as emergency spillways to safely pass a flood over the crest of the dam (Michael et. al, 2005).

The macro-roughness of the steps significantly reduces flow velocities and leads to flow aeration along the spillway. In contrast to conventional smooth spillways the cavitations risk is therefore markedly reduced.

2.3 Flows in Cascade drain

For design purposes in roadside channels, hydraulic conditions are usually assumed to be uniform and steady. This means that the energy slope is approximately equal to average ditch slope, and that the flow rate changes gradually over time. This allows the flow conditions to be estimated using a flow resistance equation to determine the so-called normal flow depth (Mays, 2005).

Flow conditions can be either mild (subcritical) or steep (supercritical). Supercritical flow may create surface waves whose height approaches the depth of flow. For very steep channel gradients, the flow may splash and surge in a violent manner and special considerations for freeboard are required.

More technically, open-channel flow can be classified according to three general conditions:

- Uniform or non-uniform flow
- Steady or unsteady flow
- Subcritical or supercritical flow

In uniform flow, the depth and discharge remain constant along the channel. In steady flow, no change in discharge occurs over time. Most natural flows are unsteady and are described by runoff hydrographs. It can be assumed in most cases that the flow will vary gradually and can be described as steady, uniform flow for short periods of time.

Subcritical flow is distinguished from supercritical flow by a dimensionless number called the Froude number (Fr), which is defined as the ratio of inertial forces to gravitational forces in the system. Subcritical flow ($Fr < 1.0$) is characterized as tranquil and has deeper, slower velocity flow. In a small channel, subcritical flow can be observed when a shallow wave moves in both the upstream and downstream direction.

Supercritical flow ($Fr > 1.0$) is characterized as rapid and has shallow, high velocity flow. At critical and supercritical flow, a shallow wave only moves in the downstream direction (Morris, 2009).

2.4 The Hydraulic Jump

Generally, the hydraulic jump can be defined as an abrupt change in depth from supercritical to sub-critical flow and accompanied by a significant energy loss. Usually, a hydraulic jump primarily serves as an energy dissipater to dissipate the excess energy of flowing water downstream of hydraulic structures such as spillway, cascading drain and sluice gate.

The rapidly flowing liquid expands which in an open channel appears as an increase in elevation that converting some of the initial kinetic energy of flow into a lower kinetic energy and an increasing of potential energy and the remainder to irreversible losses. Moreover, this phenomenon dependent on the initial fluid speed and if the initial fluid speed is below the critical speed then no jump is possible.

For relatively low initial flow speed which is above the critical speed an undulating wave appears. When the flow speed increases further the transition grows more abrupt and at high enough speeds the front will break and curl back upon itself. This rise can be accompanied by violent turbulence, eddying, air entrainment and surface undulations.

The Figure 2.6 below shows how the hydraulic jump occurs. The existing of hydraulic jump will decrease the flow rate of the water. Next, hydraulic jump can works to recover head or raise the water level on the downstream side of a measuring