Application of StormPav Green Pavement System in a Government Buildings Redevelopment Scheme

Darrien Yau Seng Mah, Ching Vern Liow, Md Abdul Mannan

Abstract: StormPav Green Pavement System is a non-commercialized permeable road with a function of stormwater detention. This paper demonstrates the application of the R&D product in part of a 14,000 m2 government building complex as a new feature of sustainable drainage system. To assess its stormwater impacts to the project site, two software are utilized to analyze the stormwater flow processes when merely 10% of the project area is incorporated with StormPav. Firstly, Storm Water Management Model (SWMM) is used to simulate the project-wide stormwater flow, in which reductions between 22% - 6% in terms of peak flow rates are predicted compared to conventional drains when subjected to 5 – 180 minutes of 10-year Average Recurrent Interval (ARI) design rainfall. Secondly, SolidWorks Flow Simulation (SWFS) simulates the detailed flow processes within the StormPav system, in which it is found 0.5 – 1.3 m/s of velocities are predicted around the inlets and outlet that conform to the local stormwater management standard. Besides, SWFS allows visualization of velocity and streamline profiles across the StormPav system that conventional SWMM could not provide.

Index Terms: On-site detention, Post-development, Pre-development, SolidWorks, Stormwater.

I. INTRODUCTION

This paper describes a case study of a redevelopment scheme involving a government building complex. The compound is about 14,000 m2 (1.4 hectares/less than 80 hectares) and it falls under the category of small urban catchment. The complex is packed with buildings and paved walkways that constitute 90% of the area; while green areas for the remaining 10%. The existing drainage plan is presented in Figure 1a. The conventional drainage plan involves only concrete drains. The red lines indicate 450mm wide drains, while the green lines indicate 300mm wide drains.The complex was officiated in 1912. Over the 107 years of usage, it went through several upgrading. The scope here limited to its stormwater drainage facility. The existing drainage was the rapid discharge system, in which stormwater was meant to be collected in the drains to be disposed of the compound as soon as possible [1]. However, the recent development since the 90s had called for a different approach to urban stormwater management. The century-old complex was deprived of sustainable drainage features [2,3]. The intended redevelopment scheme has allowed the opportunity to retrofit one or few new stormwater features.

There are three drainage outlets designated for the complex. Tracing the drainage network, three sub-catchments could be delineated in Figure 1b. Sub-catchment 3 has the largest catchment area and a large car park of 1420m2; therefore, having an On-Site Detention (OSD) in Sub-catchment 3 is justifiable. OSD is a method of providing manmade stormwater storage structure [4] to temporary detain some portion of potential stormwater generated from any project site. The main purpose of OSD is to alleviate the peak flow rate and abrupt high volume of stormwater being flushed to downstream waterways [5,6] that may cause environmental problems like flash flooding and erosion.

In the case of the studied government building complex, the large surface area provided by the car park could be exploited to have subsurface storage underneath the parking lots [7]. Some modifications to the existing drains are needed. The drains are directed to the subsurface storage via two inlets and one outlet. The subsurface storage could be designed in several ways. The authors are introducing StormPav Green Pavement System, or in short, StormPav, in this paper. StormPav is a R&D product, in which the authors are part of the research team.

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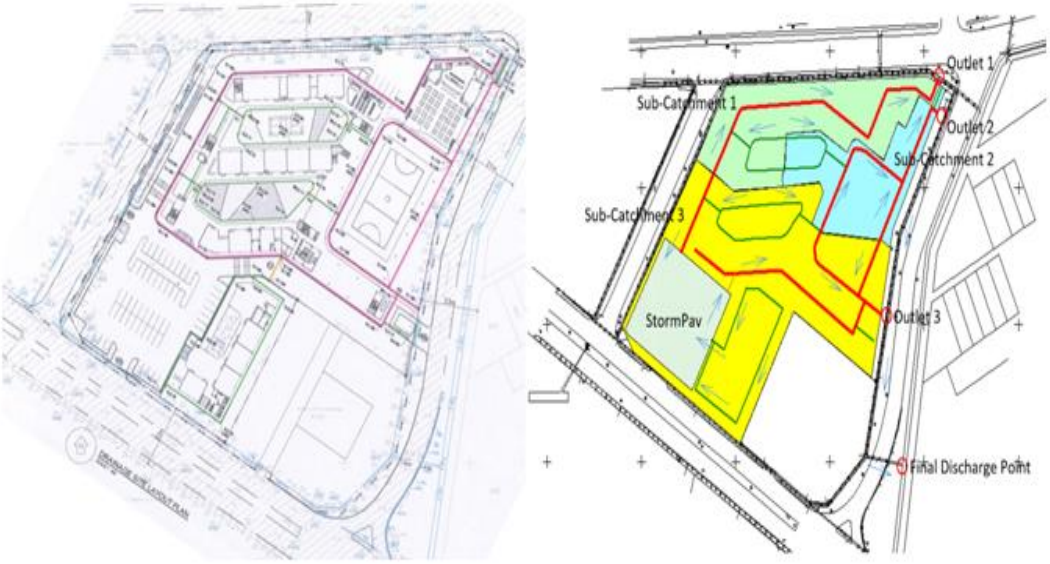
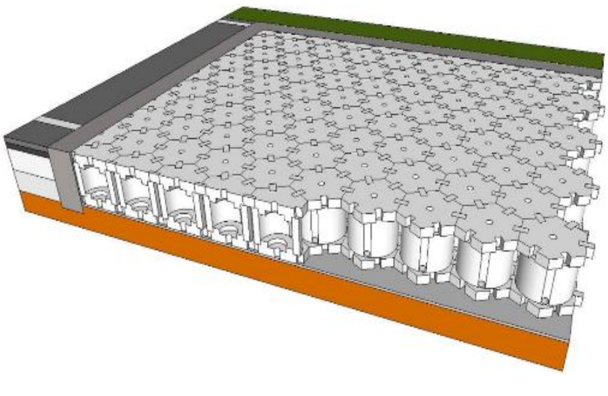


Fig. 1: Plans for a) Existing Drainage and b) Redeveloped Drainage

II. INCORPORATING STORMPAV AS OSD

StormPav is a new form of permeable road [8]. Referring to Figure 2, a small-scale pilot study has been completed [9]. It consists of three concrete pieces to make up a single modular unit. The top and bottom of the modular unit are hexagonal plates with service inlets. The inlet hole on the top plate allows water to be drained to the hollow cylinder under it; while the inlet hole on the bottom plate allows infiltration to the underlying soil. The hollow cylinder with side service inlet functions as the temporary storage for stormwater that would otherwise accumulate on road surfaces. The plates are interlocked with keys to create a monolithic structure for the top and bottom layers [10].

A single modular unit is specially designed to withstand up to 10 tons of heavy traffic loadings (compared to the required 4 tons for normal practice). The hollow cylinders are not sealed to the plates but are resting freely in between the top and bottom monolithic layers. As such, water could seep among the cylinder units. For every single modular unit, 40% of it are solid concrete while 60% are empty spaces [11]. It calculates to a water storing capacity 0.19 m^3/m^2 of pavement area. For the car park area of 1420 m^2, the StormPav OSD shall have a storing capacity of 270 m^3. Surface infiltration rate is found to up to 10,000 mm/hr [12].



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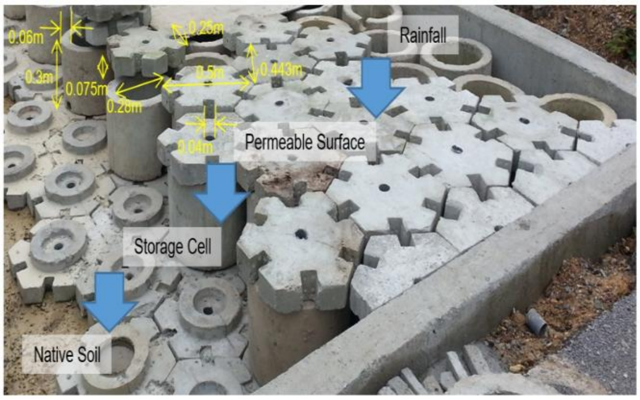

b)

Fig. 2: StormPav Green Pavement, a) Technical Drawing and b) Stormwater Detention Mechanism

III. METHODS

Computer simulation of water system is a common industrial practice to test the workability of a system under study [13]. Drainage system of the government building complex is simulated through two software, namely SWMM Version 5.1 and SWFS Education Edition 2018-2019. SWMM is combined hydrological representation of stormwater being generated from a catchment, as well as hydraulic representation of the stormwater flow mechanism through a series of conduits and appliances [13,14]. However, SWMM is a 1-D model, while SWFS is a 3-D model that could simulate detailed flow patterns within the StormPav modular units [16].

IV. Flow Analysis with SWMM

The three afore-mentioned sub-catchments are subjected to 10-year ARI design rainfall based on local climate for rainfall durations of 5, 10, 15, 30, 60, 120 and 180 minutes. Three scenarios are computed for comparison of stormwater impacts due to the government building complex.

The first scenario refers to a pre-development condition. We have no record of the native land use 100 years ago and therefore it is an imagery scenario, taking the compound as a forested catchment. The second scenario involves lump catchment modelling of the three sub-catchments assuming the compound is impervious surface area. Runoff generated from the school is eventually drained to a final discharge point. The location is pinpointed in Figure 1b. The third scenario depicts the lump catchment modelling of three sub-catchments. The difference with Scenario 2 is that Sub-Catchment 3 has been incorporated with StormPav OSD modelled as embedded component within the sub-catchment. Modelling results are summarized in Table 1.

Generally, the reductions of peak flow rates are estimated from the SWMM modelling when StormPav Green Pavement is incorporated. The reductions range from 22% for 5-min design rainfall to 6% for 180-min design rainfall. It is about 10% in average compared to conventional drainage system.

The impacts of StormPav are limited due to two factors. Firstly, there are limited land spaces in the century-old government building complex. In this project, only the car park is utilized. The volume of stormwater being detained thus resulting in the reduction of peak flow rate could be further improved by applying StormPav to replace roads and other paved surfaces in the compound. Secondly, the current version of StormPav modular unit is designed to have mobility as priority. The concrete pieces are relatively small so that it could be handled by workers during transportation and construction without machinery. The dimension of the concrete pieces could still be explored to increase its water storing capacity without compromising its mobility.

Table 1. Comparisons of Peak Flow Rate at Final Discharge Point

Scenarios	Peak Flow Rate (cms) Subjected to 10-year ARI Design Rainfall for Duration:						
	5 min	10 min	15 min	30 min	60 min	120 min	180 min
Pre-Development	0.16	0.15	0.37	0.39	0.26	0.21	0.16
Post-Development (Conventional Drainage)	0.18	0.43	0.55	0.43	0.3	0.21	0.16
Post-Development (Drainage & StormPav)	0.14	0.4	0.48	0.37	0.28	0.19	0.15
Comparison of Drainage with & without StormPav	-22%	-7%	-13%	-14%	-7%	-9%	-6%

V. Flow Analysis with SWFS

Contrary to SWMM that provides project-wide flow simulation, SWFS provides the flow patterns of a focus component instead of the entire drainage system. In this case, SWFS simulates the flow within the StormPav OSD. Flow analysis in terms of velocity profiles are presented in Figure 3. Simulation of the StormPav OSD presents a snapshot of the peak velocities across the system. For demonstration, the figure depicts the results due to 180-minute 10-year ARI design rainfall. Generally, majority of the system lies within 0 – 0.2 m/s for having water filling the void spaces. Only small areas around the two inlets and outlet show relative more velocities than the rest in Figure 3a.

For Inlet 1 in Figure 3b, turbulent flow is observed and velocity as high as 1.3 m/s is estimated by SWFS. Higher velocity is expected for shorter rainfall duration. This phenomenon is normal for water inlet. Note that semi-circular concrete piece at Inlet 1 is meant to force the stormwater to flow in via a side service inlet and to slow down backflow of stormwater to the connected drain.

Inlet 2 in Figure 3c has less turbulent flow than Inlet 1 due to its smaller contributing catchment area. Its velocity ranges at Inlet 2 are about 0.5 – 0.7 m/s. Similar to Inlet 1, turbulent flow is observed at the Outlet in Figure 3d but on a lesser extent. Velocity ranges at the outlet are about 0.8 – 1.0 m/s. Benchmarking to the allowable velocities for urban drains are 0.2 – 2.6 m/s, simulated flow patterns within the StormPav OSD appear as acceptable for a stormwater detention structure and no overflowing is predicted.

Simulated streamlines associated with the velocities due to 180-minute 10-year ARI design rainfall are presented in Figure 4. The streamlines show how the water particles would flow. Referring to Figure 4a, it shows that once the water enters the StormPav OSD via Inlet 1, the water is flowing across its width before curving towards the outlet. The distance of Inlet 1 and Outlet is greater and thus forming larger curves. On the other hand, the distance of Inlet 2 and Outlet is shorter, it forms shorter and complex curves before leaving the OSD via the Outlet.

Outlet in Figure 4d. Ability to visualize streamlines in SWFS allows engineers to identify possible water congestion that may cause overflowing from the system. In this case, although

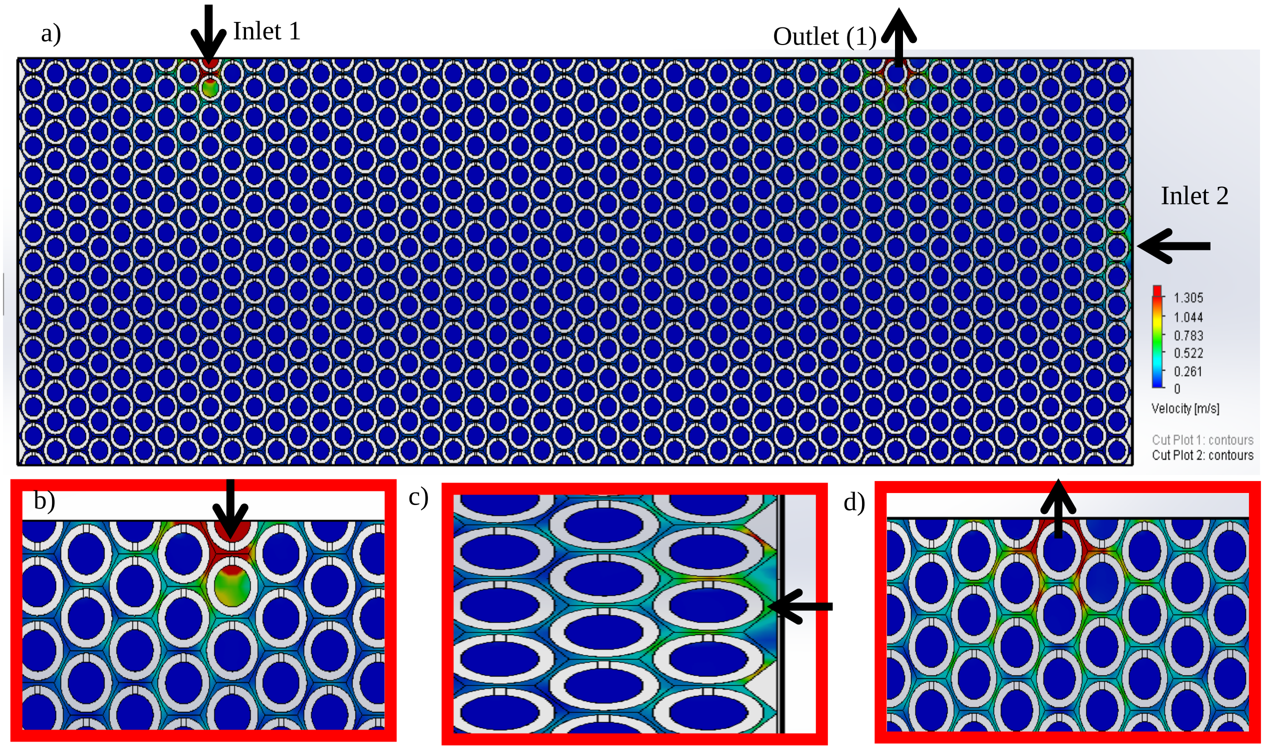

Fig 3. Velocity Profiles of StormPav Green Pavement for a) Plan View, b) Inlet 1, c) Inlet 2 and c) Outlet

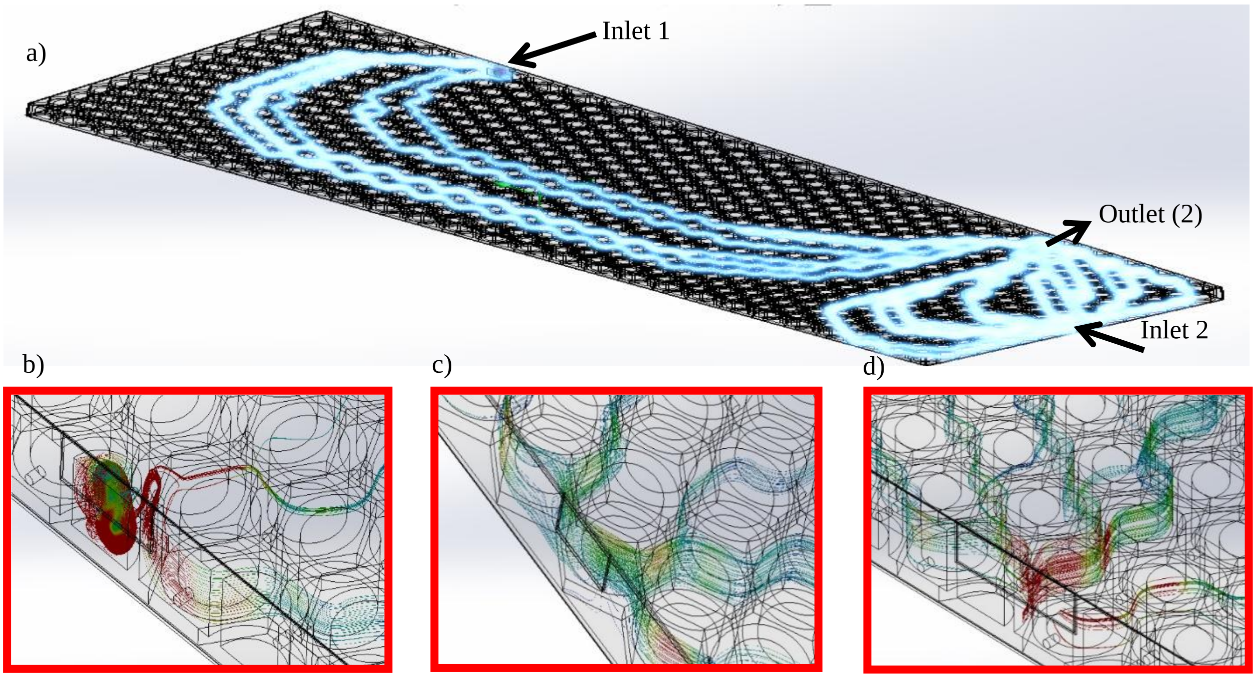

Fig 4. Streamline Plots of StormPav Green Pavement for a) Plan View, b) Inlet 1, c) Inlet 2 and c) Outlet

Generally, dense streamlines indicate turbulent flow, while sparse streamlines indicate lesser or laminar flow. Dense streamlines are observed to occur only at the Inlet 1 in Figure 4b. Sparse streamlines are observed at Inlet 2 in Figure 4c compared to Inlet 1. Moderate streamlines are observed at no overflowing is predicted but it points out the weak spot of the design that calls for attention of the engineers involved.

VI. CONCLUSION

For 14,000 m^2 of government building complex, a redevelopment scheme has facilitated 10% (1420 m2) of the total surface area with StormPav Green Pavement as new sustainable drainage feature. With the aid of SWMM, the compound is subjected to hydrological and hydraulic modelling of the stormwater flow processes. Limited by the available land spaces in the complex, StormPav is demonstrated that with as little as 10% of coverage, it results in peak flow rate reductions range from 22% to 6% when subjected to 10-year ARI design rainfall with rainfall durations from 5 to 180 minutes.

With the aid of the second software, SWFS provides a different perspective by having visualization of the flow patterns within the StormPav OSD. Simulated velocity profiles across the system show most of the OSD is stagnant/slow filling water between 0 - 0.2m/s; while small areas at the vicinities of Inlet 1, Inlet 2 and Outlet are with faster flow between 0.5 – 1.3 m/s which are acceptable by the standard of urban stormwater management. Simulated streamlines illustrate a picture how moving water running through the StormPav OSD. The streamlines show little resistance of water flow regarding the current StormPav OSD design.

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