THE EFFICIENCY OF A DEPRESSED GULLY INLET OF A MALAYSIAN DRAIN

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By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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ABSTRAK

Kajian ini dijalankan untuk mengkaji kesan lekukan dan kecekapan pengairan galur di Malaysia. Galur direka untuk mengumpul air saliran hujan sebelum ia disalirkan ke sistem saliran peparitan. Kebiasaanya, reka bentuk galur adalah kecil, tegak dan sering diletakkan bersebelahan dengan jalan raya dan persimpangan jalan. Objektif pertama bagi kajian ini adalah untuk menentukan prestasi hidraulik sistem galur melalui reka bentuk, kecerunan dan aliran yang berbeza. Objektif kedua ialah untuk menentukan kadar ketinggian air bagi sistem galur yang berbeza . Oleh itu, dalam skala penuh satu model fizikal terdiri daripada pelantar ujian dengan tangki masuk dan tangki kelaur di kedua-dua hujung pelantar telah direka untuk menggambarkan interaksi hidraulik antara di atas dan di bawah Sistem perparitan tanah melalui galur dan kawasan tadahan. Dalam kajian ini mempunyai tiga keadaan sistem galur yang pertengahan dan penuh. Keadaan pertengahan adalah suatu keadaan, yang membolehkan sebahagian daripada menghampiri dalam aliran ke aliran melepasi sistem ke dalam galur yang seterusnya, manakala bagi keadaan penuh terdapat sejumlah besar tiada mana-mana aliran melalui. Ujian ini juga dijalankan dalam beberapa bentuk kecerunan untuk menunjukan keadaan berbeza di jalan raya.

ABSTRACT

This study was conducted to study the effect of depression on the efficiency of a gully inlet of a Malaysian drain. Stormwater inlets or gullies are designed to collect rainfall runoff before it is drained into a storm drainage system. Usually, the design of gullies is small, vertical and often placed next to street curbs and road intersections. The objective of this study is to determine the efficiency on the hydraulic performance of a gully system with different longitudinal bed slope and cross slope under different flow conditions in order to determine the head-discharge relationship of the grates used. Therefore, a full scale physical model comprising of a testing platform with an inlet tank and an outlet tank on both ends of the platform has been designed to reflect the hydraulic interaction of the gully inlets and the designated catchment area. In this study, two types of systems were tested which were intermediate and terminal. The intermediate condition is a condition, which allows some of the approaching flow to flow past the system into the next downstream gully, while for the terminal condition there is no any significant amount of flow to pass through. The results obtained from the tests are presented in the form of head-discharge relationship and the efficiency of the grates were established.

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NOMENCLATURES

S_L	Longitudinal slope
S_x	Cross slope
n	Manning's roughness coefficient
Q	Total discharge
Q_i	Discharge intercepted
Q_b	Bypass flow
E	Efficiency

CHAPTER 1

INTRODUCTION

1.1 Introduction

Stormwater inlets or gullies are designed to collect rainfall runoff before it is drained into a storm drainage system. When heavy rainfall and flood event occurs, the excess flow is drained into a storm drainage system through gully grate from the surface to below ground, however, drainage systems might be pressurised, and the flow may surcharge through the gullies and manholes. This phenomenon is usually called reverse flow (Lopes et al., 2012).

Only some of the water may flow into the pipes and a large volume of runoff will be transported to the surface during and/or after a heavy rainfall, if the intake capacity of the drainage system is limited. This might occur even if the underground drainage system has sufficient capacity. The water in the drainage may return to the street if the capacity of the inlet is insufficient. For these case the water will flow from the drainage to the street, causing surface flooding (Mark et al. 2004).

1.2 Background and Problem Statement

The hydraulic capacity of a stormwater inlet depends upon its geometry and characteristics of the gutter flow. Inlet capacity controls the rate of water discharge from the gutter and the amount of water that can enter into the storm drainage system (Stewart et al. 2006). The surcharge flow can cause the water to rise to a level above the surface where water might escape from the drainage system or interrupt surface water from entering the drainage system (Schmitt et al., 2004).

During storm events, solids such as trash deposited on above-ground surfaces gain access to the drainage system mainly by suspension in the runoff. Solids transport to the gully takes place mainly by the release of surface deposited solids by rainfall, with surface runoff entering the system during storm events. Other causes include the action of the wind and vehicle-generated turbulence and vibration (Butler et al.,1994).

Numerical and experimental studies on gullies are uncommon because of performing the calibration is difficult and cost of the experimental facilities(Leandro et al. 2014). Seeing that there are different in the geometry of gullies in different countries, and it will affect the efficiency of gullies. There is a lack of understanding and research regarding the performance of gully inlets in term of efficiency especially in Malaysia. The efficiency of gully inlet might be reduce due to poor design of gully grate in term of (spacing between grate, shape of gully grate and the depressed gully grate). Therefore, this study was proposed to get establish an understanding of the performance of grates in term of efficiency.

1.3 Objectives

The objective of this study are:

- To determine head-discharge relationship of the hydraulic grates used.
- To determine the efficiency of a gully system with different longitudinal bed slope and cross slope under different flow conditions.

1.4 Scope of Work

The scope of this research is to study the effect of depression on the efficiency of a gully inlet of a typical Malaysian drain. The experiment was tested with variables slope, the geometry of gully grates and flow condition.

- **Longitudinal Slope**

  Three longitudinal slopes (S_L) were used – horizontal, 1 in 100 and 1 in 50 were used to reflect the different type of road conditions.

- **Cross slope**

  One cross slope (S_x) were used in this study which is 1 in 80.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Stormwater inlets or gullies are designed to collect rainfall runoff before it is drained into a storm drainage system. Usually, the design of gullies is small, vertical and often placed next to street curbs and road intersections (Carvalho et al., 2011). Gullies are commonly located in gutter sections, paved medians, and roadside. Gully-pots are typical features in urban drainage systems, gully-pots were installed for retaining larger particles and hence reduce the clogging problem in drainage system (Deletic et al. 2000).

According to Urban Stormwater Management Manual for Malaysia 2nd Editon (DID, 2012) gullies are used to collect runoff and discharge it to the downstream drainage system. The hydraulic capacity of stormwater inlet is influenced by the geometry and the characteristics of the gutter flow. Inlet capacity control both the discharge rate of water from the gutter and the rate of water that can intercept through the gully grate and enter the drainage system.

In the process of modelling and managing the inflow of stormwater into storm drainage system and infiltration into drainage, the understanding of these processes are necessary to predict these flow are operating under a ponding situation or subjected to a flowing state (Mustaffa et al.2006). A study by Mustaffa et al., (2006) proved that the flow through stormwater inlets can be calculated using the orifice equation with a coefficient of discharge as long as the grating are submerged.

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Numerical and experimental studies on gullies are uncommon because performing the calibration is difficult and the cost of the experimental facilities is high (Leandro et al. 2014). There are different geometry of gullies in different countries, including Malaysia. To date, there are no standard design and significant amount of experimental data (to the authors' knowledge), to determine and hence understand the performance in terms of hydraulic capacity of these gullies. Therefore, this study was proposed to fill in the gap of knowledge in terms of efficiency of a gully inlet of a typical gully used in Malaysia.

2.2 Open-Channel Flow

Open-channel flow is a flow in a channel that open to the atmosphere, an open-channel flow includes liquids typically water or wastewater, that are exposed to gas (usually air), which is at atmospheric pressure. Open-channel flow is a flow such as the flow of water in rivers and flood, as well as the draining of rainwater off highways, parking lots, and roofs (Cengel and Cimbala, 2014).

Flow in open-channels can be classified as steady and unsteady flow, depending on how the flow depth, which is the distance of the free surface from the bottom of the channel measured in the vertical direction along the channel (Cengel and Cimbala, 2014). In an open channel, steady flow conditions may be achieved when the discharge and boundary conditions remain constant for a reasonable period of time. (Leng and Chanson, 2017)

2.3 Gully Grating

Inlets used for the pavement drainage of surfaces can be divided into the following classes, which are grate inlets, curb-opening inlets, slotted inlets and combination inlets. Grate inlets comprise of an opening in the gutter covered by a grate. Curb-opening inlets are vertical openings in the curb covered by a top slab. Slotted inlets comprise of a pipe cut along the longitudinal axis with bars perpendicular to keep up the opened opening. Combination inlets consist of both a curb-opening inlet and a grate inlet placed in a side-by-side configuration, but the curb-opening may be located in part upstream of the grate. (DID, 2012). Figure 2.1, shows the example of major inlet types used in Malaysia.

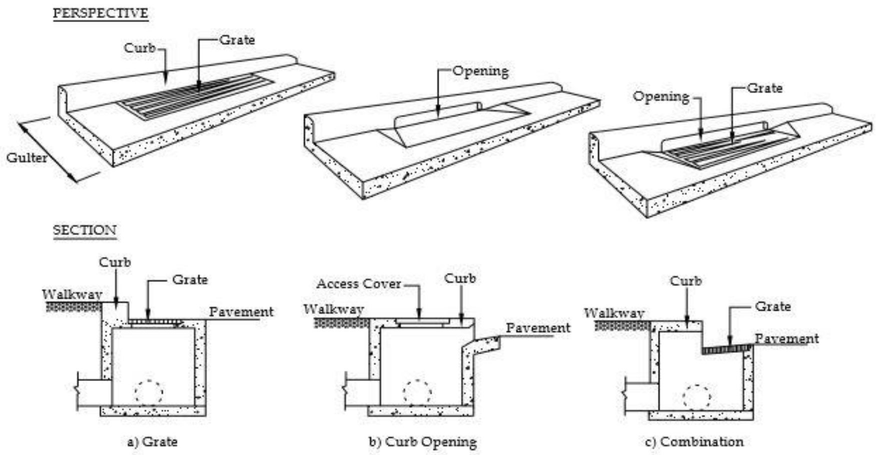

Figure 2.1. Major inlet types used in Malaysia (DID, 2012)

Based on BS 7903 the portion of the total waterway area within 50 mm of the curb should not be less than 45 cm^2. Gullies are commonly rectangular or triangular with one side adjacent to the curb. Circular gullies, and any other shapes that are highly asymmetric in a direction transverse to the curb, are unlikely to be acceptable. The curb face of the frame should be hard against the curb (Manual and Roads n.d.).

Grate inlet is effective road pavement drainage inlets because it can handle clogging due to debris. Table 2.1, shows grates ranked for susceptibility to clogging based on laboratory tests (DID, 2012).When the velocity approaching the grate is less than the "splash-over" velocity, the grate will intercept essentially all of the frontal flow. Besides, when the approaching flow velocity exceeds the "splash-over" velocity for the grate, only a portion of the flow will be intercepted, whereas a part of the flow along the side of the grate will be intercepted, dependent on the cross slope of the pavement, length of the grate, and the flow velocity.

Table 2.1 Average Debris Handling Efficiencies of Grates (DID, 2012)

Rank	Grate	Slope Longitudinal	
		0.005	0.040
1	Curve Vane	46	61
2	30°85 Tilt Bar	44	55
3	45°85 Tilt Bar	43	48
4	P – 50	32	32
5	P – 50 x 100	18	28
6	45°60 Tilt Bar	16	23
7	Reticuline	12	16
8	P-30	9	20

For urban drainage system, stormwater inlets are one of the important parts, because of their role to control the amount of water conveyed from the ground surface to drainage system. The capacity of inlets, therefore, affects efficiency and reliability of the whole storm drainage system. The term inlet capacity defines the largest quantity of gutter/overland flow that can be captured by the inlet. This definition assumes that the functionality of the inlet is not affected by conditions in manhole, pipe or any other device, or by backwater effects and surcharging. Inlet capacity depends on the longitudinal and cross slope of the street, position and size of curbs and pavement roughness (Despotovic et al. 2005).

Two types of inlets can be classified in terms of location for the stormwater drainage system, which is in-sag and on-grade inlets. The latter intercepts only a portion of the total gutter flow, while the former is typically designed to capture 100% of the inflow, determined as the surface runoff from local drainage basin plus any bypass flows from upstream inlets. Proper maintenance and attention should be given to the flow of drainage water through sag inlets, because they frequently encounter water ponding, which tends to increase the water spread over the road pavement (Almedeij et. al., 2006).

2.4 Hydraulic Capacity

The hydraulic capacity of a storm drainage inlet depends upon its geometry as well as the characteristics of the gutter flow. Inlet capacity governs both the rate of water discharge from the gutter and the amount of water that can enter into the storm drainage system (Russo et. al.,2006). An inlet may operate like a weir when the water depth is shallow and not submerged, or like an orifice when it is submerged. Among various types of street inlets, grates are considered to be most efficient in both hydraulic performance and trash control (Guo, 2000).

For inlet capacity, there are three main parameters affecting the capacity of inlets in the roads/streets (Despotovic et al. 2005):

- Cross slope . This parameter is an adjustment between two demands, which is a need for efficient removal of storm runoff (need for an increased lateral slope), and need for safe and comfortable traffic (need for a decreased lateral slope). Small slopes are acceptable only on streets with a gutter. For roads without gutters, it is not advisable to have long parts with small lateral slopes.
- Longitudinal street slope. For streets with small lateral slope, and especially when curbs are present, zero longitudinal slopes should be avoided as well as changes in slope sign.
- Pavement roughness is described by Manning coefficient (n). Typical values of Manning coefficient are 0.015–0.025$m^{-1/3}s$ for concrete pavement, and 0.012–0.016 $m^{-1/3}s$ for asphalt pavement.

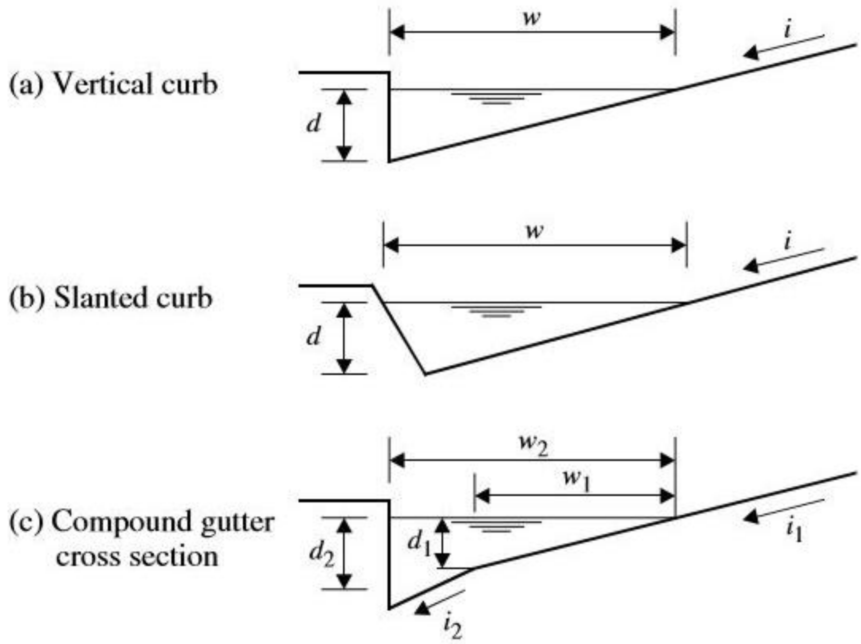

Figure 2.2 Gutter cross sections (Despotovic et. al., 2005)

To establish the spread of water on the shoulder, parking lane and pavement section, the approach flow must be known (Did 2012).

$$Q = \frac{K_u}{n} {S_x}^{1.67} {S_L}^{0.5} T^{2.67} \qquad \text{[Equation 2.1]}$$

Where,

K_u = 0.367;

n = Manning ‘s roughness coefficient;

Q = Flow rate (m^3/s);

S_x = Cross slope (m/m);

S_L = Longitudinal slope (m/m); and

T= Width of flow or spread (m)

Table 2.2 Pavement Roughness Coefficients(DID, 2012)

Gutter/ Pavement Materials	Manning's Roughness, n
Concrete gutter, troweled finish	0.012
Asphalt pavement:	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter-asphalt pavement:	
Smooth	0.013
Rough	0.015
Concrete pavement:	
Float finish	0.014
Broom finish	0.016

2.5 Efficiency of Gully Grate

In cases of no surcharged drainage systems, the hydraulic efficiency of an inlet can be defined as the ratio of the discharge intercepted by the grate to the total discharge approaching the grate.

$$E = \frac{Qi}{Q}$$

[Equation 2.2]

Where,

E = efficiency of the inlet,

Q_i = discharge intercepted by the inlet; and

Q = total discharge approaching the inlet

Considering uniform flow conditions as a first approach, efficiency, E lean on several parameters, such as approaching flow (Q_a), type of grate, gutter longitudinal slope (S_L) and paved area cross slope(S_x), pavement roughness (n), gutter geometry, and clogging factor(Gómez and Russo, 2009).

When the inlet capacity is greater than approaching flow, it is usually assumed that inlets capture the whole approaching flow. Besides, when inlet capacity is smaller than approaching flow, the inlet captures only a portion of the approaching flow, while the remaining flow passes over the inlet and is then captured by the downstream inlet (Despotovic et. al., 2005). The three of this flow components are shown in Figure 2.2.

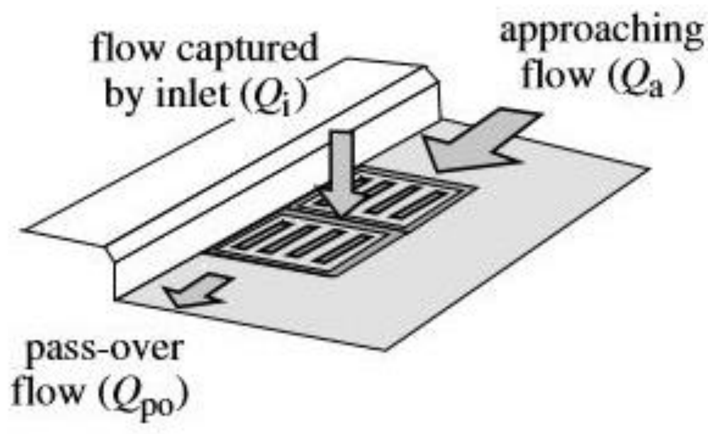

Figure 2.3 Definition of flow components (Despotovic et. al., 2005)

Bypass flow (Q_b) or the discharge that has not been intercepted by the stormwater inlet can be defined as (Haestad and Durrans, 2003):

$$Q = Q - Qi \quad \text{[Equation 2.3]}$$

Due to inlet malfunction, the inlet does not capture whole approaching flow even if the approaching flow is smaller than inlet capacity. Therefore, inlet efficiency is usually less than 100% for any approaching flow to the inlet. Usual causes for malfunction of inlets when their capacity is partially or completely reduced are (Despotovic et. al., 2005):

- the inadequate position of the inlet in relation to the curb or street other elements,
- deformation of the surrounding street pavement due to high temperatures and/or heavy traffic – clogging of the inlet grate openings by leaves or other debris,
- clogging of manholes, pipes or any other device downstream of the inlet.

It is necessary to determine distances at which inlets should be placed in a street in design urban storm drainage networks. Distances between inlets would depend on their capacity if the inlet capacity is overestimated by assuming the efficiency is 100% and the distances between the inlets are also overestimated. It will be a potential for surplus storm runoff to remain on the street surface. Also, if an inlet is placed in an inadequate position that would contribute to the increased clogging, there will also be a surplus of water on the surface (Despotovic et. al., 2005).

2.6 Design Storm

The intensity and frequency of rainfall in Malaysia are much higher when compared to other countries, especially in temperate climates. The specification of a rainfall event as a design storm is common engineering practice. There are two types of design storm recognised, which are synthetic and actual (historic) storms. Synthesis and generalisation of a large number of actual storms are used to derive the former. The latter are events which have occurred in the past and may have well-documented impacts on the drainage system(Did 2016). The Rational Method is the most frequently used technique for runoff peak estimation in Malaysia. It is expressed as:

$$Q = \frac{CiA}{360} \quad \text{[Equation2.4]}$$

Where,

Q = flow (m^3/s),

C =dimensionless runoff coefficient [Table 2.3],

i = rainfall intensity (mm/h), and

A = the drainage area (m^2).

The total storm rainfall depth at a point, for a given rainfall duration and average recurrence interval (ARI), is a function of the local climate. Rainfall depths can be further processed and converted into rainfall intensities (intensity = depth/duration), which are then presented in IDF curves. There are three variables, which are frequency, intensity and duration. These variables are related to each other, the data are normally presented as curve displaying two of the variables, such as intensity and duration, for a range of frequencies(DID, 2016)

IDF curves are calculated from local pluviometer data. Recognising that the precipitation data used to derive the above were subjected to interpolation and smoothing, it is desirable to develop IDF curves directly from local rain-gauge records if the records are sufficiently long and reliable. Figure 2.4 show the IDF curves for Kuala Lumpur (DID, 2016).

Table 2.3 Recommended Runoff Coefficients for Various Landuses (DID, 2012)

Landuse	Runoff Coefficient (C)	
	For Minor System (≤10 year ARI)	For Major System (> 10 year ARI)
Residential		
Bungalow	0.65	0.70
Semi-detached Bungalow	0.70	0.75
Link and Terrace House	0.80	0.90
Flat and Apartment	0.80	0.85
Condominium	0.75	0.80
Commercial and Business Centres	0.90	0.95
Industrial	0.90	0.95
Sport Fields, Park and Agriculture	0.30	0.40
Open Spaces		
Bare Soil (No Cover)	0.50	0.60
Grass Cover	0.40	0.50
Bush Cover	0.35	0.45
Forest Cover	0.30	0.40
Roads and Highways	0.95	0.95
Water Body (Pond)		
Detention Pond (with outlet)	0.95	0.95
Retention Pond (no outlet)	0.00	0.00

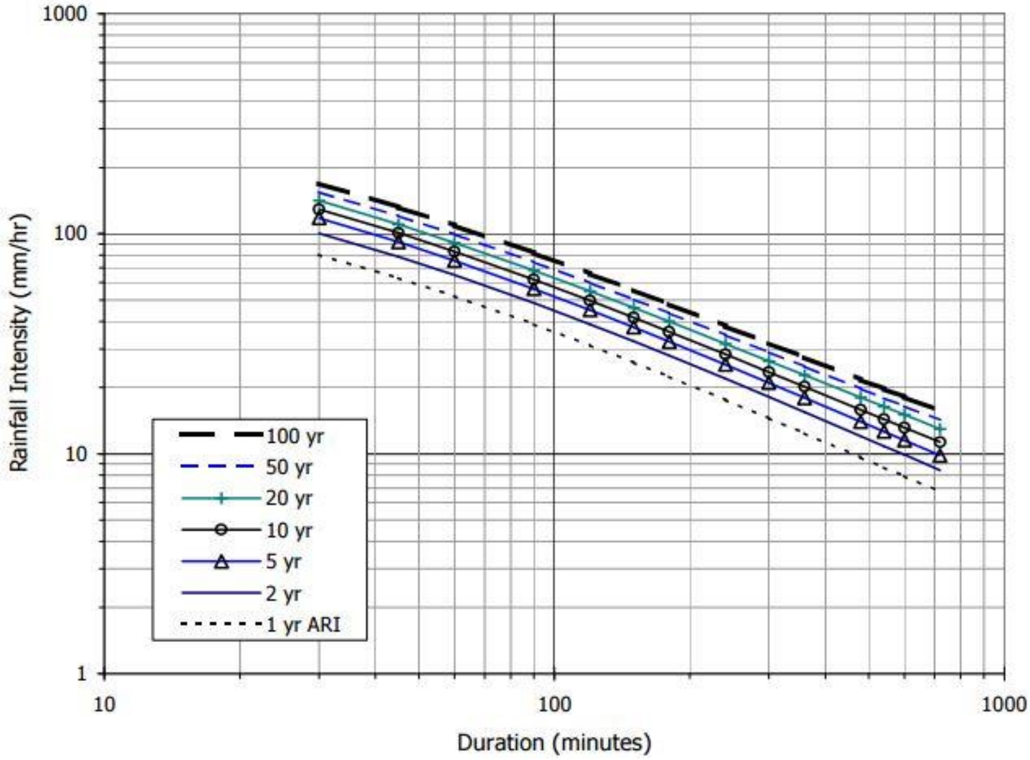

Figure 2.4 IDF curves (DID, 2016).

2.7 Hydroplaning

Hydroplaning means loss of tyre traction cause by a layer of water builds between the tyres and surface of the road. A combination of standing water on the road, car speed, and or worn-out can cause hydroplaning (Hydroplaning, 2017). When hydroplaning occurs, there is a significant loss of braking traction and steering control which may result in fatal accidents (Santosh et al. 2012).

When a vehicle is moving on a wet pavement at high speed, the rainwater flows through the tire tread grooves and increases the hydrodynamic pressure. When hydrodynamic force happens, the tire traction efficiency will decrease, therefore decreasesing the tire contact force, such that the driving controllability and the braking performance decreases when compared to driving on a dry road. (Liu et al. 2016).

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CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will present the equipment used in this experiment, workflow chart and the testing that was conducted in this study.

3.2 Equipment

There are several equipment have been use in this study.

3.2.1 Ultrasonic Flow Meter

An ultrasonic flow meter (non-intrusive Doppler flow meter) is a volumetric flow meter which requires particulates or bubbles in the flow. The EESIFLO EASZ-10P is a handheld non -invasive microprocessor based meter for measuring the flow rate and total volume of liquids flowing through process and effluent pipelines. It is suitable for a wide range of liquids, including aerated water, liquids containing suspended solids, slurries and sludges. The EESIFLO EASZ-10P requires fluids with a minimum concentration of 100 ppm of solids or bubbles having minimum size of 100 microns and works on most pipes 2 inches and above (Eastern Energy Services Pte Ltd., 2003) The flow meter is clamped to the pipe in order to obtain measurements. Ultrasonic sound is transmitted into a pipe with flowing liquid, and the discontinuities reflect the ultrasonic wave with a slightly different frequency that is directly proportional to the rate of flow of the liquid. Figure 3.1 shows the picture of ultrasonic flow meter and table 3.1 shows the specification of equipment.

Table 3.1 Specification of Ultrasonic Flow Meter (Eastern Energy Services Pte Ltd., 2003)

Specifications:	
Velocity Range	0.3 to 10.0 m/s
Accuracy	Better than ± 2% of FS
Repeatability	± 1%
Cable length	2 metre length
Temperature	Sensor -20 to 90°C, Electronics -10 to 50°C
Electronics	Black Moulded ABS
Enclosure	196 x 100 x 40mm
Transducer	IP68 St/Steel epoxy-faced 81 x 23 x 23mm

Figure 3.1 Ultrasonic Flow Meter (Eastern Energy Services Pte Ltd., 2003)

3.2.2 Stremflo- Nixon Flowmeter

The Streamflo-Nixon flowmeter series are used to measure, indicate and record very low velocities of water and other conductive fluids. It is designed primarily for laboratory and specialised industrial use. The miniature head of the flow-sensing probe can be inserted into small ducts and channels. The Nixon flowmeter is used to measure the velocity of the flow of water at the testing platform. The calibration of Nixon flowmeter was conducted and the result will be discussed further in section 4.2 in Chapter 4. The parameter measured in this calibration is velocity, which was taken from an average of fifty points for five different flowrates. Figure 3.2 show the Nixon flowmeter used in this experiment.

Figure 3.2 Nixon flowmeter.

3.2.3 Point-Gauge

The point-gauge is a commonly used laboratory instrument to measure the depth of a steady-state water surface during hydraulic testing. A mounting frame is clamped to a suitable support structure and a gauging rod is free to slide up and down over the water surface. The steel-gauging rod that is lowered to the lowest point of reference (datum) initially and set the vernier scale on the point gauge to zero. Zero can be reset by a locking screw positioned on the vernier scale. Figure 3.3 show the vernier scale on the point gauge.

Figure 3.3 Point-gauge

3.3 Work Flowchart

The overall flowchart of this study is shown in figure 3.4

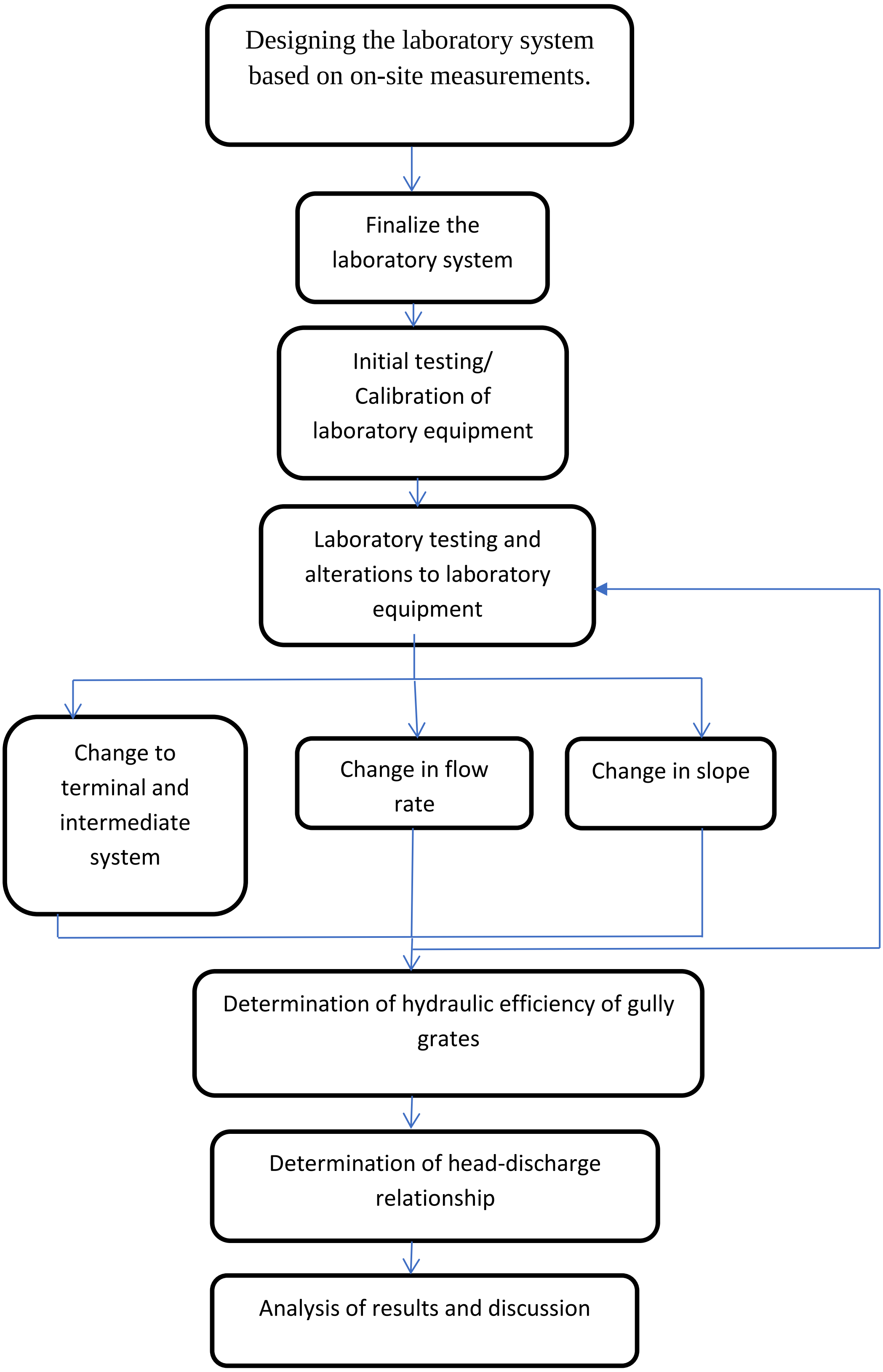

Figure 3.4 Flowchart

3.4 Laboratory Description

To study the effect of depression on the efficiency of a gully inlet of a typical Malaysian drain, a full-scale laboratory system was designed to reflect the hydraulic efficiency via gully inlets. The laboratory system is constructed comprising of a testing platform, gully grate, inlet tank, and outlet tank. Table 3.2 shows the details of the gully grate and figure 3.5 shows the drawing of gully grate.

Table 3.2 Details of gully grate

Clear Opening	Size
135mm x 55mm	1100mm x 500mm

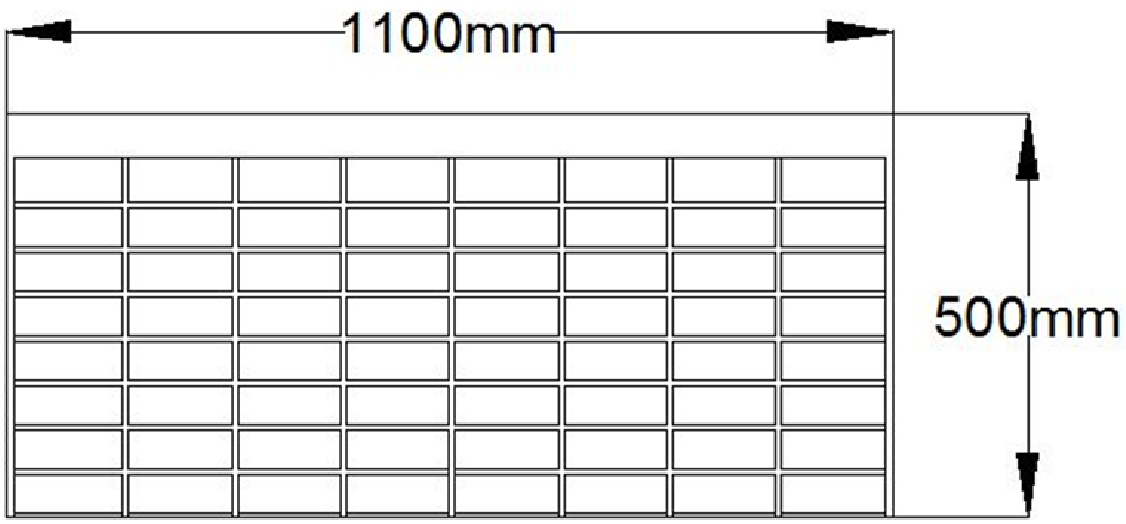

Figure 3.5 Gully Grate

The testing platform is a rectangular platform 1.83m (L) x 2.44m (W) and drains a total area of 4.39 m^2. Both inlet and outlet tank has the dimension of 1.83m (L) x 0.61m (W). The flow for the entire system is pumped from the sump and is circulated through the entire system before being transferred back into a sump. The dimensions of the laboratory system is shown in Figure 3.6.

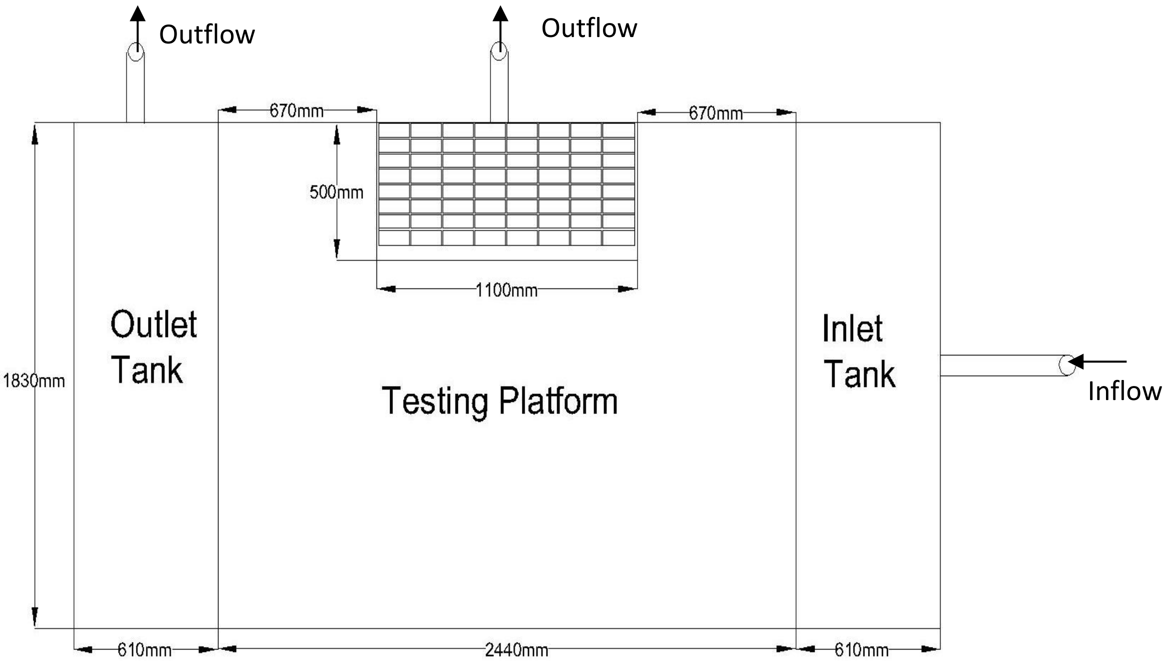

Figure 3.6 Dimensions of the laboratory rig

3.5 Design The Laboratory System

3.5.1 Preliminary Site Assessment

Preliminary site assessment was conducted before the physical model was constructed. The reason for preliminary site assessment is to obtain the dimension of gully grate to be used in the design of the physical model. The site is located at Bandar Baharu which is 9.8 kilometres from USM Engineering Campus. Figure 3.7 shows the location of the site from the Google map, with the red circle pointing to the actual place where is the measurement was taken.

Figure 3.7 Location of the site from the Google map.

The dimensions/measurement of the gully grate was taken using the measuring tape and a ruler. Precautions were taken because the site is located on the highway with heavy traffic. Figure 3.8 – 3.9 shows the picture of the site.

Figure 3.8 Taking the dimension of gully grate

Figure 3.9 Side view of gully grate