Faculty of Engineering

Application of StormPav Modules as Alternative Home-Based On-Site Detention System

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Application of StormPav Modules as Alternative Home-Based On-Site Detention System

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A thesis submitted

In fulfillment of the requirements for the degree of Doctor of Philosophy

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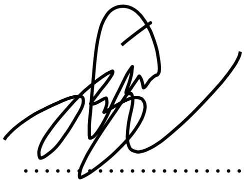
DECLARATION

I declare that the work in this thesis was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Except where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



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ABSTRACT

On-site stormwater detention system within a residential property is meant for an environmental protection device that temporarily stores stormwater within the property lot to mitigate flash flood, particularly during rainy seasons. A field test is constructed in a real-life terrace house's car porch with a 4.40 m (W) x 4.70 m (L) x 0.45 m (D) tank filled with precast-concrete modular units (StormPav) with an effective storage volume of 3.97 m^3. Inflow downpipe is installed to the detention tank and connected to the roof gutter which receives rainwater from the house roof; while a pipeline is installed to discharge outflow from the tank to the house perimeter drain. It has recorded sixteen observed storm events coincided with the 2019/2020 Northeast Monsoon that consist of rainfall depth categories ranging from 0-20 mm, 20-30 mm, 30-40 mm, 40-50 mm rainfall depths. Another four historical storm events that coincided with Northeast Monsoon seasons from 2015-2017 are sourced to augment the analysis. The Kolmogorov-Smirnov goodness of fit tests between the observed and modelled cumulative distributions have produced 0.01-0.14 maximum vertical distances that are lower than the 0.41-0.68 critical values which indicating close matches. Outcomes from the validated model have suggested to use an outlet size of 0.055 m. By combining the analyses from the field test and SWMM model, it is found the home-based system is able to contain all stormwaters of the rainfall depths mentioned above. Collected field data from a 95m^2 roof catchment is used to model an OSD system with 50m^2 and 150m^2 roof catchments. The 150m^2 roof catchment had steep line graphs and the OSD system could handle up to 30mm rainfall, but had the highest water detention and attenuation rate (65%). The 50m^2 roof catchment had the lowest attenuation rate (15%) due to limited detention.

Keywords: Field test, orifice, rainfall, StormPav, SWMM.

Ujikaji Lapangan Penahanan Di Tapak Berasaskan Rumah Menggunakan Sistem "StormPav Green Pavement"

ABSTRAK

Kajian ini meneroka sistem penahanan air hujan di tapak harta perumahan yang bertujuan melindungi alam sekitar dengan menyimpan air hujan secara sementara untuk mengurangkan banjir kilat semasa musim hujan. Ujian lapangan telah dibina di tepi rumah teres sebenar dengan tangki 4,40 m (W) x 4,70 m (L) x 0,45 m (D) yang diisi dengan unit modular konkrit pracetak (StormPav) dengan jumlah simpanan yang berkesan 3.97m^3. Saluran air masuk dan keluar disambungkan untuk menerima air hujan dari bumbung rumah dan mengalirkan air keluar dari tangki ke longkang perimeter rumah. Sebanyak enam belas peristiwa hujan dirakam semasa Musim Timur Laut 2019/2020 dalam kategori kedalaman hujan 0-20 mm, 20-30 mm, 30-40 mm, dan 40-50 mm. Empat lagi peristiwa hujan bersejarah dari tahun 2015-2017 yang bertepatan dengan Musim Timur Laut juga digunakan untuk analisis tambahan. Ujian kesesuaian keseragaman Kolmogorov-Smirnov antara taburan kumulatif yang diperhatikan dan model yang dimodelkan telah menghasilkan jarak maksimum 0.01-0.14 yang lebih rendah daripada nilai kritis 0.41-0.68 yang menunjukkan kesesuaian yang rapat. Melalui gabungan analisis dari ujian lapangan dan model SWMM, didapati sistem berdasarkan rumah mampu memuat semua air hujan pada kedalaman yang disebutkan di atas. Data lapangan yang dikumpulkan daripada kawasan penampungan bumbung seluas 95m^2 digunakan untuk memodelkan sistem OSD dengan kawasan penampungan bumbung seluas 50m^2 dan 150m^2. Kawasan penampungan bumbung seluas 150m^2 menunjukkan graf garisan yang curam dan sistem OSD mampu menangani hujan pada kedalaman 30mm, tetapi mempunyai kadar penahanan air dan pengurangan yang tertinggi (65%). Kawasan penampungan bumbung seluas 50m^2

menunjukkan kadar penahanan yang paling rendah (15%) kerana had penahanan yang terhad.

Kata kunci: *Ujian lapangan, orifis, hujan, StormPav, SWMM.*

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LIST OF ABBREVIATIONS

ARI	Average Recurrent Interval
CFD	Computational Fluid Dynamics
DID	Department of Irrigation and Drainage
MSMA	Manual Saliran Mesra Alam
OSD	On-site Stormwater Detention
SWMM	Storm Water Management Model
WSUD	Water Sensitive Urban Design

CHAPTER 1

INTRODUCTION

1.1 Background

As a piece of land experiences urbanization, the surface of the land changes from forest to physical infrastructures like buildings and roads. Referring to Figure 1.1, a land in its natural form, which is covered with vegetation, 50% of the rainwater is being infiltrated into the soil layer and parts of the rainfall is taken up by the plant roots. As such, surface runoff from forested land is as low as 10%. However, as the vegetation is replaced with physical structures, the rainwater is blocked by the buildings and roads to get into the soil layer. Instead, 55% of the rainwater accumulates on the ground surface. In this case, the surface runoff due to physical development is high (Saraswat et al., 2016).

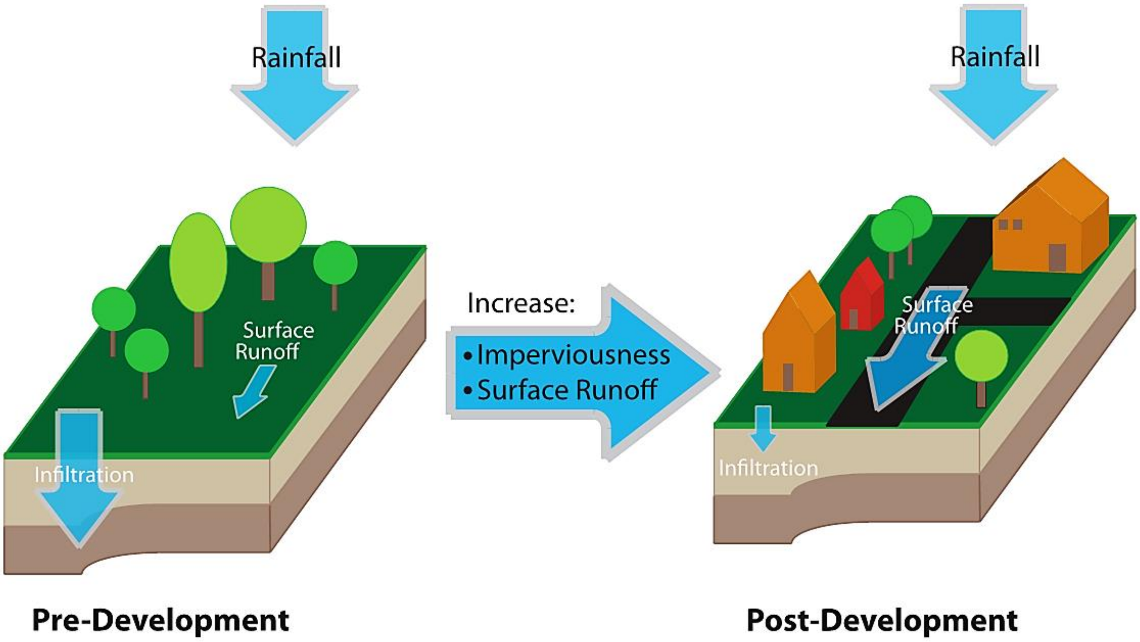

Figure 1.1: Impacts of Urbanization (Avenue Consultants, 2019)

High amount of surface runoff may lead to environmental problems, such as flash flood, erosion, and pollution. There is a need to contain the high amount of surface runoff. Engineers are trying to direct the accumulated surface runoff on ground surface to structures mimicking the functions of natutal soil layer and plant roots. With parts of water being captured by the intended structures, the amount of surface runoff is proven to reduce to near pre-development condition (Hou et al., 2022). Many types of structures have been tried on which these are further described in Chapter 2.

On-Site Detention (OSD) is one of the measures creating man-made structures in the urban environment to control stormwater surface runoff. OSD plays a role to detain a portion of the surface runoff, as mentioned above, so that the surface runoff at one time could be reduced by lowering the peak runoff. The design and structure of OSD changes over time, in which big structures are favored in the early days, and then later smaller structures are introduced. Another problem arises in the construction of these structures as the availability of open land is increasingly difficult to come by (Muangsri et al., 2022). The trend nowadays leans towards the concept of sponge city which small pockets of water detention structures are scattered along the stormwater flow paths (Fu et al., 2023). These structures are small and designed to merge with urban infrastructures. In another word, the structures are designed to be multi-purpose. Take the focus of this study, a residential car porch is a structure for housing vehicles, and at the same time, tried for water detention structure underneath it.

In the case of a housing estate, if each house could detain a portion of stormwater from the premise, the accumulated effect from the whole housing estate would have an effective reduction of urban runoff. StormPav Green Pavement System, or in short, StormPav, could function as a form of OSD as reported in Mah et al (2014). The concrete pieces that make up the StormPav, provide empty spaces in between the pieces to store water (Figure 1.2). It has three layers, in which the top and bottom layers are hexagonal plates with service inlets; while the middle layer is packed with hollow cylinders. In line with the concept of OSD, the middle layer plays a major role in allowing stormwater from the ground surface to be stored within this layer and to be discharged at a slow rate through an outlet structure.

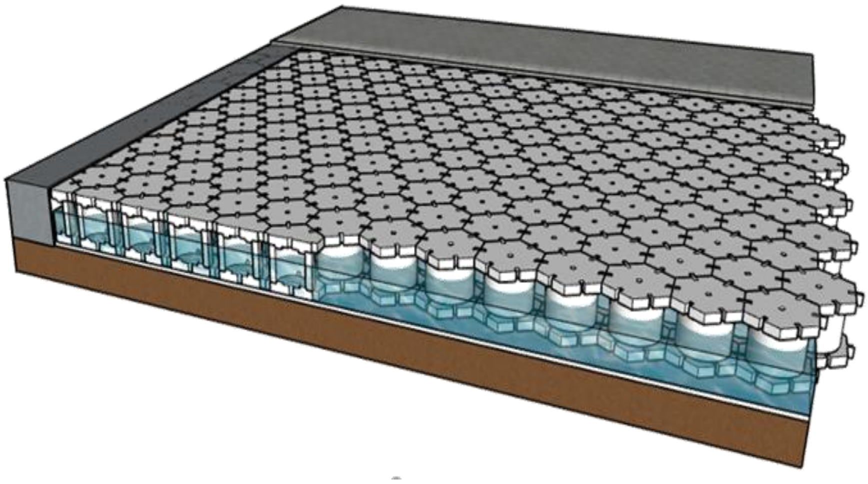

Figure 1.2: StormPav Green Pavement System (Liow et al., 2019b)

OSD could appear in different forms. Apart from road, StormPav could be applied as home-based OSD. The idea is to make use the space provided by residential car porch. Mah and Ngu (2017) reported that a sizable car porch area in each single home could be put into good use by having an undergound OSD to detain stormwater from residential roof. An example of such a system is depicted in Figure 1.3. A surface area of 4.6m x 4.3m was identified as the optimum size fitting two cars most commonly found among malaysian residential houses. It was concluded that the use of StormPav as the undergound OSD is practical for managing urban stormwater.

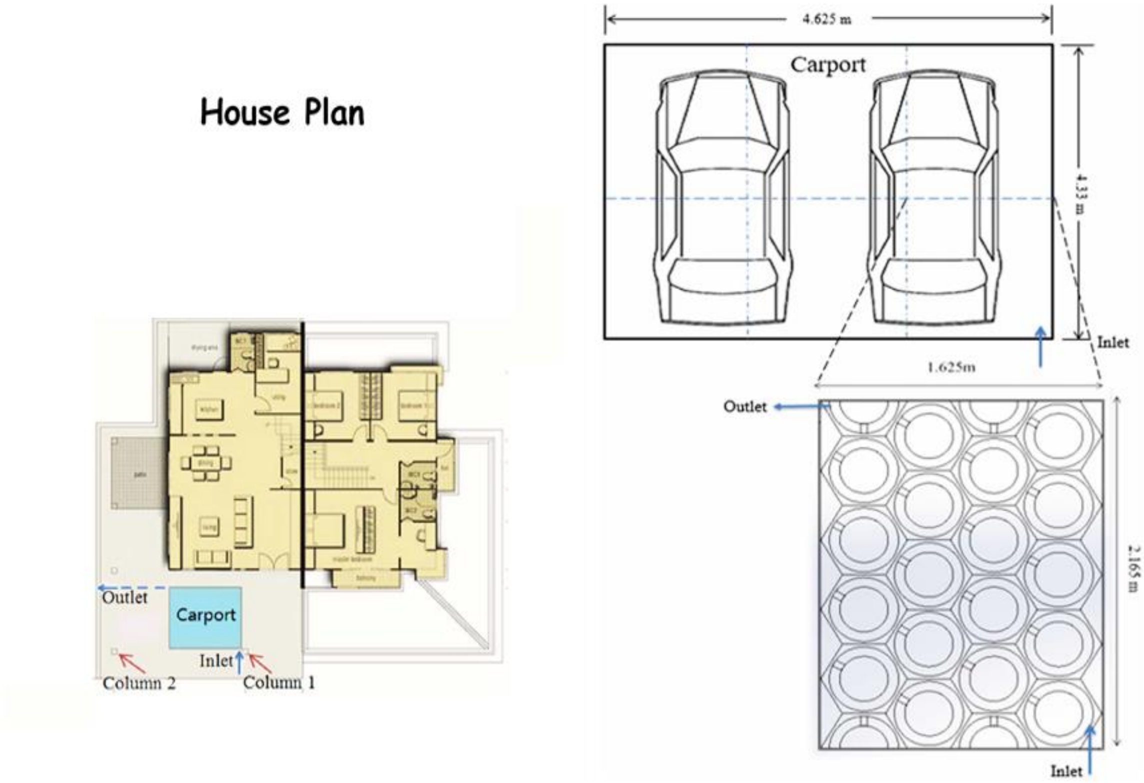

Figure 1.3: StormPav as Home-Based OSD (Mah and Ngu, 2017)

The home-based OSD mentioned above had been studied on the basis of computer simulations using Storm Water Management Model (SWMM). The computer model could not provide a successful quantitative result if it could not correspond directly to reality (Kamphuis, 2010). It was followed by a small-scaled physical model that was one sixth (2.2m x 1.6m) in relation to the full tank (4.6m x 4.3m) (Figure 1.3). Both studies were tested based on design rainfall. It was a process involving statistical analysis and probability of historical rainfall to classes of rainfall intensity. Only 10-year Average Recurrent Interval (ARI) was considered for minor system in residential area. The system was designed to withstand 15 minutes of continuous rainfall under the said ARI (Mah, 2016). However, the system had not been tested under actual rainfall, particularly during the rainy season.

1.2 Problem Statement

While there have been studies on StormPav as an underground on-site stormwater detention (OSD) system, there is limited research on its practical application as a home-based OSD solution in residential settings under actual rainfall conditions. Previous investigations have mostly relied on computer simulations and small-scale lab data, leaving a gap in understanding StormPav's real-world performance and effectiveness in mitigating stormwater runoff in car porch of residential houses. Hence, this research is exploring StormPav as a home-based OSD system in residential settings under actual rainfall conditions. The hypotheses put forward are:

a) Field testing could better describe the actual performance of StormPav than the numerical and small-scale lab data from the previous studies;

b) With field measurement, validation of the SWMM model is able to be performed to determine the degree to which the SWMM model is an accurate representation of the real world.

By conducting field tests and computer modelling, this research shall provide practical insights into StormPav's performance and its potential application in mitigating stormwater runoff (Landahl and Mollo-Christensen, 1992; Sargent, 2013). The results will contribute to the existing knowledge of stormwater management and offer valuable guidance for future sustainable urban development. The following shortcomings of the system are identified:

a) How the system responses to actual rainfall events, is unknown;

b) The stormwater characteristics, due to actual rainfall from catchment area to the multiple-chamber detention storage provided by StormPav, are unknown;

c) The flow mechanism due to actual rainfall among the StormPav modular units, in terms of its flow and water level in tight spaces, is unknown;

d) While the system had been modelled to reduce urban runoff, performance of the system due to actual rainfall is yet to be validated.

1.3 Objectives

The aim of this study is to characterize the stormwater detention under residential car porch by using a field test. The field test is set up in a house using StormPav Green Pavement System to collect first-hand data on rainfall, flow and water level acting upon the said system. This is followed by a computer modelling of the system to better describe the system's behaviour. The objectives of this study are:

a) To analyse the responses of system to actual rainfall events;

b) To analyse the catchment area to detention storage characteristics;

c) To analyse the relationships of flow and water level within the system;

d) To evaluate the performance of urban runoff reduction.

1.4 Scopes of Work

This study covers:

a) Rainfall patterns are highly influenced by geographical location and climate condition. As the selected area is located at Samarahan, Sarawak, the rainfall patterns