FIELD INVESTIGATION ON THE PERFORMANCE OF STREET INLETS

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***Abstract* -** Street inlets, also known as storm water inlets, are provided to intercept rainwater runoff from the roads. These inlets are part of the drainage system. The nature of roads in Malaysia where there is too much surface runoff leads to urban flooding. With urbanization, there are more concrete structures and thus less rainwater infiltrates into the ground. This research is aimed to identify several existing street inlets in Malaysia with case studies carried out within the area in Universti Teknologi PETRONAS, and also to determine the efficiency of the selected street inlets by means of field investigation. A collection tank to simulate rainfall is used to measure and analyze the efficiency of the street inlets. Based on field investigation, street inlets with the addition of deflectors have proven to improve performance and efficiency of the inlet in intercepting surface runoff**.**

I. INTRODUCTION

A. Background of Study

Rain water runoff presents numerous safety hazards in urban areas. On-road ponding and urban flooding are some of the hazards. In an urban setting these hazards are substantially magnified due to the increased traffic. Thus, street inlets, also known as storm water inlets, are provided to intercept this runoff from the roads.

This research is a field investigation to study the efficiency of street inlets that exist in Malaysia and understanding the hydraulic behavior of selected street inlets. There are three main designs of street inlets i.e. curb inlet, grate inlet and a combination of them both. The site location in which this field investigation is carried out is various street inlets located in Universiti Teknologi PETRONAS.

B. Problem Statement

Malaysia is subjected to the equatorial climate, thus having no dry season. With yearly precipitation between 2000 mm and 3000 mm, the degree of excess runoff generated from developed areas results in immediate flash flood. The nature of roads in Malaysia where there is too much surface runoff that leads to urban flooding. With urbanization, there are more concrete structures and thus less rainwater infiltrates into the ground. Roads, roofs, car parks, and paved surfaces allow a significant increase in rainwater runoff quantity. Apart from that, surface runoff also leads to traffic hazards. It can be hypothesized that without blockage, the storm water will 100% be intercepted by street inlets.

C. Objectives

The objectives of this project are:

1. To identify several existing street inlets in Malaysia with case studies carried out within the area in UTP.
2. To determine the efficiency of the selected street inlets by means of field investigation.
3. To propose a design to improve performance of street inlet.

D. Scope of Study

The scope of study of this project is field investigation involving various street inlets located within Universiti Teknologi PETRONAS. It includes the study of the dimensions of these inlets, the locations of these inlets, the inlet capacity calculation and hydraulics consideration.

II. LITERATURE REVIEW

Urban storm water management is everything done within a catchment to remedy existing storm water problems and to prevent the occurrence of new problems [1]. In urban areas, streets are part of the storm water drainage system. These streets are equipped with street inlets, or also known as storm water inlets, to intercept runoff.

A. Types of Street Inlets

There are three types of street inlets, i.e. curb inlets, grate inlets and combination of these two. Each type has its own design and capability.

Curb Inlets

Curb inlet, in some literature known as kerb inlet, is a vertical opening in the curb through which is covered by a top slab [2].

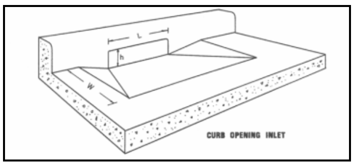


Figure 1: Curb Inlet (Adapted from Guo, 1997)

Curb inlet that is located on curb and gutter, will provide delineation on the roadway. Gutter is the side pavement next to the curb. The width of the gutter is usually about one to two feet. The capacity of a curb inlet, like any weir, depends upon the head and length of overfill.

Grate Inlets

Grate inlets, shown in Figure 2, also in some literature referred to as gutter inlets are another variation of street inlets. A grate inlet is an opening in the gutter covered by one or more grates that are parallel with the flow. There are two types of grate inlets, namely grate with longitudinal bars and grate with transverse bars.

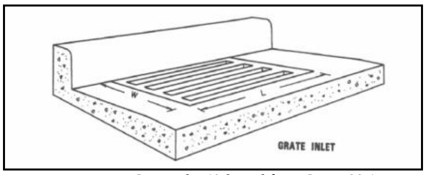


Figure 2: Grate Inlet (Adapted from Guo, 1997)

The term longitudinal bar grate refers to a grate in which the bars are orientated parallel to the direction of flow, as shown in Figure 3(a). Transverse bar refer to bars located perpendicular to the direction of flow, as shown in Figure 3(b). Grate inlets with longitudinal bars are more preferable than inlets with transverse bars.

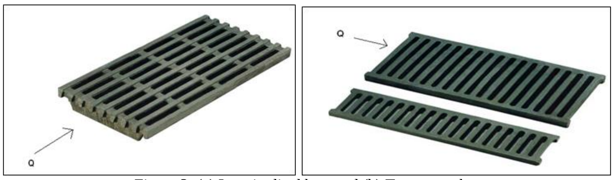


Figure 3: (a) Longitudinal bars and (b) Transverse bars

Generally, a grate inlet operates either as an orifice or weir, depending on the condition of water above the inlet [2], [3]. It functions as a weir under shallow conditions while orifice-operated inlet takes place when the inlet operates under the submerge condition.

Combination Inlet

A combination inlet, as shown in Figure 4 consists of a grate inlet and also a curb opening. The flow interception capacity of this type may be approximated by the sum of the flow amounts intercepted by the grates and curb-opening.

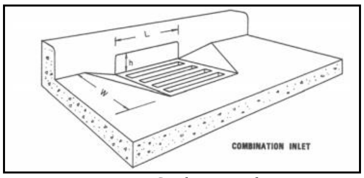


Figure 4: Combination Inlet

The combination inlet offers an overflow drain if part of the inlet becomes completely or severely clogged by debris. Maintenance of combination inlets is usually facilitated by the fact that the grate is removable, providing easy access to the inlet and associated storm drain system.

B. Governing Equations of Street Inlets

There are two types of equation that may be used for the calculation of flow for these street inlets. The orifice equation is used if there is a maximum flow of water to submerge the entire inlet. On the other hand, if there is only a small amount of storm water running over the inlet, the weir equation is used.

Orifice Equation

An orifice is a submerged opening with a closed perimeter through which water flows.

Figure 5: Orifice flow through a grate inlet

For orifice flow through a grate inlet, the equation is given as:

$$Q = NC\sqrt{2g}W_gL_gd^{\frac{1}{2}} \qquad (1)$$

Where
Q = orifice flow
N = orifice area opening ratio
C = orifice discharge coefficient
W_g =grate width
L_g =grate length
d=water depth

For orifice flow through a curb inlet, the equation is given as below:

$$Q = C\sqrt{2g}L_cH_cd^{\frac{1}{2}} \qquad (2)$$

Where
L_c= length of curb-opening
H_c= height of curb-opening

Weir Equation

A weir is a barrier in an open channel over which water flows.

Figure 6: Weir flow through a grate inlet

For weir flow through a grate inlet, the equation is given as:

$$Q = NC\sqrt{2g}(2W_g + L_g)d^{\frac{1}{2}} \qquad (3)$$

Where
Q = weir flow
N = weir length opening ratio after subtracting steel bars
C = weir discharge coefficient

For weir flow through a curb inlet, the equation is given as:

$$Q = C\sqrt{2g}L_cd^{\frac{3}{2}} \qquad (4)$$

C. Studies on Street Inlets

Previous investigations that were done on street inlets were studied and compared. Studies done were categorized into experimental, numerical and also by means of field investigation. This was done to validate the hypotheses proposed and also to further understand the topic.

Mutaffa [4] suggested that several factors need to be taken into consideration in the designing of a street inlet. Among them include

- The assumed capacity of an inlet based on past experience
- The structural strength of the inlet grating
- The effect of the inlet on traffic
- The effect of the grating on pedestrians
- The costs of installation and maintenance

No single type of inlet can be considered the best [5]. When selecting inlets, hydraulic considerations are sometimes sacrificed relative to potential for clogging, nuisance to traffic, convenience, safety and cost. The American Society of Civil Engineers drafted out these following factors to be considered before choosing an inlet type [6]:

- *Likelihood of clogging*: If clogging due to debris is not expected, a grate or combination type inlet will provide more capacity than a curb opening inlet. Otherwise, a curb opening inlet may be favourable. A local depression at will increase the inlet capacity.

- *Traffic Considerations*: If traffic is expected close to the curb and the street slope is steep, a deflector inlet should be used. If the street slope is relatively flat and a potential exists for debris clogging the deflector slots, a gutter or combination having a grate inlet with longitudinal bars should be used. These however, may be hazardous to bicycle traffic.

- *Safety*: This includes traffic and pedestrian safety as well as safety of road users such as cyclists.

Laboratory studies done confirm that the efficiency of an inlet depends on the length of the opening, longitudinal slope, cross-fall and whether there are any deflector bars to divert flow into the grate [7]. The capacity of an inlet increases with respect to water depth, starting with weir flow and then switching to orifice flow.

The operation of a combination inlet is dominated by the grate when water depth is shallow, and then switched to the curb opening when water depth becomes deep [8]. The transition flow can be modelled as a mixing flow.

All cases investigated in this study were under no clogging condition, which otherwise may have affected the efficiency. It has been recommended that a decay-based clogging factor be applied to the grate area when the grate operates as an orifice or to the wetted perimeter when the grate operates as a weir [9].

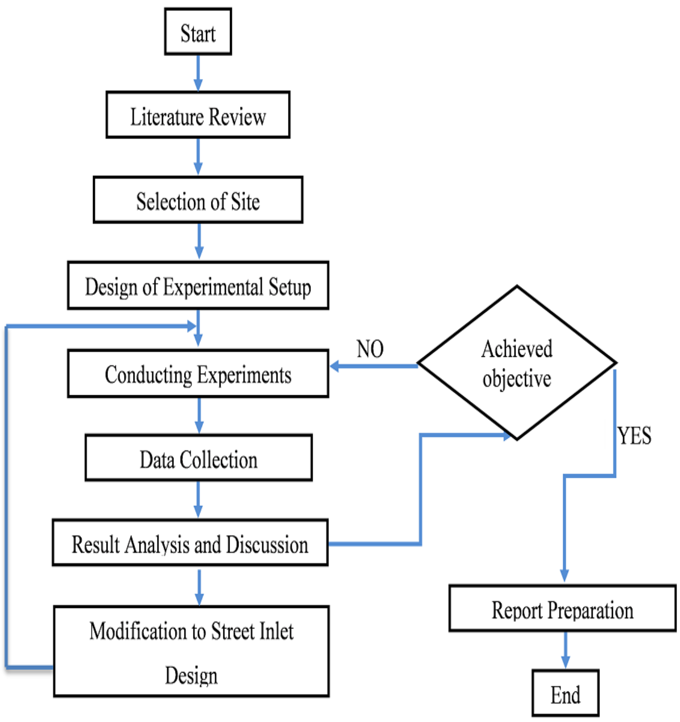
D. Critical Review

The analysis for the performance of each type of inlets is investigated by determining the inlet interception capacity. These inlet capacity calculations are based on the Urban Stormwater Management Manual for Malaysia [10]. A few justifications were made while studying flow estimation and methodology of flow, as well as making assumptions and simplifications for the theoretical evaluation on the storm water inlet performance.

Based on the literature review carried out, it can be concluded that the geometry of a street inlet plays a key role in the storm water drainage. An inlet may perform differently depending on the water depth. Clogging of street inlets also affect the performance in intercepting runoff. This study was conducted to refine the current design methods for street inlets.

III. METHODOLOGY

The following is the flow chart of the methodology of this project:



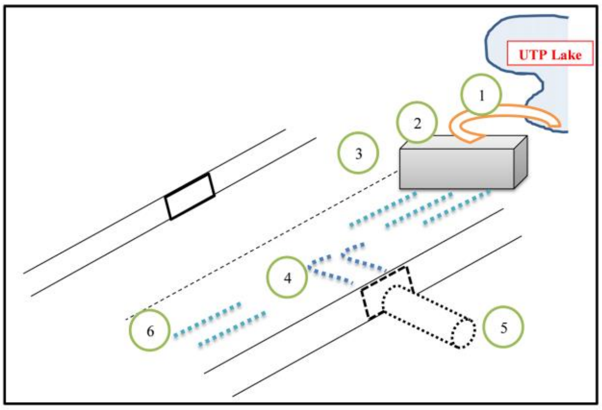


Figure 7: Experimental Setup

1. Water source from a lake will be used.
2. Collection tank will be used to produce the sheet flow. The approaching flow, $\boldsymbol{Q_a}$, will be calculated using equation (4).
3. Water is released from the collection tank in the form of sheet flow.
4. Intercepted flow, $\boldsymbol{Q_i}$ into the street inlet.
5. $\boldsymbol{Q_i}$ will be collected into a beaker.
6. Bypass flow, $\boldsymbol{Q_b}$ to be calculated using equation (5).
7. $\boldsymbol{Q_a}$ will be varied, and steps 1 to 6 will be repeated.

Modifications to the existing street inlet will be done by the addition of deflectors as shown in Figure 8. The deflectors will be varied at different angles, where 0°≪θ≪90°.

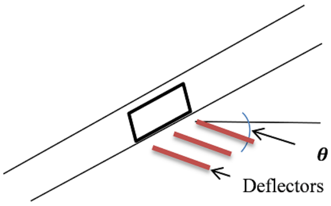


Figure 8: Experimental Setup

The investigation will be governed by this following equation:

$$Q_b = Q_a - Q_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where

$\boldsymbol{Q_a}$ = approaching flow

$\boldsymbol{Q_i}$ = intercepted flow

$\boldsymbol{Q_b}$ = bypass flow

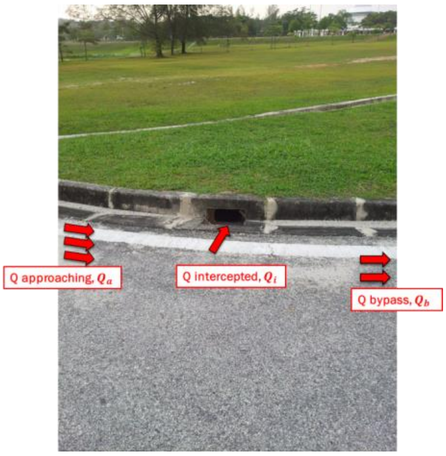


Figure 9: Flow of surface runoff

Figure 10: Plan view of collection tank for field investigation

IV. RESULTS AND DISCUSSION

A. Field Investigation Results

Primary Test

A primary test was conducted to gauge efficiency, $\boldsymbol{\eta}$ of street inlet at varied height, H. The approaching flow is then calculated using equation (4). The H is varied by adjusting the valve. The result of the primary test is as shown in Table 1.

Table 1: Primary test to gauge efficiency, $\boldsymbol{\eta}$ of street inlet at varied H

$\boldsymbol{H(m)}$	$\boldsymbol{Q_a(\frac{m^3}{min})}$	$\boldsymbol{Q_i(\frac{m^3}{min})}$	$\boldsymbol{\eta} = \frac{Q_i}{Q_a}$ (%)
0.005	0.037	0.014	37.84
0.010	0.104	0.015	14.37
0.015	0.192	0.016	8.33

Figure 11: Collection tank used to produce sheet flow

Based on the results of this test, it can be seen that the efficiency of the inlet decreases with increased flow. When the approaching flow is overwhelming the inlet will not be able to perform at its level best. It can be deduced that the curb inlet is only able to cater for so much before failing thus producing reduced efficiency.

Angle of deflector, θ test

A second field test was carried out to determine the optimum angle of deflector that would channel the most flow into the curb inlet. Three cylindrical rods of diameter 10mm were used as deflectors. The results are as shown in Table 2.

Table 2: Angle of deflector, θ test

$\theta(°)$	$Q_a(\frac{m^3}{min})$	$Q_i(\frac{m^3}{min})$	$\eta = \frac{Q_i}{Q_a}$ (%)
30	0.037	0.014	37.84
45	0.037	0.016	43.24
60	0.037	0.013	35.14

Based on this test results, it can be observed that 45° produced the highest flow intercepted, thus, the highest efficiency. 30° were too acute of an angle thus resulting in minimal interception.

Figure 12: Deflectors at an angle of 45°which produced the highest efficiency.

Location of source test

This experiment was carried out to investigate the efficiency of the inlet with respect to travel distance, L. This L is a representation of the variation of distance from the source of on-road ponding to the nearest street inlet.

Table 3: Location of source test

$L(m)$	$Q_a(\frac{m^3}{min})$	$Q_i(\frac{m^3}{min})$	$\eta = \frac{Q_i}{Q_a}$ (%)
1.8	0.037	0.015	40.54
2.4	0.037	0.011	29.73
3.0	0.037	0.007	18.92

Figure 13: Varying location of approaching flow from curb inlet

Based on this test results are as shown in Table 3, it can be observed that the nearer the location of source is to the inlet, the higher the efficiency. This is apparent in cases of on-road ponding, where runoff naturally flows to the inlet nearest within its proximity.

B. Discussion on Findings

Based on the results of the individual tests findings, it can be deduced that there are limitations to the current design of curb inlets that limits the capability of these inlets. The efficiency results of the primary test prove that less than half of surface runoff is actually intercepted by street inlets. This, on the other hand, also indicates that a large quantity of the surface runoff acts as bypass. If this situation is let to prolong, it poses a threat to the safety of road users especially motorists.

The deflector test results also prove that modification to the curb inlet may increase the value thus the efficiency of the inlet. Having a medium to channel the approaching flow to the inlet may assist in increasing the intercepted flow. These deflectors do not interfere with road use since it is small in diameter and do not obstruct traffic or road users in any way.The final test of location of source was a test to simulate the incidents of on-road ponding which occurs frequently in cases of heavy downpours. This test goes on to prove that the efficiency of the interception increases when the inlet is close to the source of flow.

Flow across intersections, ramps, and to a lesser extent, driveways, may cause a traffic hazard, while flow across cross-walks and curb ramps may cause a pedestrian hazard. Inlets at these locations should be designed to capture 100% of the flow. Inlets should also be located hydraulically to prevent excessive gutter flow and excessive ponding, at a reasonable distance apart which would enable them to perform better in cases of ponding due to flash floods and also sagging location.

V. CONCLUSION

Street inlets play a crucial role in drainage and safety of road users. To increase the efficiency and at the same time, reduce untoward incidents, several measures can be taken. The depth of flow in the gutter can be increased by increasing the cross-slope in the pavement. The flow can be concentrated at the inlet by depressing the gutter, also the curb and the gutter opening can be combined in a single inlet. Deflectors at an angle of 45° should be placed in the path of the water to increase overfill into the street inlet. Apart from that, since the geometry of a street inlet plays a key role in the storm water drainage, the street inlets should be placed at reasonable distances to cater for on-road ponding.

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REFERENCES

[1] Walesh, S. G. "*Urban surface water management*." John Wiley & Sons, 1989.

[2] Mays, L. W. "*Water resources engineering*." John Wiley & Sons, 2001.

[3] Guo, J. "Street Hydraulics and Inlet Sizing". Water Resources Publications, LLC, 1997, pp 12-17.

[4] Mustaffa, Z. *An experimental investigation of the hydraulics of street inlets* (Doctoral dissertation, UNIVERSITI TEKNOLOGI PETRONAS), 2003.

[5] John Hopkins University. "The Design of Storm Water Inlets". Department of Sanitary Engineering and Water Resources, 1956, pp 17-22.

[6] Design and construction of urban stormwater management systems. *American Society of Civil Engineers ASCE*, 1992.

[7] Guo, J."Street Storm Water Conveyance Capacity." J. Irrig. Drain Eng., 126(2), 2000, pp 119–123.

[8] MacKenzie, K., and Mommandi, A."Design of Street Sump Inlet." J. Hydraul. Eng., 135(11), 2009, pp 1000–1004.

[9] Guo, J. "Design of Street Curb Opening Inlets Using a Decay-Based Clogging Factor." J. Hydraul. Eng., 132(11), 2006, pp 1237–1241.

[10] Department of Irrigation and Drainage Malaysia. "Urban Stormwater Management Manual for Malaysia". Property Drainage and Inlets, v9, 2000, pp 24-14.