HYDRAULIC EFFICIENCY OF GULLY INLETS, CURBS AND COMBINATION INLETS: A SYSTEMATIC REVIEW

NUR AFIQAH BINTI SYAHRUNNIZAR

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2021

HYDRAULIC EFFICIENCY OF GULLY INLETS, CURBS AND COMBINATION INLET: A SYSTEMATIC REVIEW

by

NUR AFIQAH BINTI SYAHRUNNIZAR

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of the requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)
(CIVIL ENGINEERING)

School of Civil Engineering
Universiti Sains Malaysia

August 2021

ACKNOWLEDGEMENT

All praise and blessings to Allah SWT for allowing me to finish this thesis successfully; I am so grateful to God for the strength and hardships bestowed on me. Special gratitude goes out to Dr Nuridah Sabtu – my Final Year Project (FYP) supervisor, for her generous support and patience in providing knowledge and guidance from the beginning to completing the thesis. I have gained a great deal of wisdom both academically and personally during the completion of the thesis. Thank you for the tremendous positive feedbacks given, along with the continuous support received. Next, my thanks and appreciation goes to my family members for their unconditional support and prayers. Their unwavering support in me was the only source of my strength when I was struggling. Not to forget my friends who constantly strive to complete my undergraduate studies for four years as a student. Last but not least, I would like to express my deepest gratitude to the School of Civil Engineering, Universiti Sains Malaysia, for giving me a chance to conduct my project as a token for me to hone my knowledge in the engineering area, specifically in civil engineering

ABSTRAK

Tesis ini dilakukan untuk mengkaji kaedah menentukan kecekapan hidraulik gegeluk dan mengenal pasti batasan gegeluk, bebendul dan kombinasi gegeluk untuk konfigurasi reka bentuk yang berbeza. Pada masa kini, kekurangan pengetahuan mengenai jenis struktur ini belum dapat diatasi sepenuhnya. Beberapa kajian yang dilakukan adalah hanya terbatas pada parameter tertentu. Akibatnya, batasan-batasan ini menyukarkan untuk menghasilkan hasil umum yang berlaku untuk jenis gegeluk yang lain. Peningkatan jumlah kajian telah menghasilkan pendekatan dan metodologi yang berbeza untuk mengukur kecekapan hidraulik dan mencapai formulasi umum atau gabungan dengan pelbagai saluran masuk. Kelemahan dan jurang yang ketara menghalang penilaian kecekapan hidraulik dan penilain untuk penyelidikan masa depan. Kajian literatur sistematik telah dilakukan untuk membantu jurang pengetahuan dalam memahami kecekapan hidraulik dengan mengembangkan soalan kajian yang dapat dijawab. Artikel-artikel yang dikaji telah dilakukan untuk menjawab persoalan kajian. Asas formulasi oleh HEC-22 membuat anggaran yg berlebihan untuk kecekepan hidraulik oleh gegeluk dan the persamaan yang dicipta adalah terhad kepada sesetengah ciptaan and parameter gegeluk

ABSTRACT

This thesis was conducted to study the methods of determining the hydraulic efficiency of gully inlet, curb inlet and combination inlet and identify their limitation for different configurations. Nowadays, the lack of knowledge about these types of structures has not been fully overcome. Some of the studies conducted were restricted to a specific limit of parameters. Consequently, these limitations made it difficult to produce general results that apply to other types of inlets. The increasing number of studies has resulted in different approaches and methodologies to quantify the uptake process and achieve general or unified formulations with various inlets. The significant weaknesses and gaps impede hydraulic efficiency assessment and the path forward for future research. A systematic literature review was performed to aid the knowledge gap in understanding hydraulic efficiency by developing answerable review questions. The reviewed articles were conducted to answer the review questions. The basic formulation by HEC-22 overestimate the hydraulic efficiency of inlet and the developed equation is limited to certain design and parameters of the inlet.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF SYMBOLS

E	Efficiency of inlet
Q	Total flow
Q_{in}	Intercepted flow
S_L	Longitudinal slope
S_T	Transverse slope
Q_b	By-pass flow
Q_m	Maximum discharge
Fr	Froude number
y	Inflow depth
L_g	Length of grate
W_g	Width of grate
T	Width of flow or spread
C_d	Discharge coefficient
i	Rainfall intensity
L_s	Inlet spacing
L	Length of inlet
T	Water spread

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

1.1 Introduction

The development of urbanization has spread across the globe over the last few decades to establish a better society especially toward urban drainage system that provides a channel for surface runoff to flow into underground drainage system also known as an outfall. Streets or paved surfaces are part of the stormwater drainage system in urban areas (Mustaffa, 2003). Above and below ground drainage systems are connected via a gully system with several linking elements such as grate inlets, curb and combination inlets. These elements are considered to be important in urban drainage systems so that they can intercept the stormwater ponding on the paved surfaces into an outfall and at the same to control or reduce the street ponding (Sabtu et al., 2016).

The inlets can transport water from the surface to the drainage system during the lower intensity of rainfall. However, during extreme rainfall, the process of interception is disrupted due to the turbulent nature of the flow, and then resulting in water ponding on the paved surface, but when the rain subsides, the inlet might still be able to capture and re-route the flow. Therefore, the hydraulic efficiency of inlets in intercepting water is essential for maintaining road service standards and ensuring traffic safety (Mustaffa, 2003).

The hydraulic efficiency of inlets is regulated by factors such as dimensions, types, grades, and flow characteristics at the upstream section of the inlet. Adequate design of inlets gives a better performance in terms of intercepting water and providing a safe environment for road users.

A thin layer of upstream flow forms and gradually increases in depth when approaching the edge of pavement on steep roads due to gravitational driving force. The depth of approaching water is factored by longitudinal slopes, transverse slope and gutter design that will flow into the drainage system. An adequate transverse slope needs to be considered because when water flow becomes higher, it will cause the water to flow over the inlet; thus, resulting in a significant amount of flow bypassed the inlet and reducing the efficiency of the inlet to intercept the water.

There are four commonly used inlets to intercept runoff: grate inlets, curb inlets, slotted inlets, and combination inlets (grate and curb inlets). Inlets are effective structures that intercept water to the underground drainage system. They are typically rectangular shaped and positioned at the same level as the road pavement. They are usually covered with a grate of various sizes and shapes depending on the location and uses (Gomez, 2016).

The purpose of conducting a systematic literature review is to study the methods and their limitations to determine the efficiency of different designs and geometry of the gully system.

1.2 Problem Statement

Malaysia always experiences seasonal monsoon due to its location near the equator; thus, it often leads to urban flooding in some regions during the high intensity of rainfall. Today's standard designs of the insufficient inlet capacity to convey stormwater runoff from the roadway into the outfall are inadequate to capture the uncontrolled amount of precipitation. Water ponding on the paved surface causes numerous safety hazards in urban areas, especially in the areas where the percentage of impervious regions is high. The performance of the drainage system depends on the main components (grate inlet, curb inlet, combination inlet, etc.) and their geometry conditions. Therefore, these components' function is crucial to transport the surface runoff to control and reduce rainwater accumulation on the surface

By conducting a systematic literature review, this study can fill the gap of knowledge of hydraulic efficiency of gully system so that future engineers might be able to adapt several improvements to the existing drainage system to reduce the occurrence of accidents due to water ponding and hydroplaning on the street surface

1.3 Review Objectives and Questions

Review objectives and review questions are developed to define the studies of the hydraulic efficiency of the gully system. Following are the review objectives and review questions:

- Review Objectives

RO 1: To study different gully inlet, curb, and combination inlet designs

RO 2: To review the methods to determine the efficiency of the different gully inlet, curb, and combination inlet designs

RO 3: To compare and identify the limitations of each method

- Review Questions

R.Q.1: How do different gully inlet, curb, and combination inlet designs affect hydraulic efficiency?

R.Q.2: What are the utilized method to determine the efficiency of the different gully inlet, curb, and combination inlet designs?

R.Q.3: What are the limitations of each method in representing the efficiency of different gully inlet, curb, and combination inlet designs?

1.4 Scope of Work

This thesis studies the hydraulic efficiency of gully inlets, curb, and combination inlets. It includes the comparison to determine the efficiency by the different methods proposed by the researchers and identifying the limitations of each technique for different gully inlet, curb and combination inlet design

1.5 Dissertation Outline

Introduction, Literature Review, Methodology, Results and Discussions, and Conclusion and Recommendations are the five chapters of this study.

Chapter 1: This chapter summarises the study conducted and the problem statement regarding the topic, the importance and benefits, and the expected outcome. It should provide a better understanding and informative to the readers about the context of the dissertation.

Chapter 2: This chapter provides the literature review of previous research related to the topic studied and relevant review objectives and questions

Chapter 3: This chapter explains a detailed description of how a systematic literature review was conducted from the beginning to the completion of the review.

Chapter 4: This chapter presents some of the chosen case studies related to the review objectives and questions. The reviews of each case study are presented in a detailed summary of experiments done by researchers.

Chapter 5: This chapter describes the conclusions and some suggestions made based on the extracted data.

1.6 Importance and Benefit

The studies of hydraulic efficiency of gully inlet and curb designs play a crucial role in stormwater management to prevent excessive gutter flow and excessive ponding that diminishes the effectiveness of the inlets in intercepting. Besides, able to better understand the existing gully system in terms of its efficiency so that the outcome of these studies will help to adapt several improvements to the system: thus, it will reduce urban flooding and avoid accidents due to loss of friction. Conducting a systematic literature review also can highlight the gap in knowledge as increasing experimented and simulated records with the different designs of inlets and methods to determine the efficiency of inlets. Therefore, this review can overview the hydraulic behaviour between the above and below drainage systems.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The road gulley or stormwater inlet is a transfer point between the above and below ground drainage systems; therefore, it is essential for urban stormwater systems. Stormwater runoff is often directed into the underground drainage system by grate and curb inlets in roadway gutters and sump sites. The performance of inlets is described using terminologies such as interception efficiency, hydraulic efficiency, and simple efficiency. These words relate to the percentage of total approaching flow intercepted by the inlet (Brendan and Christopher, 2012).

The Urban Stormwater Management Manual for Malaysia 2nd Edition (DID, 2012) states that designing an effective drainage system that includes the gutter flow and inlet capacity is essential to sustain traffic safety to the road users. These elements are determined by the rainfall distribution and stormwater spread allowed on the road surface. However, it can cause traffic congestion by reducing its skid resistance, increasing the risk of hydroplaning, reducing visibility because of splash and spray, and making it harder to manoeuvre a vehicle when the front wheels hit puddles the inlets are unable to intercept the ponded water.

Good surface drainage systems are needed to minimize risks and damages during heavy storm events in urban areas. The incapabilities of intercepting the flow can result in an excessive runoff on street surfaces, causing severe traffic problems for both vehicles and pedestrians. Hydrological circumstances and rainfall patterns, surface flow hydraulics, hydraulic grating inlet capabilities, and hazard requirements for urban runoff during storms must be considered to comprehend surface drainage systems' hydraulic behaviour fully. The design of a surface drainage system is influenced by these considerations (Russo et al., 2013).

Street gutters, stormwater inlets, and storm sewers are all part of the drainage system. The street gutters collect runoff from the roadway and transport it to a storm inlet to prevent traffic disruption. Inlets intercept water from the streets, transport it to the sewage system, and provide access to the storm sewer system (Hromadka et al., 2020).

2.2 Stormwater Inlet

Surface runoff is collected through inlets and conveyed to storm drains or direct outlets to culverts. Inlets should be placed in the gutter section, paved medians or roadside, and median ditches to collect runoff and discharge it to the downstream storm drainage system. Its geometry and gutter flow characteristics determine the hydraulic capacity of a storm drain inlet. The amount of water that can reach the storm drainage system and the rate at which water is collected from the gutter is determined by inlet capacity. Insufficient inlet capacity or unsuitable location of inlets may cause flooding on the roadway, posing a danger to motorists (DID, 2012).

Stormwater inlets are also known as gully inlets used for drainage systems consist of four types: grate inlets, curb opening inlets, combination inlets, and slotted inlets. Figure 2.1 (a), (b), (c), and (d) shows each type of inlet, respectively.

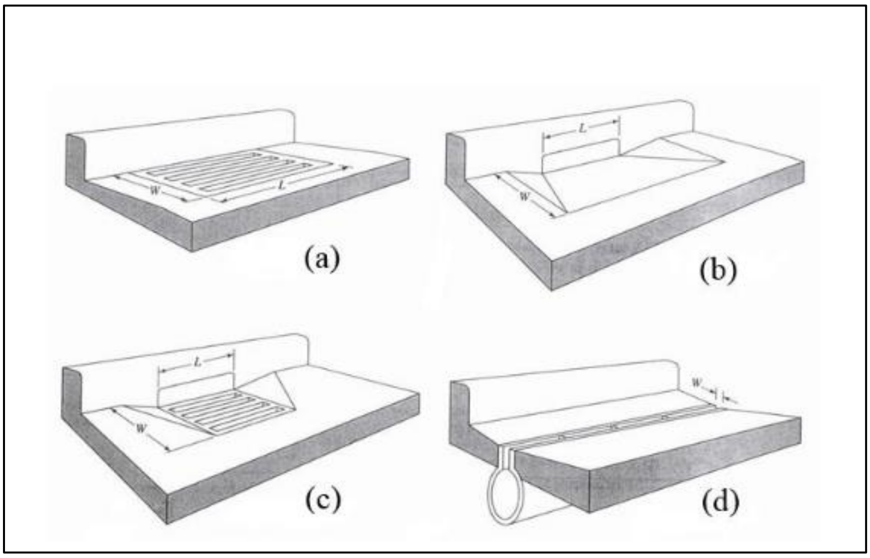


Figure 2.1 (a) - grate inlet, (b) – curb opening inlet, (c) - combination inlet, and (d) - slotted inlet (Mustaffa et al., 2020)

i) Grate inlets

These types of inlets have an opening in the gutter covered by more than one grate. Grates should be bicycle safe where they can handle appropriate loads when subjected to bike traffic. The grate can intercept almost all frontal flow if the approaching flow velocity is less than the "splash over" the grate flow velocity. However, when the gutter flow or approaching flow velocity reaches the grate's "splash over" velocity, only a portion of the flow is intercepted depending on the cross slope of the pavement, the length of the grate, and the flow velocity (DID, 2012). Grates are good at intercepting gutter flows and also include a maintenance access opening. All road grates should be bicycle-friendly, and Figure 2.2 depicts a typical diagram of bicycle-friendly grates.

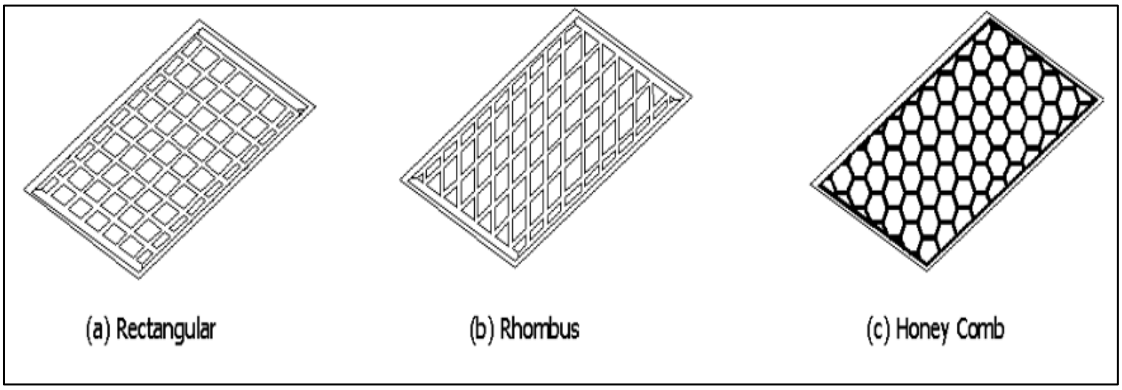


Figure 2.2 Bicycle-friendly Grates. (DID, 2000)

ii) Curb opening inlet

These inlets are vertical openings in the curb covered by a top slab. Curb opening inlets are effective in the drainage of road pavements where flow depth at the curb is sufficient for the inlet to function efficiently. In addition, curb openings are less likely to become clogged and cause less traffic disruption. They are a potential alternative to grates dangerous to pedestrians and bicycles on flatter grades in traffic lanes (DID, 2012).

iii) Combination inlet

It is a combination of grate inlet and curbs opening inlet placed together in a side-by-side arrangement, but the curb opening is located upstream of the grate. A combination inlet consisting of a curb opening and grate placed side-by-side, as shown in Figure 2.3, has the same interception capacity as the grate alone. As a result, capacity is calculated without taking into account the curb opening.

However, as shown in Figure 2.4, a combined inlet is sometimes used with a part of the curb opening located upstream of the grate. The curb opening in such an installation is known as a “sweeper” inlet because it intercepts trash that would otherwise clog the grate. The interception capacity of a sweeper combination inlet is equal to the sum of the curb opening upstream of the grate plus the grate capacity, except that an interception reduces the frontal flow and, therefore, the grate's interception capacity by the curb opening (DID, 2012).

Figure 2.3 Combination Curb-opening (DID, 2012)

Figure 2.4 Sweeper Combination Inlet. (DID, 2012)

iv) Slotted inlet

These inlets consist of a slotted opening with bars perpendicular to the opening and pipe cut along the longitudinal axis. Slotted inlets act as weirs when the approaching flow enters the inlet from the side. They can be used to intercept sheet flow, collect gutter flow with or without curbs, alter existing systems to suit road widening or additional runoff, and lessen the depth and spread of ponding at grate inlets. (MnDOT, 2000)

The major inlet types used in Malaysia are illustrated in Figure 2.5 and Figure 2.6.

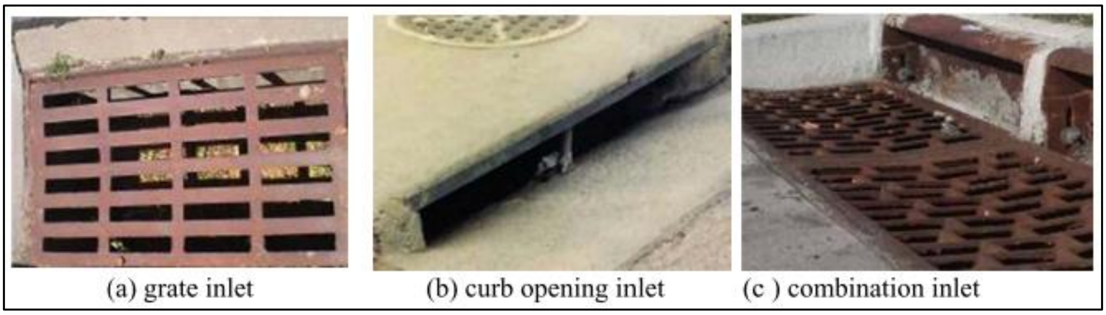


Figure 2.5 Type of Inlets (Guo and McKenzie, 2012)

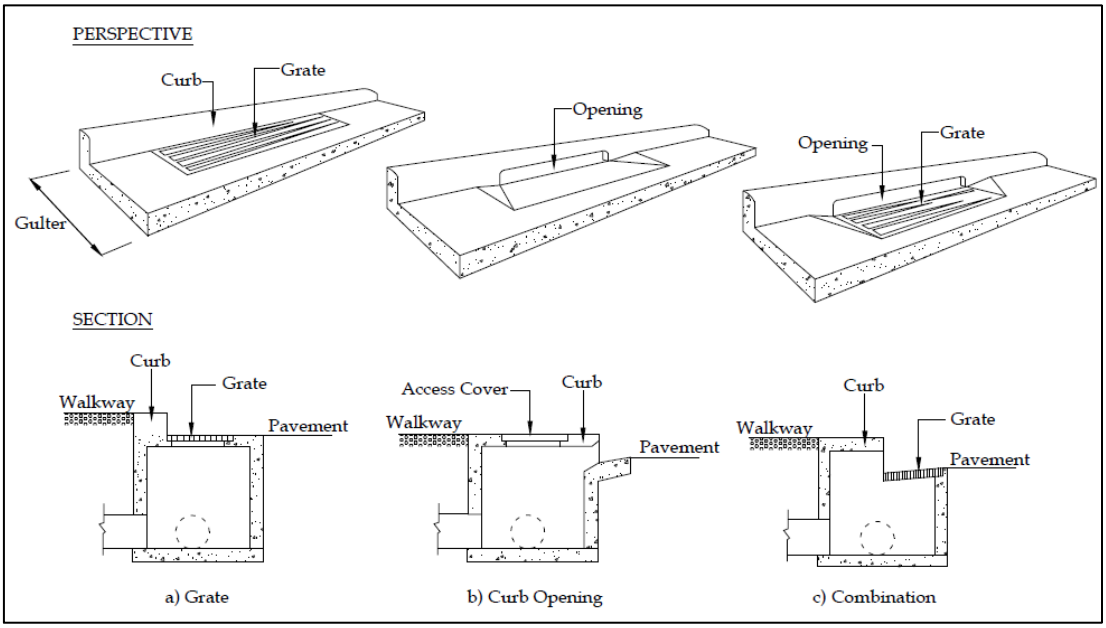


Figure 2.6 Major Inlet Types in Malaysia (DID, 2012)

2.3 Location of Inlet

Inlets are required at locations needed to collect runoff and installed in a suitable position, such as along the gutter line, not located in a pedestrian-travelling lane (MnDOT, 2000).

Inlet structures can be found at both the upstream and downstream ends of the gutter line—the geometry of the site, inlet opening capacity, and tributary drainage magnitude all influence inlet spacing. Inlet placement is typically a trial-and-error process aimed at achieving the most cost-effective and hydraulically efficient system. According to the Manual on Storm Water Drainage Systems (CPHEEO, 2019), there are several rules required when locating a suitable location of inlet:

- Inlets are placed starting from the first point of the gutter section and then spaced out on the next point when some of the bypassing flow and other incoming flow exceeds the gutter's capacity.
- The inlet should be placed where the cross slope starts to elevate super.
- Any points where runoff flows to the side and cause gutter capacity to be exceeded should have an inlet installed.
- At low points of gutter grade and median breaks, inlets are required.
- The inlet should be located upstream and downstream of the bridges to prevent storm flow on the bridge and intercept flow from the bridge.

Surface water starts to pond~~ing~~ and causes inconvenience to residents if gulleys are placed too far apart. However, if the inlets to the sewers are too close, downstream peak flows may be reinforced where pipe diameters and construction costs are increased (Hall and Hamilton, 1991).

The Urban Stormwater Management Manual for Malaysia 2nd Edition (DID, 2012) states that the use and location of flanking inlets in vertical sag curves and the spread criterion on the pavement are all regulated by geometric control to determine the suitable location of inlets. Figure 2.6 illustrates the typical location of inlets suggested by the DID (2012)

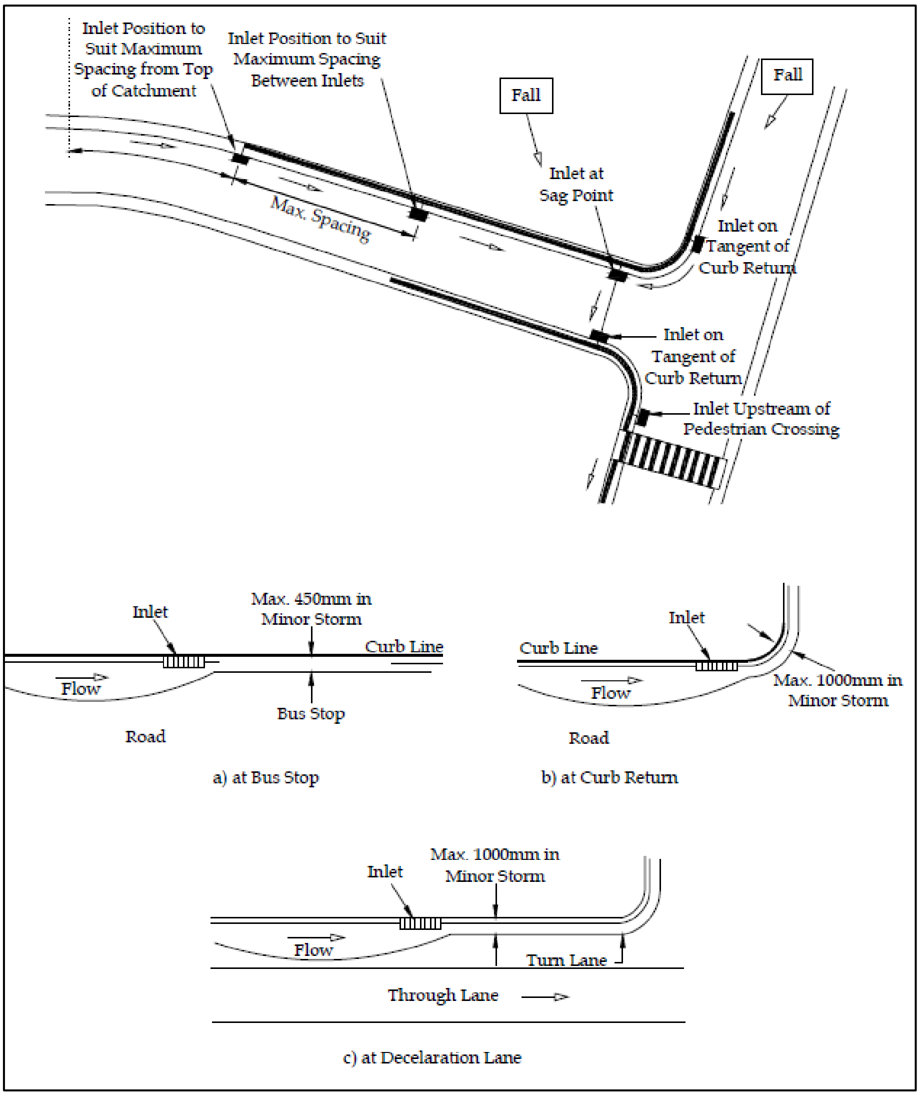


Figure 2.7 Bicycle-friendly Grates (DID, 2000)

Typical locations of stormwater inlets on the roads. (DID, 2012)

Locations of the inlet are also influenced by (DID, 2000):

- other utility service locations;
- driveway locations;
- superelevation and other changes to road cross-sections;
- maintenance requirements, such as clear access; and
- the necessity to limit flow depths on the low side of roads below crest levels of driveways servicing properties below road level

The hydraulic capacity of the grating determines the spacing of gullies in curb and gully systems. These are frequently constructed to handle more water than the grating can give. Another element influencing gully spacing is the quantity of water flowing along the road edge. The width of flow accepted varies depending on the nuisance level due to debris, vegetation, and other such materials (Davis et al., 1996).

The criterion for situating storm drains inlets between geometric or other restrictions is called design spread. The upstream inlet's interception capacity will determine the initial spread. Spread increases as flow are contributed to the gutter portion from the downstream direction. At the point when the gutter spread approaches the design spread, the next downstream inlet is located. As a result, the amount of upstream bypass flow, the tributary drainage area, and the gutter geometry all influence the spacing of inlets on a continuous gradient (DID, 2012).

2.4 Hydraulic Capacity

The phrase inlet capacity refers to the maximum gutter/overland flow that the inlet can capture. This definition presupposes that the inlet's function is unaffected by circumstances in the manhole, pipe, or any other device, as well as obstruction due to backwater and surcharging effects. The capacity of the inlet is determined by the street's transverse and longitudinal slopes, the location and size of curbs, and the roughness of the pavement (Despotovic et al., 2005).

A gully inlet's hydraulic capacity is determined by its geometry and the characteristics of the gutter flow. The amount of water that may enter the storm drainage system and the rate at which water is removed from the gutter are both determined by inlet capacity. Inadequate inlet capacity or a wrong inlet position might result in flooding on the road, posing a threat to users (DID, 2012)

The hydraulic performance of a grate relies on the water level on top of the grate itself. The grate will function as a weir when the water depth is too shallow to submerge the entire grate surface. When the whole grate area is immersed, the grate functions as an orifice (McKenzie et al., 2016).

2.5 The Efficiency of Inlet

The efficiency of the inlet, E is defined as the discharge intercepted by the inlet over the total discharge approaching the inlet can be defined as:

$$E = \frac{Q_{int}}{Q} \qquad \text{Equation 2.1}$$

Where:

Q_{int} = Discharge intercepted by inlet (m^3/s); and

Q = Total discharge approaching the inlet (m^3/s).

The effectiveness of a gully gratings-based surface water drainage system is determined by various parameters, including the spacing between the inlets and the grating design used. The velocity of flow, the relative length of the grate (length/width), the relative depth of discharge (depth of flow/width of grate), the cross-fall, the longitudinal grade, the geometric arrangement of the grate, and the rate of flow all influence the grate’s efficiency. The grate’s efficiency is predicted to decrease when the water bypass or “jump over” the grate. However, the actual effect of velocity is heavily influenced by the grate’s geometric configuration (Black, 1967). Figure 2.8 shows the geometry and condition of the gully system.

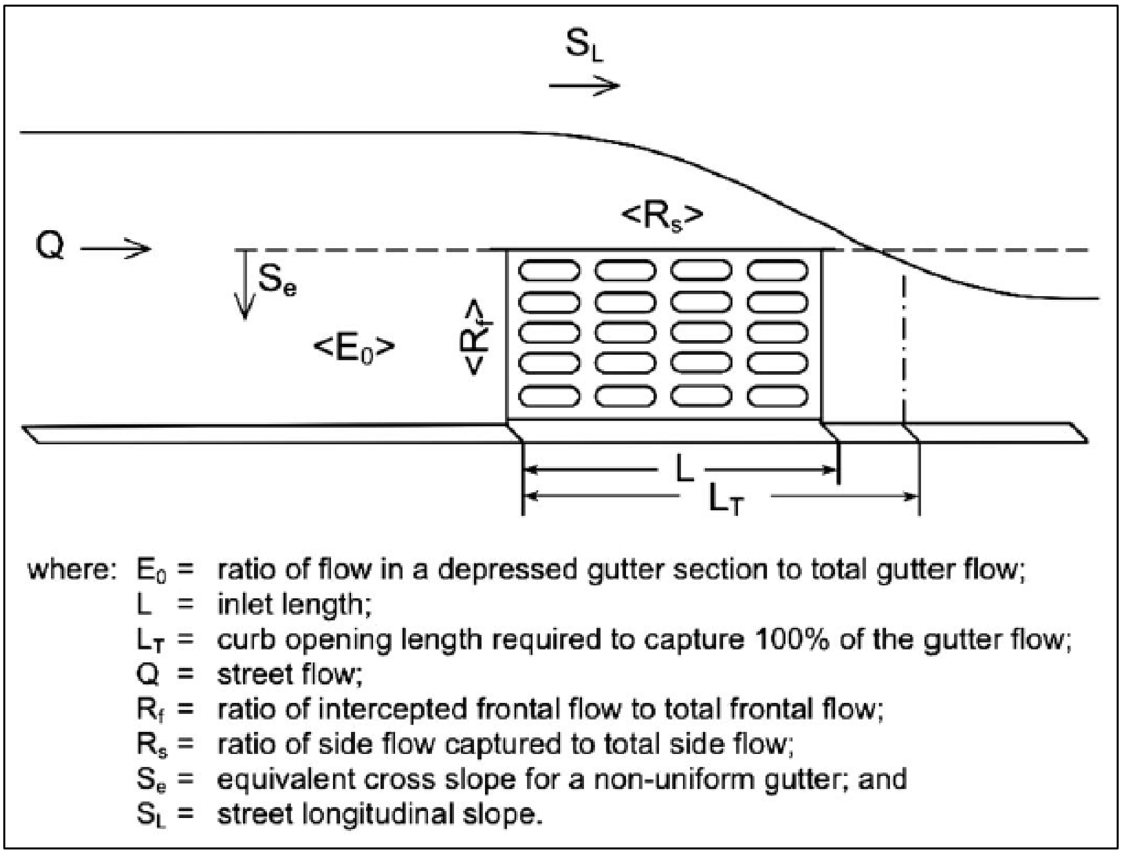


Figure 2.8 Inlet and gutter schematic (Comport and Thornton, 2012)

Bypass or "jump over" flow occurs when the inlets cannot intercept the approaching flow, and then resulting a significant amount of flow bypassed the inlet. It can be expressed as:

$$Q_b = Q - Q_i \qquad \text{Equation 2.2}$$

where:

Q_b = bypass flow;

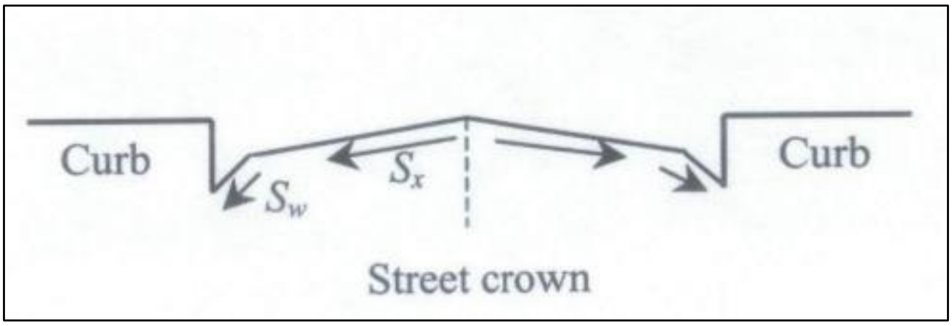
Q_i = intercepted flow; and

Q = total approaching flow.

Increases in inlet length, roadway cross slope, and highway roughness enhance inlet interception. In contrast, raising the longitudinal slope of the roadway reduces inlet interception. Experiments have demonstrated that lowering the gutter section at an entrance improves inlet interception. Allowing a small percentage of the flow in the gutter to bypass the inlet is another way to increase the design inlet interception (Frank et al., 2007).

2.6 Road Slopes

The slope of the paved areas is one of the factors that influence the efficiency of the inlet. It uses gravity to transport water surface runoff from one location to another. The longitudinal slope (S_o), transverse slope (S_x), and gutter slope (S_w) are the three main components that make up the road slope classifications. Road slope classification varies by region and province. The longitudinal slope is a slope that runs the length of the road and changes based on the elevation of the ground surface. From the street crown to the curb, the cross slope spans half of the road cross-section. Transverse slope also known as cross slopes are developed by including the need for relatively steep cross slopes for drainage with the flat cross slopes for the easiness of road users (Mustaffa, 2003). Figure 2.7 depicts the cross-section of the road



.

Figure 2.9 Cross-section of the road (Mustaffa, 2003).

The gutter slope can be found when the depressed gutter is designed to concentrate the approaching flow into the inlet. The cross slope serves as the starting point for the gutter slope ((Mustaffa, 2003).

Brown et al. (2013) state that minimum longitudinal slope is essential for curb inlets because the curb restrains the flow. The desired gradient should be greater than 0.5 % for curbed pavement, with an absolute minimum of 0.3 %. Table 2.1 shows details of an acceptable range of cross slopes with various pavement surface types.

Table 2.1 Normal Cross Slope, Brown et al. (2013)

Surface type	Cross slope
High type surface Two lanes Three or more lanes in 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 Bituminius or concrete With curbs	 2.0 – 6.0 ≥ 4.0

A steeper cross slope of 2.5 % can be employed in locations prone to severe rainfall events to aid drainage. It is preferable to enhance the cross slope of the outermost lanes on multi-lane highways where three (3) or more lanes are inclined in the same direction to counter the increment of the flow depth. The two (2) lanes adjacent to the crown line should be installed with a regular slope, and the slope of subsequent lane pairs or sections should be increased by around 0.5 to 1 % outward (Brown et al., 2013).

CHAPTER 3

SLR, DATA EXTRACTION & SYNTHESIS: METHODOLOGY

3.1 Introduction

This chapter presents the methods for conducting a systematic literature review (SLR) on the hydraulic efficiency of gully inlet, curb, and combination inlets. This review aims to improve our understanding of existing scientific knowledge and research on hydraulics efficiency of different gully inlet, curb and combination inlets design and the limitations of each method and design. The significant weaknesses and gaps impede hydraulic efficiency assessment and the path forward for future research.

3.2 SLR Protocol

The protocol was developed when executing the systematic review literature. The protocol lays out all three protocols (sub-processes) that must be adopted to avoid author bias during a study. The first protocol began by formulating the review questions, followed by defining the searching strategy. Then, the inclusion and exclusion criteria were selected among specified primary studies in the searching strategy systematically. Subsequently, the derived data elements from the preliminary analyses were established to answer the review questions.

3.2.1 Formulation of Review Questions

The formulation of the review question was the first step of a systematic literature review. These review questions were created to answer the hydraulics efficiency of different gully inlet, curb, and combination inlets and their limitations of each method and design, followed by pre-formulated specific review topic and objectives.

3.2.2 Searching Strategy

The second step of conducting SLR was the searching strategy. The number of databases available for SLR searches was limited, though the topic area heavily influences the number of databases found. As a result, the search string description was based on the terminology defined for the hydraulic efficiency of gully inlets, curb, and combination inlet in the SLR application that focused primarily on its review topic, objectives, and questions. This stage consisted of identification, screening, and eligibility.

3.2.2(a) Identification

The identification step was to search for any synonyms, similar phrases, or variations for the main keywords for more related articles for the study. The online thesaurus, keywords used in previous research, keywords suggested by Scopus, and key phrases were used to identify suitable keywords. The searching process was conducted on selected leading and supporting databases using advanced searching techniques such as the Boolean operator, phrase searching, truncation, wild card, and field code function separately or by combining these searching techniques into a complete searching string the main and enriched keywords.

Scopus and Science Direct were the search databases used in this analysis. The search was performed in these globally recognized databases to gather relevant information from journals. The search strings were used to search and collect related literature articles on the selected databases. The number of available publications and the date of acquisition was also noted. Table 3.1 shows the main keywords enrichment for review topic, objectives, and question

Table 3.1 Enriching main keywords for review topic, objectives and questions

Section	Main keywords	Enriched keywords
Review topic: Hydraulic Efficiency of Gully Inlets, Kerbs, and Combination Inlets: A Systematic Review	hydraulic efficiency	-
	gully inlet	catch basin, stormwater inlet
	combination inlet	-
	curb	kerb
R.O.1: To study different gully inlet, kerb and combination inlets designs	study	investigate, evaluate, examine, determine, identify, review
	different	dissimilar, distinct
	gully inlet	catch basin
	combination inlet	-
	kerb	curb
	design	construction, model, composition
R.O.2: To review the methods to determine the efficiency of the different gully inlet, kerb, and combination inlet designs	review	investigate, evaluate, examine, study, identify
	method	procedure, approach, methodology, technique., way, process
	determine	investigate, evaluate, examine, study, identify, review
	efficiency	effectiveness, performance
	different	dissimilar, distinct
	gully inlet	catch basin
	combination inlet	-
	curb	kerb
	design	construction, model, composition
R.O.3: To compare and identify the limitations of each method	compare	analogize, equate, assimilate
	identify	investigate, evaluate, examine, study, determine
	limitation	limit, constraint, restriction

	method	procedure, approach, methodology, technique, way, process
	determine	investigate, evaluate, examine, study, identify, review
	efficiency	effectiveness, performance
	gully inlet	catch basin
	combination inlet	-
	curb	kerb
	design	construction, model, composition

TITLE-ABS-KEY syntax was used to the variations of the above keywords, such as (“hydraulics efficiency”) AND (“gully inlet” OR “catch basin”) AND (“curb” OR “Curb”) AND (“combination inlet”). The syntax functioned to widen the searching strategy of the literature articles on their title, abstract and keywords. However, some search terms were required to run separately or in restricted combinations due to the database’s specifications and limitations. Table 3.2 shows the full search string developed for the review topic, and Table 3.3, Table 3.4 and Table 3.5 present the full search string for review objectives.

Table 3.2 Full search string for review topic

Database	Search string
Scopus	TITLE-ABS-KEY ((hydraulic) AND ("efficiency" OR "performance") AND (gully) AND ("kerb" OR "Curb") AND (inlet) AND (combination inlet))
Science Direct	((hydraulic) AND ("efficiency" OR "performance") AND (gully) AND ("kerb" OR "Curb") AND (inlet) AND (combination inlet))

Table 3.3 Full search string for review objective 1

Databases	Search string
Scopus	TITLE-ABS-KEY (("study" OR "investigate" OR "evaluate" OR "examine" OR "determine" OR "identify") AND ("different" OR "dissimilar" OR "distinct") AND ("gully inlet" OR "catch basin") AND ("curb" OR "Curb") AND ("combination inlet") AND ("design" OR "construction" OR "model" OR "composition" OR "model"))
Science direct	(("study") AND (“different”) AND ("gully inlet") AND ("kerb" OR "Curb") AND ("combination inlet") AND (“design”))

Table 3.4 Full search string for review objective 2

Databases	Search string
Scopus	TITLE-ABS-KEY (("study" OR "investigate" OR "evaluate" OR "examine" OR "determine" OR "identify") AND ("method" OR "procedure" OR "approach" OR "methodology" OR "technique" OR "way" OR "process") AND ("determine" OR "investigate" OR "evaluate," OR "examine" OR "study" OR "identify") AND ("efficiency" OR "effectiveness" OR "performance") AND ("gully inlet" OR "catch basin") AND ("kerb" OR "Curb") AND ("combination inlet") AND ("design" OR "construction" OR "model" OR "composition" OR "model"))
Science direct	(("study") AND (“method”) AND (“determine”) AND (“efficiency”) AND ("gully inlet") AND ("kerb" OR "Curb") AND ("combination inlet") AND (“design”))

Table 3.5 Full search string for review objective 3

Databases	Search string
Scopus	TITLE-ABS-KEY (("compare" OR "analogize" OR "equate" OR "assimilate") AND ("study" OR "investigate" OR "evaluate" OR "examine" OR "determine" OR "identify") AND ("limitation" OR "limit" OR "constraint" OR "restriction") AND ("method" OR "procedure" OR "approach" OR "methodology" OR "technique" OR "way" OR "process") AND ("determine" OR "investigate" OR "evaluate," OR "examine" OR "study" OR "identify") AND ("efficiency" OR "effectiveness" OR "performance") AND ("gully inlet" OR "catch basin") AND ("kerb" OR "Curb") AND ("combination inlet") AND ("design" OR "construction" OR "model" OR "composition" OR "model"))
Science direct	(("identify") AND (“limitation”) AND (“method”) AND (“determine”) AND (“efficiency”) AND ("gully inlet") AND ("kerb”) AND ("combination inlet") AND (“design”))

The preliminary of the searching studies was found to be 21 records. The search string was re-evaluated due to an insufficient number of articles. The second attempt of the searching strategy was conducted with lesser keywords to widen the search in the databases. The terms gully inlet, grate inlet, curb inlet, and combination inlet were used in the second attempt to represent both the review topic and the review objectives. These types of inlets were commonly used by researchers on the determination of hydraulic efficiency. Table 3.6 shows the full search string for mentioned keywords.