Efficiency of simple curb inlet design in Malaysia

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Abstract. This paper attempts to investigate the efficiency of typical curb inlet design used in Malaysia. Curb inlet is a common type of stormwater inlet of the urban drainage systems which functions to intercept excess stormwater on the street and convey them to another drainage system. The design (shape and type) of stormwater inlets used in a developing country like Malaysia, however might be considered as ‘too simple’ as compared to other developed countries. The choice of design might be heavily subjected to the aspect of easiness during construction. For a tropical country that receives a lot of rain throughout the year, this conventional design may eventually lead to street ponding. Thus, the effectiveness of these structures is then considered very crucial. Field investigation has been carried to study the actual performance of the curb inlet and its efficiency is reported. Results showed that the existing curb design would be efficient to intercept lower discharges because at higher discharges, the flow would be flowing downstream as bypass flows. Simple modification was proposed to the existing curb inlet by placing a 45° deflector near the curb, which was found to be able to intercept 10% more flows to the inlets.

1. Introduction
In urban areas, streets are part of the stormwater drainage system. Stormwater inlets, also known as street inlets such as the grate, curb and combination inlets (Figure 1) are structures located on the street, in which its main function is to intercept excess stormwater. The under-estimated design of street inlets results in many unavoidable consequences that cause a nuisance to the pedestrians and roadway users. For instance, when water on the street exceeds certain allowable water depth and spread, the accumulated water at any sump locations starts to pond. Ponded water can also be observed at the vicinity of inlets that are blocked by debris. This situation in a way diminishes the effectiveness of the inlets in intercepting water.

The performance of street inlets is governed by many factors that include the type, size, shape, pattern of inlet bars, area of openings, street slopes and the characteristics of flow at the upstream section. Based on these factors, researches started to critically study the effectiveness of different types of street inlets. Results from experimental investigations, for example, are widely referred by engineers when designing the inlets [1, 2]. Later, the others study and many others conducted studies in many aspects of street inlets, but the emphasis was mainly given to inlet bar orientations and patterns [1-7]. Since the nature of inlets located elsewhere are mostly adapted to its surroundings, the inlet designs vary in many ways. Therefore, current results are not applicable unless similar conditions and environments are applied.
In a developing tropical country like Malaysia, the annual precipitation is between 2000 and 3000 mm. Rainwater (surface) runoff presents numerous safety hazards in urban areas especially for the impermeable surface like the roadways [8]. Thus, the function of stormwater inlets is very critical to control or reduce the rainwater accumulated on the streets. It can be hypothesized that without blockage, the rainwater will be 100% intercepted by the inlets. The design (shape and type) of stormwater inlets used in a developing country like Malaysia, however, might be considered as ‘too simple’ when compared to other developed countries in the world. The curb inlet type, for instance, is more common to be found in many places in the country. The choice of design might be heavily subjected to the aspect of easiness during construction. Consequently, this outdated design may eventually lead to ponding conditions on the road. Thus the effectiveness of these structures is then considered very crucial. Reassessment on the performance of these inlets should be carried out. Therefore, the present research aims at carrying field investigations to investigate the efficiency of a typical curb inlet design used in Malaysia. In addition to that, a simple modification is proposed to the existing curb inlet by placing deflectors near the curb.

2. Literature review

The John Hopkins University reported that there are four major groups of inlets, which include the grate inlets, curb inlets, combination inlets, and multiple inlets [2]. In addition, the previous study introduced another inlet, known as the slotted drain [9,10]. A gutter inlet (figure 1(a)) is an opening in the gutter covered by one or more grates that are parallel to the flow. A curb inlet (figure 1(b)) is a vertical opening in the curb covered by a top slab. A combination inlet (figure 1(c)) is composed of a curb and a grate inlet acting as a unit. Usually, the grate inlet is placed directly in front of the curb opening and this arrangement is called a contiguous combination inlet or a combination inlet. The intercepted flow in a combination inlet can be approximated by the sum of the amount of flow intercepted by the grates and curb openings. Slotted drain inlet (figure 1(d)) comprises a pipe cut along the longitudinal axis with a grate of spacer bars to form slot openings. In a normal design storm event, the curbs and gutters collect flows along the street and convey them in the form of a triangular channel as sketched in figure 2.

This condition is best described as flows in an open channel mode. Rainwater on the street can be classified into two categories; the frontal and side flow. Frontal flow is governed by the amount of flow carried within the gutter width. Side flow flows around the grate when the water spread, $T$ is larger than the grate width, $W$. Splash overflow is a portion of the flow that splashes over the grate. Normally the inlet does not intercept this flow.
The velocity of the approaching flow is governed principally by the shape of the channel cross-section, the slope along the channel and the roughness of the wetter perimeter. The modified Manning equation for flows in the gutter is given as [11],

\[ Q_o = \frac{\phi}{n} S_o^{1/2} S_x^{5/3} T^{8/3} \]  

(1)

Where, \( Q_o \) is the total flow, \( \phi \) is 0.375 (SI units) or 0.56 (U.S. Customary units), \( S_x \) is the cross slope and \( T \) is the top width of flow. This equation is valid for undepressed gutter but some modifications needed for depressed gutter (Figure 2(b)). The total flow, \( Q_o \) in the depressed gutter is defined as,

\[ Q_o = Q_w + Q_x \]  

(2)

where \( Q_w \) is the frontal flow carried by the gutter width and \( Q_x \) is the side flow carried by street width.

The intercepted flows into the inlet may behave differently, depending on the nature of the approaching flows, thus the choice of equations to be used is very much affected accordingly. The capacity of an inlet increases with respect to water depth, starting with weir flow and then switching to orifice flow. When the approaching flow submerges the inlet, the flow behaves as an orifice flow while when there is only a small amount of rainwater running over the inlet, the weir equation is used instead [12]. 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 [13].

Another flow component that is also important is the carryover flow \( Q_c \) that is not intercepted by the inlet and moves further downstream. The \( Q_c \) can easily be computed using,

\[ Q_c = Q_o - Q_i \]  

(3)

The efficiency, \( \eta \) of an inlet can be computed by the ratio of flows being intercepted to the approaching flows, as given by Equation 4.

\[ \eta = \frac{Q_i}{Q_o} \text{ (in \%)} \]  

(4)

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3. Methodology
The first part of the analysis presented in this paper is scoped to field investigation on the performance and efficiency of a typical curb inlet design used in Malaysia, the sample of which taken at the Universiti Teknologi PETRONAS campus. The sketch of the field experimental set up is as shown in figure 3.

Figure 3. Experimental setup at the field

Figure 3(a), water from a nearby lake was pumped into a collection tank to dampen the flow, so as to also create sheet flows onto the road. The sheet flows or approaching flows ($Q_o$) as shown in Figure 3b represents the condition of an approaching flow during rainfall events. The discharge of the sheet flow was measured using a rectangular weir placed inside the collection tank (refer to Figure 3c). The sheet flows would move downstream due to the slope of the road into the curb inlet (Figure 3a). Intercepted flows ($Q_i$) would be captured by the curb inlet and collected at the other end of the drain. It was simply measured using the volumetric approach over time. Carry overflows ($Q_c$) was later computed using Equation 3.

Later on, modifications to the existing curb inlet design was made by introducing deflectors close to the inlet, as shown in Figure 4. The intention was to direct more approaching flows to be intercepted into the inlet. The deflectors were placed and tested for different angles, $\theta$ ($0^\circ < \theta < 90^\circ$). Once again, the above experimental procedures were repeated.
4. Results and discussion

The *first* set of experiments involved investigating the performance and efficiency of the existing curb inlet design under varying approaching flows. The efficiency, $\eta$ was computed using Equation 4 and results are presented in Table 1.

| $Q_o$ [m$^3$/min] | $Q_i$ [m$^3$/min] | $\eta = \frac{Q_i}{Q_o}$ [%] |
|-------------------|-------------------|-------------------------------|
| 0.037             | 0.014             | 37.8                          |
| 0.104             | 0.015             | 14.4                          |
| 0.192             | 0.016             | 8.3                           |

The results showed that the efficiency of the inlet decreases with the increment of the approaching flows. This is true as higher discharge tends to exert faster velocity, thus more flows will be flowing downstream as carrying overflows. When the approaching flow is overwhelming the inlet will not be able to perform at its level best, thus reducing its efficiency. Consequently, when the carry overflows accumulated and not able to be captured downstream, ponding conditions will take place on the lowest point of the road, mostly close to the sump area.

The *second* set of experiments was carried out to determine the optimum angle of deflector that would direct more approaching flows into the inlet at a constant $Q_o$ of 0.037 m$^3$/min. The results for this set of experiments are shown in Table 2.

| $\theta$ [°] | $Q_o$ [m$^3$/min] | $Q_i$ [m$^3$/min] | $\eta = \frac{Q_i}{Q_o}$ [%] |
|--------------|-------------------|-------------------|-------------------------------|
| 30           | 0.037             | 0.014             | 37.8                          |
| 45           | 0.037             | 0.016             | 43.2                          |
| 60           | 0.037             | 0.013             | 35.1                          |

Based on this test results, it can be observed that the 45° deflector angle produced the highest efficiency by intercepting flows the most as compared to the 30° and 60°. It is interesting to see the
results produced by the 30° and 60° deflector angles, which implies that even the most minimum (30°) or maximum (60°) deflector angle would not necessarily become the most optimum to intercept more flows. Such a phenomenon is believed to be contributed by the hydraulics of the approaching flows and the characteristics of the cross slope ($S_x$) of the road, part of which are not critically studied in this paper.

Based on all results presented earlier, it can be deduced that there are limitations to the current design of the curb inlet that limits its capability to intercept flows. All results showed that less than 50% of rainwater flowing on the street would be actually intercepted by curb inlets, a large quantity of the rainwater would act as the bypass. Such information was not fully addressed in the design of street inlets based on the national stormwater design standards *Urban Stormwater Management Manual for Malaysia* [14]. If this situation is let to prolong, the flash flood would occur which poses a threat to the safety of road users especially motorists. The deflector test results also proved that modification to the curb inlet may increase the efficiency of the inlet. Having a 45° deflector angle with respect to the channel of the approaching flow may assist in increasing the intercepted flow capability. These deflectors would not interfere with the road users since it is small and do not obstruct traffic or road users in anyways.

### 5. Conclusions

Street inlets such as the curb inlets play a crucial role in the drainage and safety of road users. To increase the efficiency and at the same time to reduce incidents, several measures can be adapted for improvement of the existing design. The depth of flow in the gutter can be increased by increasing the cross slope of the road. The flow can be concentrated at the inlet by depressing the gutter. Deflectors at an angle of 45° should be placed in the path of the water to enhance the interception capability of a curb inlet.

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.

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