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Testing the Concept of Mitigating Overflowing Urban Drain with Permeable Road

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ABSTRACT

This study describes a new idea of allowing the overflowing urban drains that cause flash flooding to be connected to a permeable road structure beside the drain. The permeable road with water storage/convey structure could soak up the spill-over waters from drains. In this regard, the Storm Water Management Model (SWMM) was utilized to assist the investigation by simulating a historical flood event with a total rainfall of 324 mm over 5200 m^2 of commercial area. It was expected to generate 1685 m^3 of surface runoff. The model provided an insight that reducing the flood event's peak discharge by half would require to have a spill-over space of 640 m^3 in the permeable road with a surface area of 1600 m^2 and a depth of 0.40 m. This allowed a guide to the selection of suitable products to construct the permeable road.

Key words : Drain, Flood, Road, Runoff reduction, Stormwater detention, Sustainable development.

1. INTRODUCTION

Flash flooding is commonly associated with an urban environment that occurred due to the accumulation of floodwaters on impervious surfaces [1]. In Figure 1, the inundation of road may be due to a filled urban drain by the roadside, which forced the runoff to flood the road. The receding period may take minutes to hours, while the floodwaters will slowly be drained away. Nevertheless, this short occurrence may cause traffic congestion, inconveniences to the public and damages to properties [2].

Figure 1: Flash Flooding of Urban Road after Heavy Rainfall

The existing urban road drainage relies solely on urban drains to carry away any water on road surfaces. This method is increasingly challenging with the occurrence of climate change phenomena as it is common for a mere one-hour rainfall to cause flash flooding. As the road is easily affected by the flash flooding scenario, this study presents an alternative design to complement the existing road system by introducing a permeable road system that could channel excess water to a water storage below the road [3],[4]. A recent study has suggested that the subsurface storage of the proposed permeable pavement system could store and convey water simultaneously [5].

The concept involves spill-over of floodwaters from the drain to be infiltrated through a layer of permeable pavement and be directed to underground storage (see Figure 2). The nature of permeability in the pavement layer comes in a variety of porous materials; most are found in porous asphalt and porous concrete [6]. Similarly, the storage layer also comes in various designs, for examples being filled with aggregates or empty chambers created by concrete and polyethylene [7].

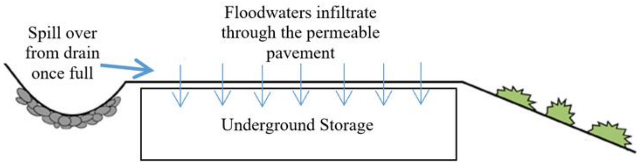

Figure 2: Concept of Proposed System

As such, the incidence of the flooded road could be alleviated by storing the runoff temporarily and delaying their release through a designated outlet downstream. Modelling of the flow processes could be conducted through a stormwater drainage model like SWMM. The software has been reported in modelling permeable roads using its Low Impact Development (LID) modules [8],[9]. Since the proposed system has not been built, a computer model is first used to test how effective can the proposed system be in mitigating the the occurrence of flash flooding.

2. MATERIALS AND METHODS

2.1 Case Study

It is assumed that urban drains received water from built-up areas of commercial buildings and roads within a city centre. To illustrate how the proposed system is functioning, the research team had selected a study area in Figure 3 of a 5200 m^2 commercial area with twenty-one premises located in Kuching city, Sarawak, Malaysia. Each of the premises had a roof area of 126 m^2 (7 m in width and 18 m in length). The 200 m long road in front of the premises was 8 m in width, inclusive of its two-way lanes and car park lots.

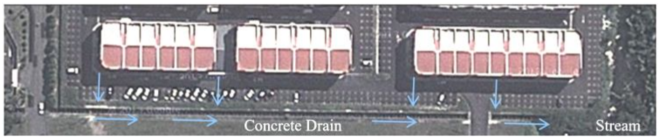

Figure 3: Study Area with Arrows indicating the Existing Drain's Flow Directions and Discharge Point

Stormwater generated by the building roof and road surfaces were drained to a 200 m long concrete drain with a dimension of 0.5 m x 0.5 m before being discharged to a tidal stream depicted at the right bottom corner of Figure 3. At times of high tide and heavy rainfall, floodwaters were spilled to the roads in front of the three rows of commercial premises. As such, the site was ideal as a case study.

2.2 Permeable Road Design

The 200 m x 8 m stretch of road in front of the commercial premises (see the highlighted stretch of road in Figure 4) were virtually designated as the intended permeable road. The water storage was treated as a variable to be determined based on the floodwater volume.

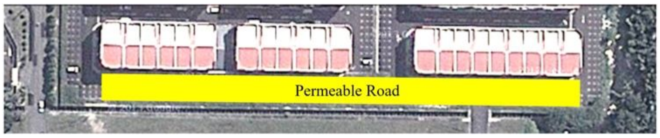

Figure 4: Proposed Layout of Permeable Road

2.3 SWMM Model Building

The impacts of the permeable road were investigated using the US Environmental Protection Agency (EPA)'s SWMM Version 5.0.

According to the Malaysian stormwater management manual, the existing stormwater drainage system was designed to a 10-year Average Recurrent Interval (ARI) design rainfall [10]. In recreating the scenario of flash flooding, the commercial area was subjected to a 10-hour extreme storm which happened on 27 February 2017 0200-1100 hours. The storm had a total rainfall of 324 mm, whereby the storm eye had a peak record of 85.5 mm (equivalent to a Red Alert/Very Heavy event). This flood event was reported in [11]. Computer models were commonly used to assist flood-related decision making [12],[13].

A schematic diagram of the existing stormwater drainage model is presented in Figure 5. The model consisted of the following components: (1) Rain gage, in which rainfall data were recorded; (2) Catchment that intercepted the recorded rainfall; (3) Nodes that represented the junctions of the drainage system; (4) Channels that represented the urban drains; and (5) Outfall that was the final discharge point of the system.

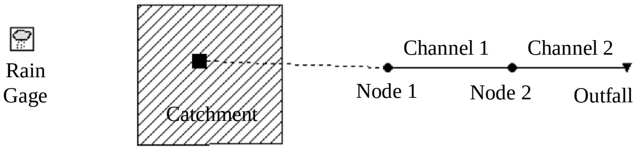

Figure 5: Stormwater Drainage Model for Existing Condition

The first model was modified to include a component of the permeable road. In the second model, presented in Figure 6, there is a storage unit with an orifice outlet that was absent in the former model. It was reported in [14] that the storage unit was best to represent the water storing capability of a permeable road.

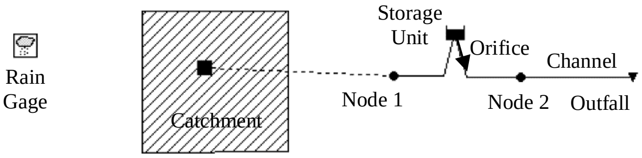

Figure 6: Stormwater Drainage Model with Permeable Road

SWMM computed runoff from the catchment based on nonlinear reservoir representation (Equation 1) [15]. The Manning's n value was found at 0.022 for roof and road surfaces [14]. The other values are characteristics measurable from the study site.

$$Q = W\frac{1.49}{n}\left(d - d_p\right)^{5/3} S^{1/2} \tag{1}$$

where,

Q = runoff generated by the associated catchment (m^3/s);
W = catchment width (m);
S = slope (m);
n = Manning roughness value (unitless);
dp = Maximum depression storage (m);
d = Depth of water over the catchment (m).

The computed Q was then routed at a time step of 30 s through the channels using kinematic wave approximation (Equation 2) which SWMM solved numerically [16]. The routing started at the first node as the upstream boundary, and stopped at the outfall as the downstream boundary.

$$q = \frac{\partial A}{\partial t} + \alpha m A^{(m-1)} \frac{\partial A}{\partial x} \tag{2}$$

where,
q = routed flow (m^3/s);
A = cross sectional area of channel (m^2);
x = distance along the flow path (m);
t = time step (s);
α = flow geometry (unitless);
m = surface roughness (unitless).

The routed flow was connected to the storage unit as inflow. Thus, Equation 3 was used to define the storage volume of the permeable road. Flow leaving the permeable road was controlled by an orifice outlet. Orifice discharge from the system is defined in Equation 4. Discharge coefficient of the orifice outlet was found as 0.060 [17].

$$St = \sum_i (q - Q_o)\Delta t \tag{3}$$

where,
St = Storage volume (m^3);
q = Inflow (m^3/s);
Qo = Outflow (m^3/s);
Δt = Duration of storm (s).

$$Q_o = A_o C_o \sqrt{2H_o g} \tag{4}$$

where,
Qo = Orifice discharge rate (m^3/s);
Ao = Orifice diameter (m^2);
Co = Discharge coefficient (unitless);
Ho = Maximum head to the centre of the orifice (m);
g = Acceleration due to gravity (9.81 m/s^2).

3. RESULTS AND DISCUSSION

The first model (Figure 7) shows modelling of the existing drain subjected to 27 February 2017 storm event. The 10-hour storm was estimated to generate 1685 m^3 of surface runoff resulting in out-of-drain flooding at the first 110 m of the drain (Stretch A-C) with a peak flood discharge at 0.095 m^3/s.

The second model (Figure 8), which was added with permeable road (following Figure 6), floodwaters were modelled to spill out from the first 50 m of the drain (Stretch a-b). The water was directed to the storage unit within the permeable road and released back to the drain at a controlled rate. This model also showed reduced water levels in the remaining drains (Stretch b-e).

The addition of permeable road was found to reduce peak flood discharge by 50% to 0.048 m^3/s. The model required a spill-over space of 640 m^3 within the permeable road. Considering the surface area of the selected road was 1600 m^2, the depth of the water storage structure shall be at least 0.40 m high.

It should be noted SWMM did not support flood mapping and it was irrelevant to do flood mapping of subsurface structure that had its water out of sight. Therefore, the figures of the two models were presented in the form of long cross-sectional plots. Another limitation of the current model set up was the exclusion of the infiltration process.

4. CONCLUSION

The SWMM models showed that instead of stopping overflowing drain, a mechanism to spill a portion of floodwaters to a permeable road proposed in this study was able to alleviate flash flooding. The surface area and depth of permeable road's structure suggested by the modelling efforts, at 0.4 m height, indicates a small structure. A structure too large is not practical as it will incur higher costs. Further investigations into this concept would involve experimenting different permeable road products by applying the suggested surface area/depth or manipulating the suggested surface area/depth.

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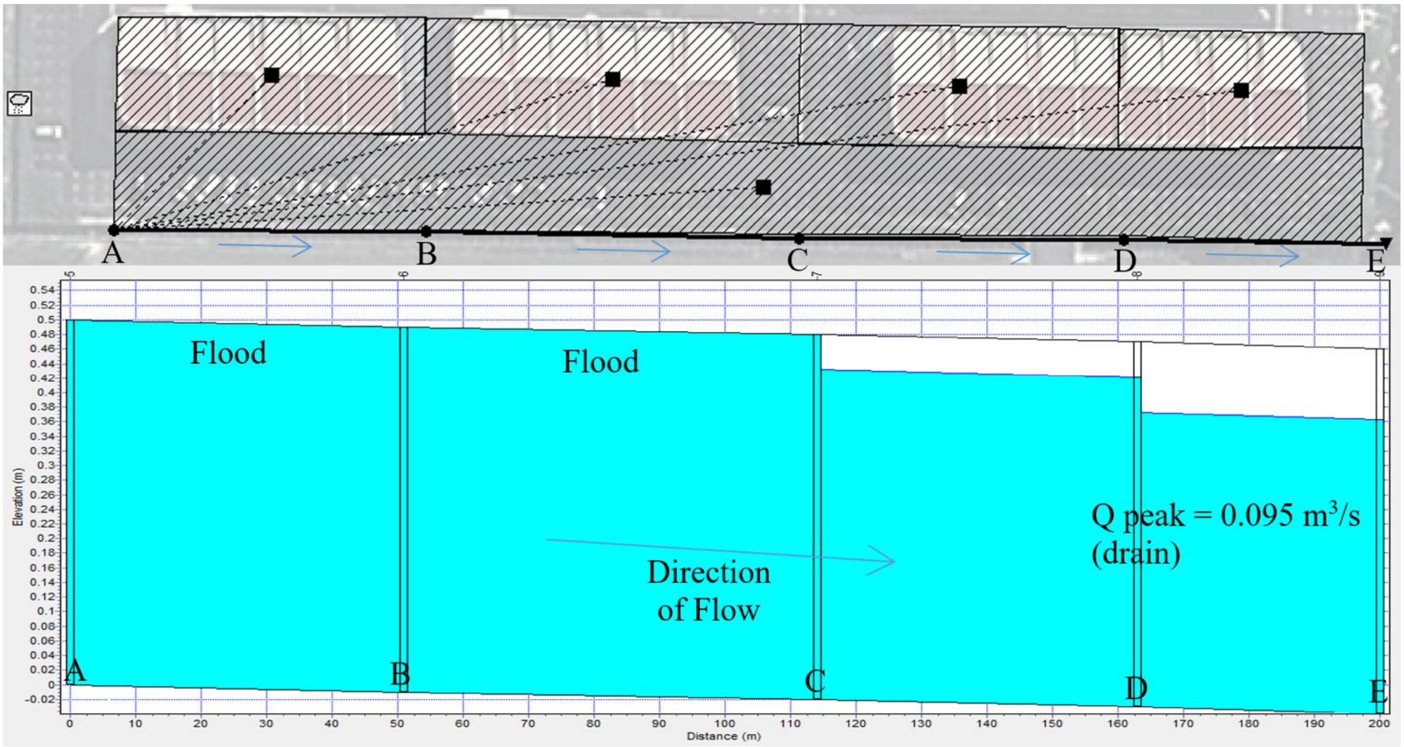

Figure 7: Modelling of Peak Flood for Existing Drain

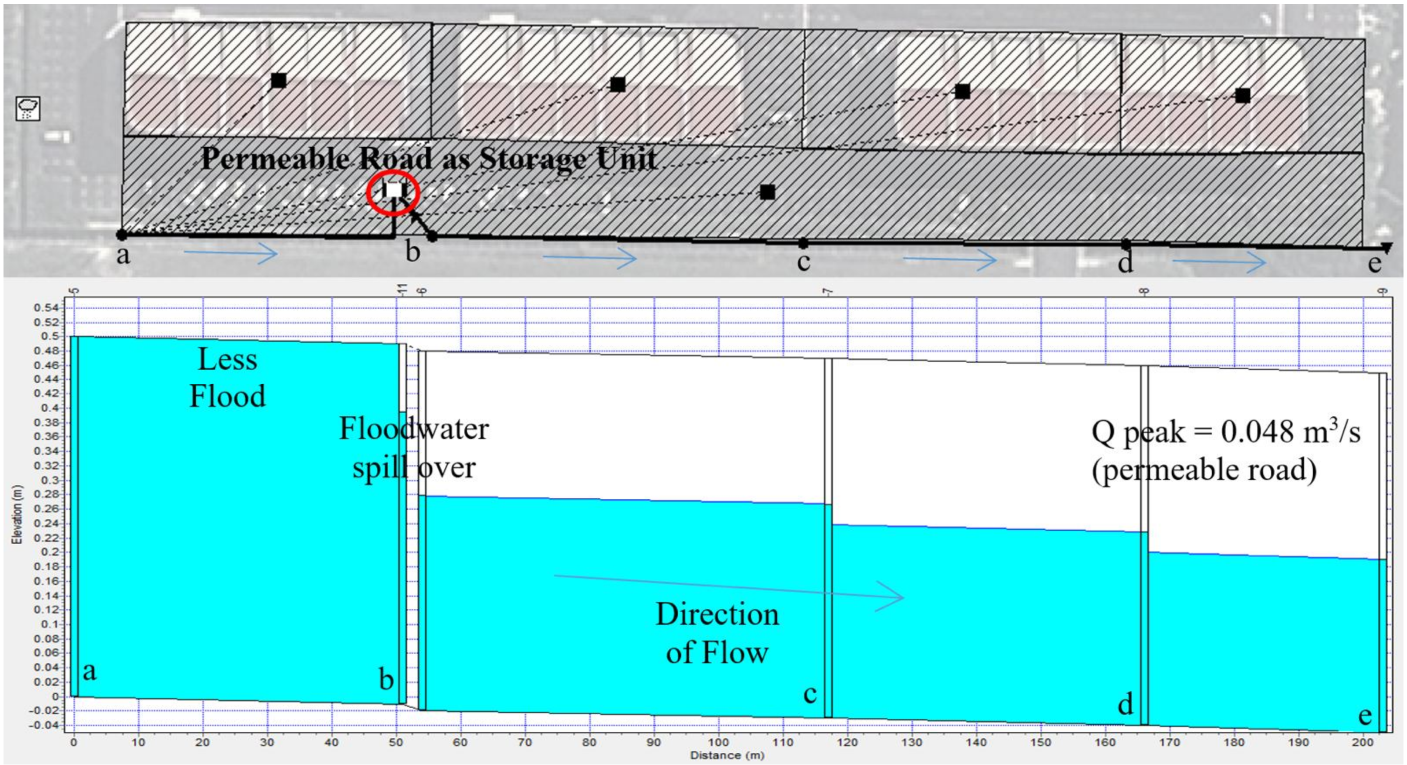

Figure 8: Modelling of Peak Flood for Drain Sided with Permeable Road

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