EXPERIMENTAL STUDY OF THE HYDRAULIC EFFICIENCY BETWEEN A DEPRESSED AND A NON-DEPRESSED GRATE IN BANDAR BAHARU, KEDAH

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EXPERIMENTAL STUDY OF THE HYDRAULIC EFFICIENCY BETWEEN A DEPRESSED AND A NON-DEPRESSED GRATE IN BANDAR BAHARU, KEDAH

By

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ABSTRAK

Kajian ini dilakukan untuk mengkaji kesan gegeluk yang tidak mempunyai lekukan dan kecekapan hidraulik gegeluk bagi sistem perparitan di Malaysia. Lokasi kawasan kajian terletak di Bandar Baharu sekitar 9.8 km dari Kampus Kejuruteraan USM. Gegeluk membantu mengalirkan air bertakung daripada permukaan jalan raya. Oleh itu, reka bentuk gegeluk perlulah betul dan tepat untuk mengurangkan isi padu air yang bertakung di atas permukaan jalan raya supaya pemandu boleh memandu dengan selesa dan selamat tanpa berlaku sebarang kejadian yang berbahaya. Tujuan utama kajian ini dilakukan adalah untuk membandingkan kecekapan hidraulik antara gegeluk yang mempunyai lekukan dan tidak mempunyai lekukan melalui sistem, kecerunan dan aliran yang berbeza. Bagi mengkaji kecekapan sistem gegeluk dalam skala penuh, satu model fizikal telah dibina untuk menggambarkan keadaan sebenar yang berlaku. Model fizikal mengandungi tangki masuk dan tangki keluar, pelantar ujian dan sistem gegeluk. Terdapat dua sistem gegeluk yang digunakan iaitu sistem pertengahan dan sistem penuh. Sistem pertengahan tidak membenarkan aliran melepasi gegeluk yang seterusnya manakala sistem penuh membenarkan aliran air melepasi gegeluk yang seterusnya. Kedua - dua sistem ini menunjukkan ciri - ciri yang berbeza bergantung bagaimana aliran bertindak balas. Selain itu, ujian ini dijalankan dalam beberapa bentuk kecerunan untuk menggambarkan perbezaan kecerunan sebenar di jalan raya. Sistem ini kemudiannya ditambah baik dengan meletakkan sekeping papan kayu pada tangki masuk bagi menambahkan jarak laluan aliran sekali gus mendapatkan aliran air yang lebih stabil.

ABSTRACT

This research was performed in order to study the effect of the hydraulic efficiency of non-depressed gully grate inlet of a Malaysian drain. The location of the site study is located at the Bandar Baharu which is approximately 9.8 km from the USM Engineering Campus. Gully inlets help to convey water ponding on the pavement surface to the inlet system; hence a proper and adequate design is necessary to reduce the stagnant water on the pavement surface so that the drivers can drive comfortably and safely without any dangerous incidents. The study was conducted with the aim to compare the hydraulic efficiency between depressed to non-depressed gully grate system with different longitudinal bed slope and cross slope under different flow conditions. In order to determine the efficiency of the gully grate system at the site, a full scaled of physical model had been constructed to demonstrate the actual conditions occur. There are two types of gully system used in this study, terminal system and intermediate system. Terminal system does not permit the approaching flow to pass through the next downstream gully whereas the intermediate system permit the approaching flow to pass through the downstream gully system. The test was also conducted with different longitudinal slope and cross slope to demonstrate the real condition of the road pavement at the highways. The system was then upgraded by adding plywood at the inlet tank to increase the flow path. The data obtained was then compared to the old system (shorter flow path) to determine the differences between two systems in terms of efficiency and water depth. Lastly, results obtained from the study are presented in the form of head (pressure) - discharge relationship, hence the comparison of hydraulic efficiency of the gully grates were established.

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NOMENCLATURES

E	Efficiency (%)
n	Manning's roughness coefficient
Q	Total discharge/ flowrate (l/s)
Q_i	Intercepted flow (l/s)
Q_b	Bypass flow (l/s)
R^2	Coefficient of determination
S_X	Cross slope / Cross fall
S_L	Longitudinal slope
T	Water spread (m)
η	Efficiency (%)

CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia often receives continuous rainfall throughout the year. Malaysia meteorological department stated that the average rainfall is 2500 mm (98 in) at Peninsular Malaysia while 5080 mm (200 in) at the East Malaysia (Sabah and Sarawak) a year (MetMalaysia, 2017). Thus, it is difficult to find the place where the average rainfall below than 100 mm per month. Hence, in order to prevent flooding especially at the roadways, the drainage system needs to be properly design.

In some cities, surfaces like roofs and terrace are directly connected to storm or combined sewer system to ensure a complete discharge of the flows produced in these areas during the downpours. In order to capture the remaining amount of water runoff at the surface of roadways, sidewalks, airport aprons and paved areas, efficient drainage system are required (Butler and Davies, 2004).

Conventional drain inlets are usually placed next to the curb to intercept the gutter flow approaching the grates. These inlets are not recommended to place in area such as parks and airport pavements where the gradient is not well-defined. Thus, the flows are not capable to drain towards the collecting hydraulic structures render them insufficient. Basically, at these areas, a series of continuous grates oriented perpendicular to the flow direction is normally installed (Gomez and Russo, 2009).

Extreme rainfall event is one of the most challenging problems in urban areas as the urban areas consist of high percentage of impervious area. Thus, when heavy rainfall events occur continuously, the storm-water runoff is insufficient to infiltrate into the ground hence, the affected areas will experience flooding. Therefore, effective removal of water from the pavement surface is crucial to maintain road service level as well as traffic safety.

Roadway drainage system is used to collect surface runoff and discharge it to the downstream drainage system. The efficiency of the drainage system depends on its geometry such as the dimension, types and grades as well as the characteristic of gutter flow itself. Gully inlets are normally placed at the paved median and roadsides. Therefore, it is important to have proper design drainage so that the water runoff can be conveyed effectively. Inadequate inlet capacity may cause water ponding on the roadway resulting in a hazard to the motorists.

The outermost layer of the road pavement should have an adequate cross fall in order to convey the runoff away from the traffic lanes effectively. An adequate cross slope is the most important thing that needs to be considered in designing the surface pavement drainage. Normally, the recommended cross fall depending on the type of road surface layer. The details of the cross fall that will be used in this study will be discussed in details in Section 3.6.

There are four types of storm-water drainage inlets which are commonly used to collect surface water runoff. The inlets can be grate inlets, slotted inlets, side inlets (curb inlets) or combination of inlets.

Gully inlets are efficient structures where it captures the water flow from the surface to the sewer systems. Normally, gully inlets are rectangular in shape and located at the same level as the road pavement, covered, in most of cases, grate can be in different sizes and shapes (G´omez, 2016).

1.2 Problem Statement

Erosion of the shoulder due to water, settlement of the shoulder, overlaid carriageway leaving the shoulder surface lower than the pavement are some of the possible causes of depressed grate inlets. Depression of the grated inlets may also occur due to traffic loads, environment and aging process which causes road deterioration such as road wear and potholes.

Presently, no studies have been conducted (to the authors' knowledge) to establish the effects of the depression on the efficiency of the grated inlet. It is hypothesised that the occurrence of depression on the road shoulder, or where the grated inlets are placed will cause the efficiency of the grated inlet to be reduced.

Therefore, this study is proposed in order to compare the hydraulic efficiency of the depressed to non-depressed (normal) of an existing grated inlet located at 500 m from the exit of Bandar Baharu toll. A full-scaled physical model of one lane road section was designed and built for testing. The model consists of an adjustable slope of the road surface and two different types of gully inlet systems.

The efficiency of these two systems was then compared. The test started with the calibration test to check the accuracy of the equipment and also to determine the traceability of the measurement. The equipment is then used to measure the flowrate as well as water level while conducting the experiment.

The study presented in this report focused on collecting data of a non-depressed gully grate system under different road conditions in order to determine the hydraulic efficiency of the inlet with the hope of improving the design methods.

1.3 Objectives

- To determine the hydraulic efficiency of a non-depressed gully inlet based on the grate capacity.
- To determine the hydraulic performance (water depth) of this system with different longitudinal bed slopes, cross fall and flow conditions.
- To compare the hydraulic efficiency performance of a depressed grate to a non-depressed grate.

1.4 Scope of Work

The study emphasis on the comparison of the hydraulic efficiency between depressed and non-depressed gully grate in Bandar Baharu, Perak. This study includes the alteration to the laboratory equipment such as the change in gully system, slopes of the roadways, and change in flowrate. The scope of the research are described:

- Gully inlets system

  Gully system can be categorized into two main systems which is terminal and intermediate system. Terminal system is where the system does not allow the approaching flow to pass through the gully system incompatibility with the intermediate system. For intermediate system, the system allows the approaching flow to pass through the gully system and go to the next downstream gully. The flow that passes through the gully system is called bypass flow and both type of the system will be used in this study.

- Different in flow path

  The lab rig is upgraded by adding the plywood to the inlet tank to increase the flow path as well as to obtain the steady flow during the testing. The old system (non-upgraded system) is the system used from the previous study where the flow path is shorter and turbulence flow occurs at the inlet tanks. The system will be discussed in details in section 3.8.

- Slope

  Longitudinal slopes (S_L) and cross fall (S_X) have been used to represent the real condition of street slopes at different road conditions. 1 in 100 and 1 in 50 are used for longitudinal slope whereas 1 in 80 and 1 in 40 are used for cross fall.

- Depressed and non-depressed gully grate

  This study aims to determine the efficiency for non-depressed gully grate in Malaysia in order to compare with the previous study conducted by Farouk (2017) which studied the effect of depression on the efficiency of a gully grate. With the data obtained from both research, therefore, the comparison of the hydraulic efficiency between depressed and non-depressed gully grate can be determined.

1.5 Dissertation Outline

This thesis consists of five chapters namely Introduction, Literature Review, Methodology, Results and Discussions as well as Conclusion and Recommendations.

Chapter 1 : This chapter includes an overview of the purpose and focus of the study, the importance and benefits, the expected outcome as well as the problem issues to be studied. This chapter should be informative to provide better understanding and able to give an early overview to the readers regarding the purpose and context of the dissertation.

Chapter 2 : This chapter comprises the previous research related to the topic studied such as problem statement, purpose and research questions. The chapter also provides literature according to the relevant variables.

Chapter 3 : The chapter provides a detailed description of all aspects of the design and procedures from the beginning to the completion of the study. This includes the explanation of the adjustment made to the laboratory equipment as well as data collection and analysis methods.

Chapter 4 : This chapter describes the finding obtained from the experiment. All the results obtained are then analysed and discussed. Then, the data is illustrated in a clear, complete and valid representation such as graphs and charts. Overall, this chapter reflect precisely on the study's findings, practical and theoretical implication.

Chapter 5 : This chapter includes the conclusions and recommendation made based on the findings. Conclusions are conclusive statement that concludes the overall research study while recommendations are the action taken to improvise the quality of the study to be more effective and precise.

1.6 Expected Outcomes

- To understand how road shoulder depressions may affect the efficiency of the grated inlet located on the site.
- To improve the understanding of existing gully system in Malaysia especially in terms of efficiency and head (pressure)- discharge relationship. Ultimately, it is hoped that the outcome of this research would help to improve road building and maintenance practice in Malaysia.

1.7 Importance and Benefits

From this study, are able to understand more on how depression affects the hydraulic performance of gully grate. The performance obtained from the laboratory test will be evaluated to understand how road shoulder depressions may affect the efficiency of the grated inlet located on the site. Besides, able to understand about the existing gully system in Malaysia in terms of efficiency and head (pressure) - discharge relationship with the hope that the outcome of this research help to enhance road building and maintenance practice in Malaysia. Thus, hydroplaning on road surface and urban flooding can be reduced to avoid accidents due to the loss of traction.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Storm-water runoff is typically conveyed into subsurface storm sewers through curb and grate inlets placed in street gutters and sump locations. Performance of inlets is often described as capture efficiency, hydraulic efficiency, or simply as efficiency. These terms are referring to the percentage of total street flow that is captured by the inlet (Brendan and Christopher, 2012).

The right and exact design of surface drainage system is necessary to reduce risks and damages during heavy rainfall events in urban areas. Inadequate surface drainage can produce water ponding on the road surface which caused serious problems for vehicular and pedestrian traffic. Therefore, adequate knowledge of the hydraulic behaviours of surface drainage are required such as consideration of hydrological conditions and rainfall patterns, the hydraulics of the surface flow, the hydraulic grated inlet capacity, and the hazard criteria related to urban runoff in case of storms. All of these factors affect the design of a surface drainage system (Russo et al., 2013).

According to Urban Stormwater Management Manual for Malaysia 2nd Edition (DID, 2012), effective drainage of pavement is necessary in order to maintain the road service levels as well as traffic safety. Since water on the road pavement can interrupt traffic, reduce skid resistance, increase potential for hydroplaning, limit visibility due to splash and spray, and cause lose control of vehicles. Gutter flow and inlet capacity need to be included into consideration in designing the pavement drainage. The design of these elements is dependent on the rainfall distribution and allowable spread of stormwater on the road surface.

The utilization of grate inlets is common in many urban areas where the ground surface is covered with the pavement such squares, parks, airport pavement and pedestrian areas. This situation results the isolated inlets to be ineffective in collecting all surface runoff into the sewer system during a rainfall event. (Russo et al., 2013) Thus, experimental data allowed a hydraulic characterization of the tested structures and empirical relationships were proposed to relate the hydraulic efficiency of these structures to relevant flow parameters, such as the Froude number and the flow depth (Gómez and Russo, 2009).

Different countries will have different geometry of gullies including Malaysia. (Farouk, 2017) was conducted the study to determine the hydraulic efficiency of depressed gully inlets. Since, there is no study related to hydraulic efficiency of non-depressed gully inlets, therefore to fill this gap, this study was proposed to compare the hydraulic efficiency between a depressed and a non-depressed grate in Malaysia.

2.2 Stormwater Inlets

Urban stormwater collection and drainage systems are the critical components of the urban infrastructure. Adequate design is importance to minimize the damage caused by the flood and limit the disruptions. The main function of the system is to collect and convey excess stormwater from the street gutters into the storm drain and discharge it into the nearest receiving water body (DID, 2012).

Storm drain inlets are used to collect water runoff and discharge it to downstream storm drainage system. Inlets are normally located in gutter sections, paved medians, as well as at the roadside and median ditches. The hydraulic capacity of a storm drain inlet depends on the geometry itself and the characteristics of the gutter flow. Inlet capacity controls both rate of water removal from the street gutter and the amount of water that can enter storm drainage system. Thus, inadequate inlet capacity or poor inlet location may cause flooding on the roadway surfaces resulting in a hazard to the motorists (DID, 2012).

There are four major types of inlets used for the pavement surface drainage; there are grate inlets, curb opening inlets, combination inlets and slotted inlets. Grate inlet is where an opening in the gutter covered by a grate. Curb-opening inlets are vertical openings in the curb covered by a top slab. Combination inlet is where curb opening inlets and grate inlets are placed together in a side-by-side arrangement, but the curb opening basically located at the upstream of the grate. Slotted inlets consist of pipe cut along the longitudinal axis with bars perpendicular to the opening to maintain the slotted opening. (DID, 2012) The major inlet types used in Malaysia are illustrated as shown in the Figure 2.1.

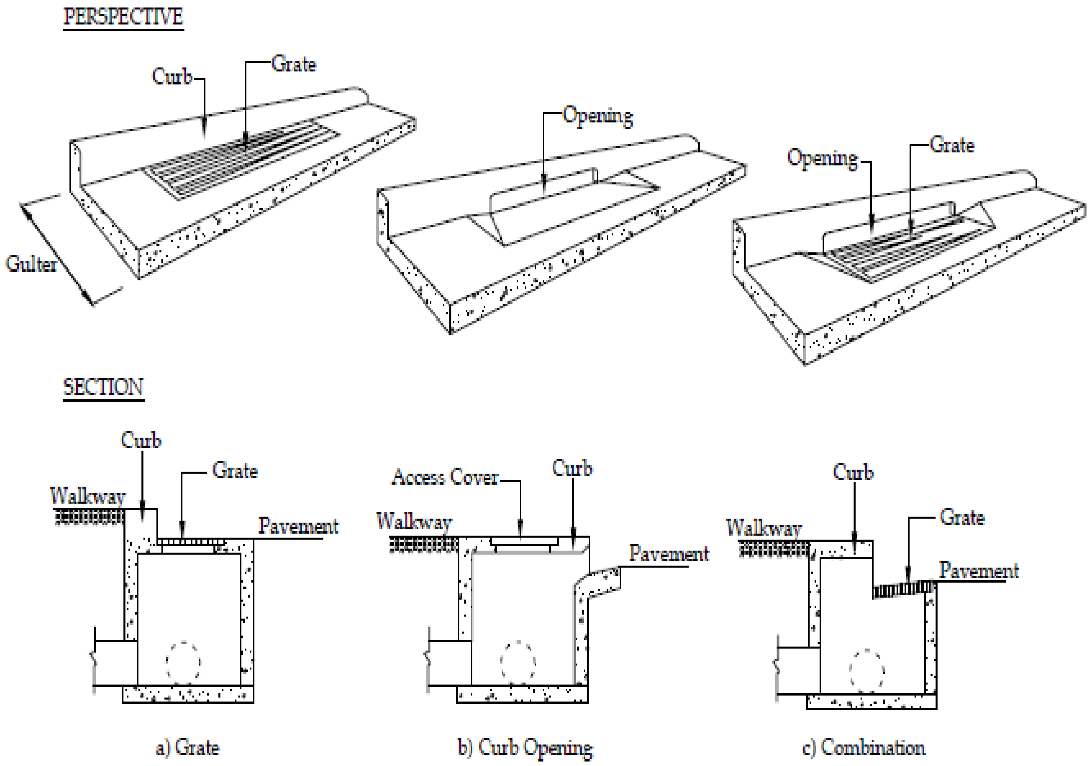


Figure 2.1 Major Inlet Types (DID, 2012)

Grates are the most effective road pavement drainage inlets compared to others types of inlets since the clogging with debris is not the issue. Table 2.1 shows grates are ranked for vulnerability to clogging based on laboratory tests done. When the velocity approaching the grate is lower than the "splash-over" velocity, the grate will intercept essentially all of the frontal flow. Incompatibly, when the gutter flow velocity exceeds the "splash-over" velocity for the grate, only part of the flow will be intercepted though only some part of the flow along the side of the grate will be intercepted depending on the cross slope of the pavement, grates length and flow velocity (DID, 2012).

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

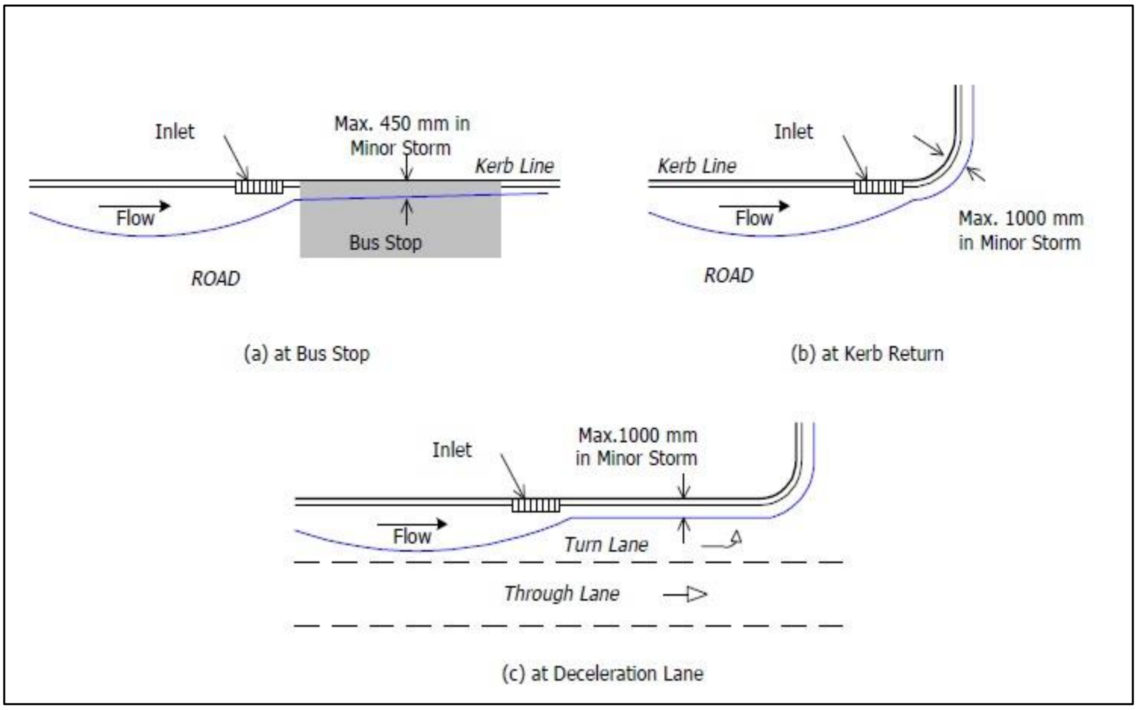
Rank	Grate	Longitudinal Slope	
		0.005	0.040
1	Curved Vane	46	61
2	30°85 Tilt Bar	44	55
3	45°85 Tilt Bar	43	48
4	P - 50	32	32
5	P - 50 x 100	18	28
6	45°60 Tilt Bar	16	23
7	Reticuline	12	16
8	P - 30	9	20

Grates are commonly used for inlet designs with the aimed to achieve a high hydraulic efficiency to intercept storm runoff through the highway medians. In practice, the performance of a horizontal grate inlet is sensitive to the amount of debris clogging (MacKenzie et al., 2016).

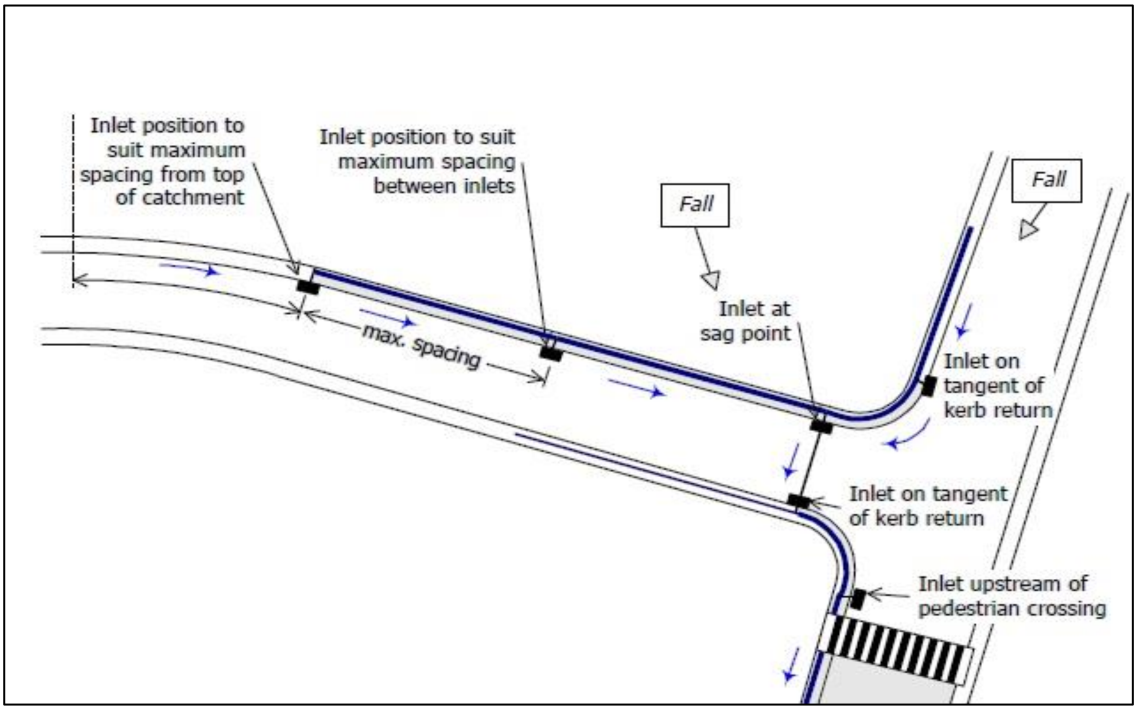
Data processing lets the authors to obtain empirical relationships that link the grate hydraulic performance to the flow parameters and grate geometry. Therefore, it is eventually possible to estimate the performance of hydraulic efficiency of transverse grates without need to conduct for laboratory tests on various sizes (Russo et al., 2013).

2.3 Locating Inlets

Inlets are required at specific locations, the use and location of flanking inlets in sag vertical curves, and the criterion of spread on the pavement and it is determined by geometric control to identify the suitable location of inlets (DID, 2012). Figure 2.2 illustrates the typical location of inlets on the roads.



(a)



(b)

Figure 2.2 (a) (b) Typical locations of stormwater inlets on the roads. (DID, 2012)

2.4 Inlet Spacing

Design spread is the criterion used for locating storm drain inlets between those required by geometric or other controls. The interception capacity of the upstream inlet will define the initial spread. As flow is contributed to the gutter section in the downstream direction, spread increases. The next downstream inlet is located at the point where the spread in the gutter reaches the design spread. Therefore, the spacing of inlets on a continuous grade is a function of the amount of upstream bypass flow, the tributary drainage area, and the gutter geometry (DID, 2012).

2.5 Hydroplaning

Pavement surface drainage plays a crucial role to improve the pavement safety and at the same time reducing the accident rates. Hydroplaning is considered as the main cause of accidents during wet conditions as a result of low quality of pavement surface drainage.

Climatic conditions (wet or dry) of the pavement surface are one of the most important parameters that influence the road safety. Many researchers proposed a relationship between accidents and weather conditions. In areas with long intervals between precipitations, after a dry period end, the number of accidents increases during the first precipitation. In wet conditions, the water ponding on the pavement surface will acts as a lubricant hence reducing the contact between the tires and the pavement surface. Thus, the friction between the two surfaces will be decreased and the pavement will exhibit a lower friction than the dry pavement surface condition. In addition to this lubricating effect of water at high speeds, lack of drainage facilities causes the presence of certain depths of water film on the pavement surface may result in hydroplaning (Behrouz et al., 2017).

Hydroplaning is a phenomenon, which occurs when water film is developed between the tires of the vehicle and the pavement surface. Hence, the water will lifts the tire up from the surface, and the vehicle begins to hydroplane. This phenomenon in consequence reduces the traction and disables the vehicles from the responding to the motorist's actions such as steering, braking or accelerating. Consequently, hydroplaning is considered as the main cause of accidents during wet weather conditions (Behrouz et al., 2017).

The traction is defined as the friction that builds up between tires of the vehicles and the pavement surface. Meanwhile, rolling traction is the interaction between the car's tires and the pavement surface which results in forward motion of the vehicles. However, when the water coats the pavement surface, the tires are unable to obtain the traction (Behrouz et al., 2017).

2.6 Hydraulic Capacity

The hydraulic performance of a grate relies on the water level on top of the grate itself. When the water level is too shallow to submerge the whole grate surface, the grate acts like a weir whereas, when the grate area is completely submerged, the grate acts like an orifice (MacKenzie et al., 2016).

Other than types of inlets, location of the inlets also influences the hydraulic capacity. For grate inlets, the capacity is largely depend on the amount of water flowing across the grate, the grate configuration and the spacing. For curb-opening inlets, the capacity is mainly depend on it opening length, the cross slope of street and gutter as well as the flow depth at the curb. In addition, local gutter depression at the curb opening will increase its capacity. Combination inlets on a continuous grade (i.e., not in a sump location) intercept up to 18% more than grate inlets alone and less likely to clog. Slotted inlets behave in a same manner as the curb-opening inlets (DID, 2016).

Inlets in sumps act as weirs at shallow ponding and as orifices when the depth increases. A transition region exists between weir flow and orifice flow more likely as a culvert. Next, grate inlets and slotted inlets have higher tendency to plug with debris compared to curb –opening inlets (DID, 2016).

The ability of an inlet to intercept flow (i.e., hydraulic capacity) on a continuous grade increases when the gutter flow increases, nevertheless the capture efficiency will decreases. Basically, the inlet capacity in the streets depends on:

- The inlet type and geometry. Each type of inlets has its own geometry configuration such as length, width, and the opening, thus the performance of hydraulic capacity will act differently according to the type of inlets used.

- The flow rate. Flow rate indicates the speed of water runoff on the pavement surface that flows into the inlets system. Flow rate also influenced by the roughness of the pavement surface. The rougher the surface, the slower the water to flow. The relationship between these two elements is illustrated in the Equation 2.1.

- The longitudinal street slope. Curbed pavement must have a minimum longitudinal gradient since the water is restrained by the curb. The desirable gradient should more than 0.5% for curbed pavement with an absolute minimum 0.3%.

- The cross (transverse) slope. Table 2.2 shows details of an acceptable range of cross slopes with various pavement surface types. These cross slopes are a consideration between the need for reasonably steep cross slopes for drainage and relatively flat cross slopes for driver comfort and safety purposes. In the areas that prone to heavy rainfall event, a steeper cross slope at 2.5% can be used to facilitate drainage.

Table 2.2 Normal Pavement Cross Slopes (DID, 2012)

Surface Type	Cross Slope (%)
High-Type Surface 2 lanes 3 or more lanes, each direction	 1.5 – 2.0 1.5 minimum, increase 0.5 to 1.0 per lane; 4.0 maximum
Intermediate Surface	1.5 – 3.0
Low – Type Surface	2.0 – 6.0
Shoulders Bituminous or Concrete With Curbs	 2.0 – 6.0 ≥ 4.0

To determine gutter flow, the Manning's equation is integrated for an increment of width across the section. This equation also illustrated the relationship between the pavement surface roughness and the flow rate of water runoff. The resulting equation is shown as below while Table 2.3 presents the manning's roughness coefficient of the pavement surface.

$$Q = \frac{K_u}{n} S_{x^{1.67}} S_{L^{0.5}} T^{2.67} \quad \text{[Equation 2.1]}$$

where,

K_u = 0.376 (DID, 2012)

n = Manning's roughness coefficient (Table 2.3)

Q = Flow rate (m^3/s)

T = Width of flow or spread (m)

S_X = Cross slope (m/m)

S_L = Longitudinal slope (m/m)

Table 2.3 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

2.7 Efficiency of Gully Grate

In the situation where there is no surcharged drainage systems (overloading of water), the hydraulic efficiency of an inlet can be defined as the ratio of the intercepted flow rate by the inlet to the total flow rate approaching the grate inlet. Inlets that have been located on the continuous grades are normally designed to intercept only some of the portion of the gutter flow during the minor storm design, for example some flow bypasses to down gradient inlets. The effectiveness of the inlet can be expressed as the efficiency and can be defined as:

$$E = \frac{Q_{int}}{Q} \quad \text{[Equation 2.2]}$$

where,

E = Efficiency of the inlet (fraction of gutter flow captured by inlet)

Qi = Intercepted flow rate by the inlet

Q = Total flow rate approaching the inlet.

Considering steady flow conditions as a first approach, thus hydraulic efficiency depends on various parameters like approaching flow (Q), types of grate, gutter longitudinal slope (I_y) and paved area transversal slope (I_x), pavement surface roughness (n), gutter geometry as well as clogging factor (Gomez and Russo, 2009). Figure 2.3 illustrates the geometry and condition of the inlet system at the streets.

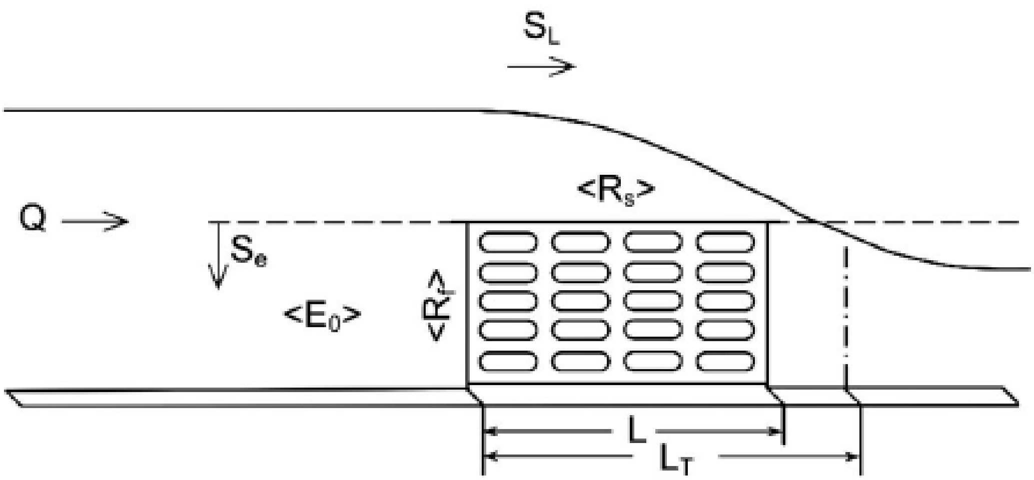


Figure 2.3 Inlet and gutter schematic (Comport and Thornton, 2012)

Bypass flow is when the approaching flow passes through the inlet and move to the next downstream gully inlets. Simply, bypass flow can be defined as:

$$Q_b = Q - Q_i \qquad \text{[Equation 2.3]}$$

where,

Q_b = bypass flow rate

Q_i = Intercepted flow rate by the inlet

Q = Total flow rate approaching the inlet

The hydraulic efficiency of a grate inlet on a continuous grade is largely dependents on the width of the grate. Generally, most of the flow within the width of the grate will be intercepted whereas most of the flow outside the width of the grate, such as in the street will not. Besides, the velocity of the gutter flow itself also influences the hydraulic efficiency performance. If the velocity is slow and the spread of water does not exceed the grate width, then all the flow will be captured by the grate inlet. But, normally even during the minor storm design, the spread of water often exceed the grate width and the velocity sometimes can be high. Therefore, some of the flow within the width of the grate may "splash over" the grate (DID, 2016).

2.8 Flow Path Length

The flow path is the route taken by storm water runoff from the point at which it falls on the roadway surface to the roadway edge. For a roadway with zero longitudinal slopes, flow paths will be transverse to the direction of travel. As the longitudinal slope increases, the flow paths will become diagonal (DMRB, 1999).

For evaluation purposes, the flow path considered is the maximum distance taken by storm water runoff in order to reach the edge of the roadway channel or drainage system. In many cases, except at super-elevation roll-overs, this will be represented by downfall at the edge of the carriageway as well as on the high side of the cross fall (DMRB, 1999).

As longitudinal slope increase, the flow path length also increase, which causes in increase of water depths. The rate of increase in water depth is partially offset by the increase in flow path slope, as it becomes more affected by the longitudinal slope and less by the cross slope (DMRB, 1999).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes equipment and methodology used in this experiment, work flow chart, calibration measurements, laboratory description and the system involves in this experiment.

3.2 Equipment

There are several types of equipment that have been used to complete this experiment. The laboratory equipment used in this study were ultrasonic flow meter, streamflo – nixon flowmeter and point gauge. These tools are mainly used to perform the experiment or to take measurements in order to obtain relative data set.

3.2.1 Ultrasonic Flow Meter

Ultrasonic flow meter uses sound waves to determine the velocity of fluid flowing inside the pipes. When there is no flow movement, the frequencies of an ultrasonic wave that transmitted throughout the pipe and it reflections are the same. When there are some flow movements, the frequency of the reflected wave will be different due to the Doppler effects. As the fluid moves faster, the frequency of the reflected wave will increases accordingly. Then, the transmitter will process the signals from the transmitted wave and its reflections in order to determine the flow rate. During the experiment, the EESIFLO EASZ-10P Flow Meter is placed at the inlet and outlet pipes to determine the current flowrate. Table 3.1 shows the specification of equipment.

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

Specifications of flow meter:	
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 40 mm
Transducer	IP68 St/Steel, epoxy-faced, 81 x 23 x 23 mm
Power	4 x AA cells incl
Battery Charger	230 Vac or 110 Vac 50/60 Hz incl
Indication	2 – Line 16 Character, Backlit LCD
Weight	0.85 kg

Figure 3.1 Ultrasonic Flow Meter