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Modelling of StormPav Green Pavement System Using Storm Water Management Model and SolidWorks Flow Simulation

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Abstract: ***Storm Water Management Model (SWMM) and SolidWorks Flow Simulation (SW-FS) models to represent StormPav Green Pavement System are tested through a case study of commercial premises. Modelling effort of simplifying the complex StormPav system to take in only the effective storage volume is attempted using the 1D SWMM. A 3D modelling of capturing the multi-compartmental and multi-unit StormPav system is attempted using SW-FS. The modelling outputs in terms of velocity distribution within the StormPav system of the two developed models are found to reasonably matched.***

Index Terms**:** ***hydraulics, permeable road, road drainage, routing, stormwater***

I. INTRODUCTION

This paper is describing methods to model StormPav Green Pavement System. It is intended as a permeable road [1] with subsurface storage underneath its pavement layer [2]. Attempts have been made to model the StormPav system as permeable road [3] and on-site detention [4,5]. But the focus here is to represent the system as stormwater conveyance, rather than detention storage.

A single unit of StormPav consists of three precast concrete pieces, namely a hollow cylinder sandwiched between two hexagonal plates. Presented in Fig 1, it shows a small-scale pilot study of StormPav system [6], in which the top hexagonal plate functions as the pavement, the bottom hexagonal plate as the base and the hollow cylinder as the storage chamber.

Each hexagonal plate has a 40mm service inlet that when placed on top, it drains surface water up to 10,000mm/hour; while at the bottom, it allows infiltration to the soil. The surface area on a single plate is 0.1624m^2. Height of each plate is 0.075m. Each hollow cylinder has a 40mm side service inlet. The cylinder has an inner diameter of 0.28m and a thickness of wall of 0.06m. Height of each cylinder is 0.3m.

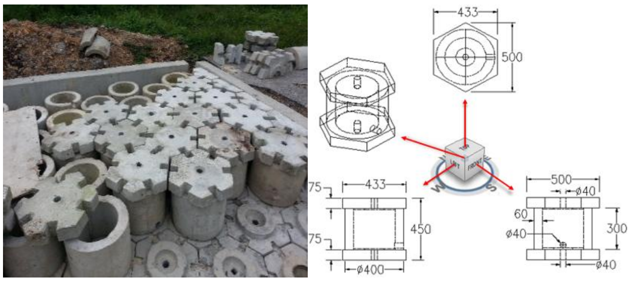

Fig. 1: StormPav Green Pavement System

II. THEORY

Arranging the StormPav units together to replace the conventional road, it forms a long rectangular container with multiple compartments within. By design, the hollow cylinders are not sealed to the plates; therefore, water is free to seep in and out of the cylinders and the spaces between them. The assumptions made are as described below.

Firstly, water naturally takes the form of its container [7]. As such, once stormwater is directed to the StormPav system, it fills up the compartment and fulfills the function of water detention. Secondly, water flows from a region of high pressure to a region of low pressure. By providing an outlet to the container [8], the velocity at the outlet increases, the pressure at the vicinity of the outlet decreases [9]. Thirdly, fluidity of water could flow through wide and tight spaces alike [10]. The multi-compartment nature of StormPav is not a hinder to water flow.

Based on the second and third assumptions, it is deduced that flow through the StormPav system is possible. Representing the system in a computerized environment is explored next. The authors are presenting two different models, namely SWMM and SW-FS.

SWMM is a freeware under the license of US Environmental Protection Agency that is practical to use. It is a one-dimensional (1D) model that utilizes Dynamic Wave technique to solve the St Venant equations to its flow modelling.

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Comparing the two, SW-FS is the advanced three-dimensional (3D) model that could capture the multi-compartment StormPav units through its meshing technique [11,12]. Flow is mathematically computed using the Navier-Stokes equations that cater for x-, y- and z-directions of modelled parameters. However, such a model is expensive that may not be affordable to some users. Some more, the authors find the computational procedures require high-end hardware with large memory.

III. METHODS

A typical commercial area is selected as a case study so that a realistic situation could be envisioned to allow simulation of StormPav system to flow stormwater. The case study is depicted in Fig 2. Authors choose a stretch of urban road flanked by two rows of commercial premises. StormPav system is applied as the road, in which the drains in front of the premises are removed. Stormwaters from the roofs and road surfaces are directed to the StormPav system.

SWMM could not represent in details of the multi-compartment StormPav units. Referring to Figure 3a, the StormPav system in between the two rows of premises is modelled as closed rectangular channel with an orifice outlet at the end of the system. The authors simplify the StormPav system by considering the effective storage volume (after minus out the concrete volume) and flow resistance in the system [13,14].

In SW-FS, the StormPav system is taken as symmetrical in nature, half the road shall cater to capture the stormwaters from one row of premises while the other half of the road for the opposite row of premises. Therefore, only half of the road is considered in the simulation. Hardware owned by the authors could not accommodate the whole stretch of the StormPav system. Only three short stretches are selected. Referring to Figure 3b, the upstream corner lot is named Stretch i that shall receive stormwater from the premise (denoted as a) and stormwater intercepted by the road surface (denoted as b). The intermediate lot is named Stretch ii that shall receive stormwater from the premise (c), road surface (d) and upstream flow (e). The downstream corner lot is named Stretch iii that shall receive stormwater from the premise (f), road surface (g) and upstream flow (h).

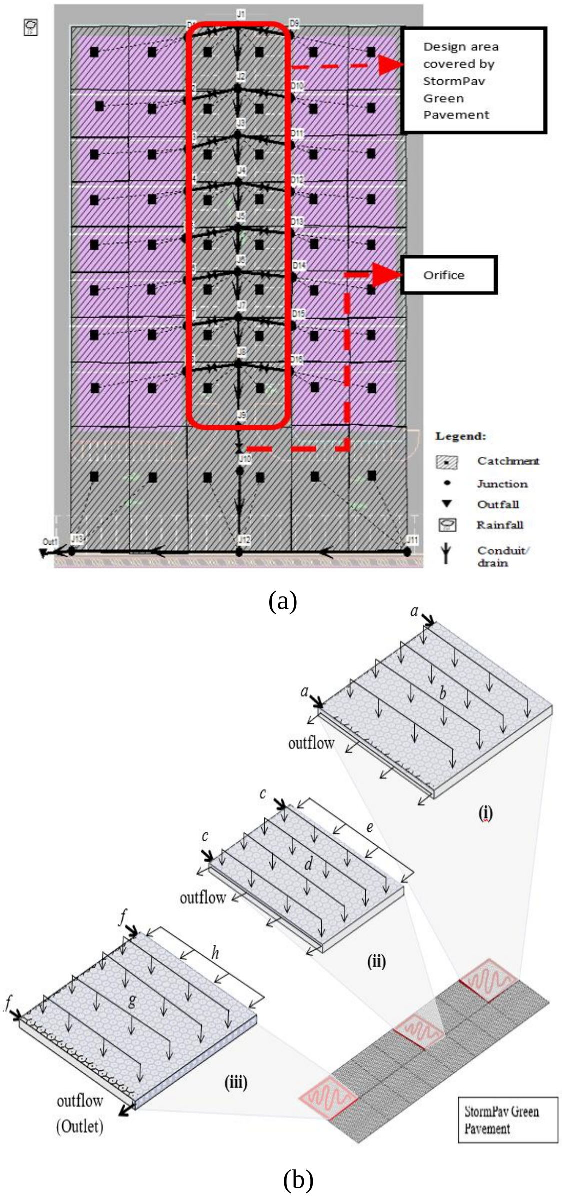


Fig. 3: Developed Models, (a) SWMM and (b) SW-FS

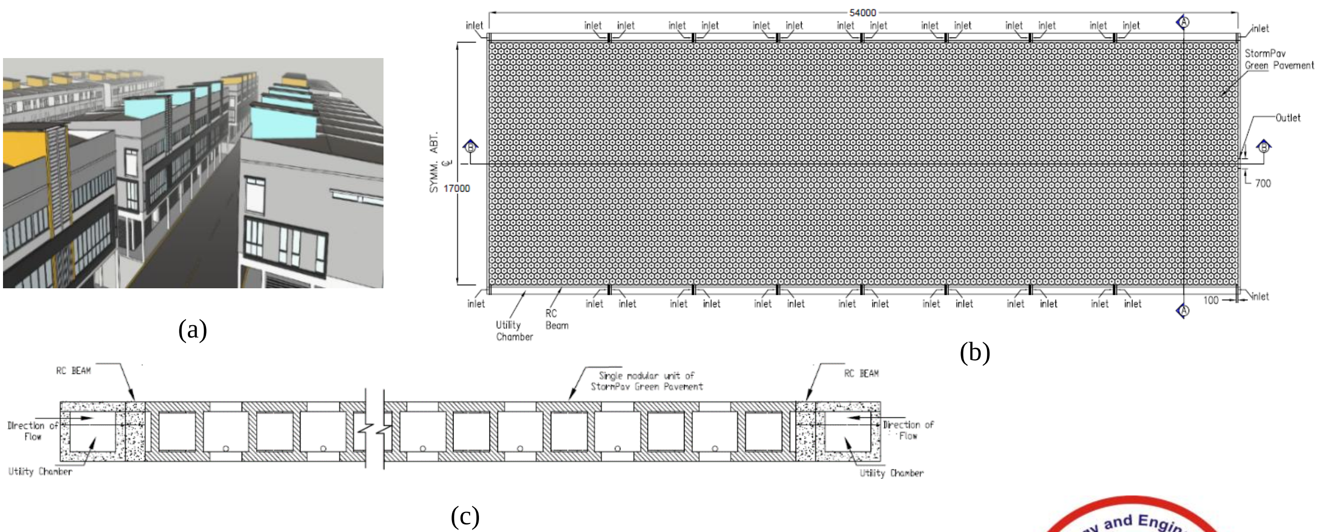


Fig. 2: Study Area, (a) Typical Commercial Premises, (b)Plan View and (c) Long Section View of StormPav Green Pavement System

IV. RESULTS

SWMM has limited visualization; therefore, its modelled results are tabled at the end of this section. Contradictory, SW-FS produces 3D views of the StormPav system. Demonstrated below are visualization of flow patterns due to 180-minute 10-year ARI design rainfall.

The velocity cut plot of Stretch i of StormPav system is illustrated in Fig 4. The highest velocity is estimated at 0.16m/s at the outlets. The colour being displayed is more prominent at the inlets relative to the whole part. Whereas, the other regions within the part shows monotone colour. Generally, the velocity in most part of the system is estimated at 0.02m/s. As the velocity coverage at the inlets is little compared to other regions, therefore it is taken as outlier. Velocity range at other regions is taken as the representative of Stretch The velocity cut plot of Stretch ii of StormPav system is illustrated in Fig 5. The highest velocity is estimated at 0.12m/s at the inlets. Comparatively, the value is slightly lower than the previous stretch because of the difference in catchment areas. The intermediate premise has a smaller roof catchment area compared to corner premise. The range of colour being displayed in the figure is similar to the previous figure. Therefore, similar notion is made like the former. Generally, the velocity in most part of the system is estimated at 0.04m/s.

The velocity cut plot of Stretch iii of StormPav system is illustrated in Fig 6. This is the stretch which the water from the upper stretches eventually accumulate. The accumulated water is expected to be discharged at the outlet. Velocity is

estimated the highest at the outlet, recorded at 1.4m/s, ten times higher than the previous stretches. The colour being displayed appears more intense at the outlet in this case. Despite so, the general velocity in most of the system is estimated at 0.07m/s.

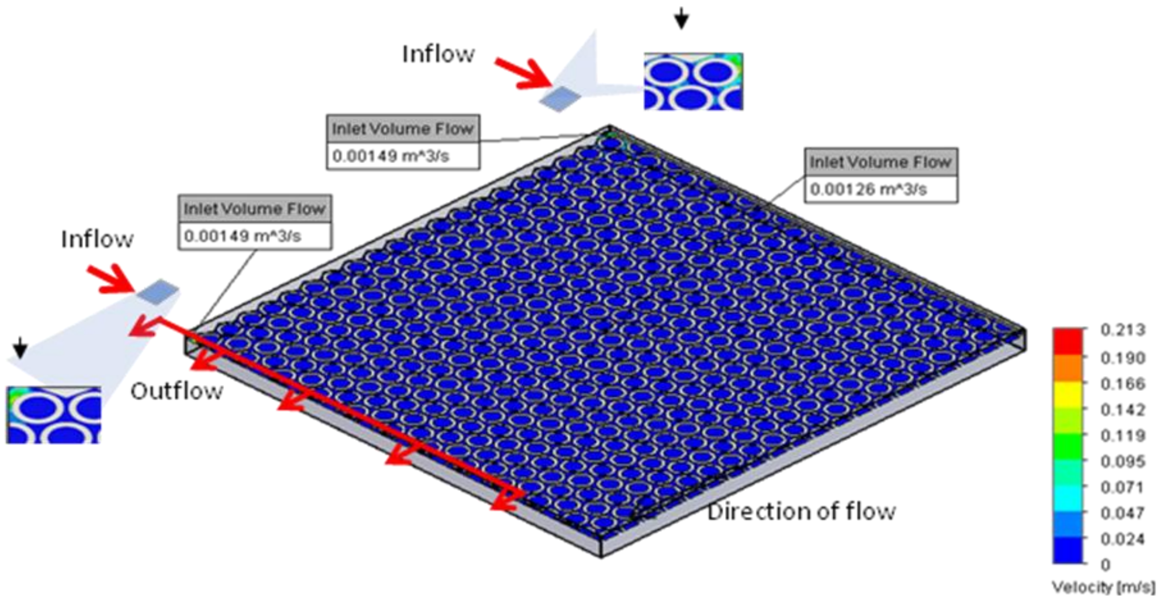


Fig. 4: Velocity Cut Plot of Part i due to 180-minute 10-Year ARI Design Rainfall

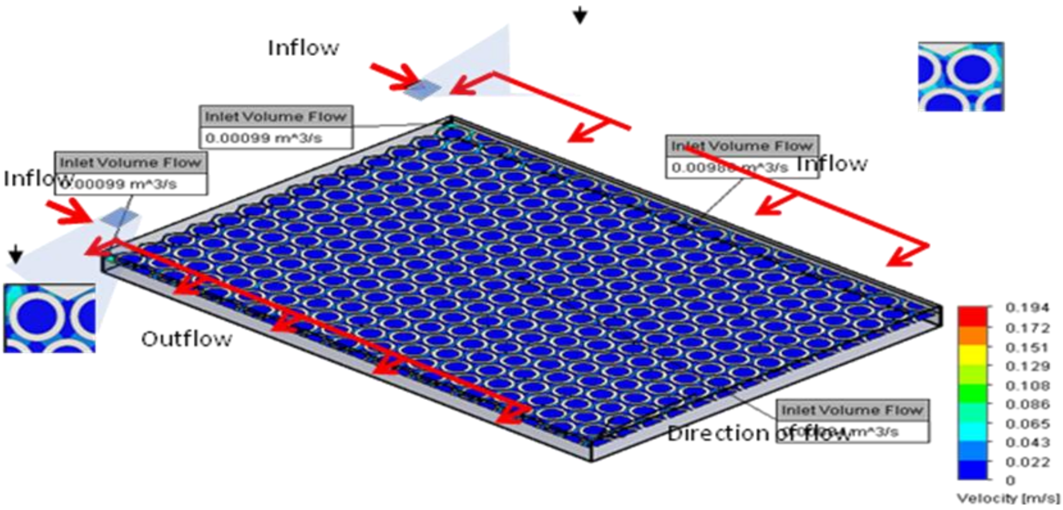


Fig. 5: Velocity Cut Plot of Part ii due to 180-minute 10-Year ARI Design Rainfall

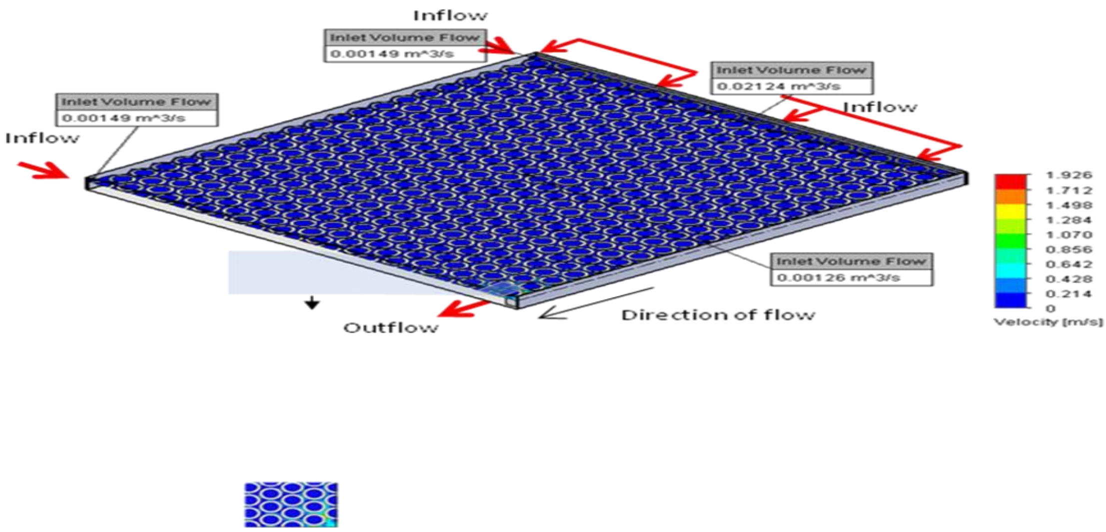
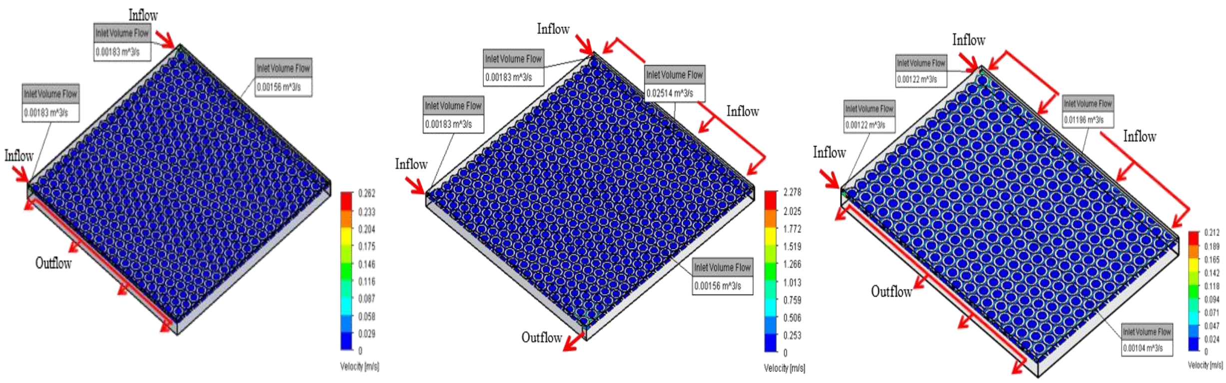


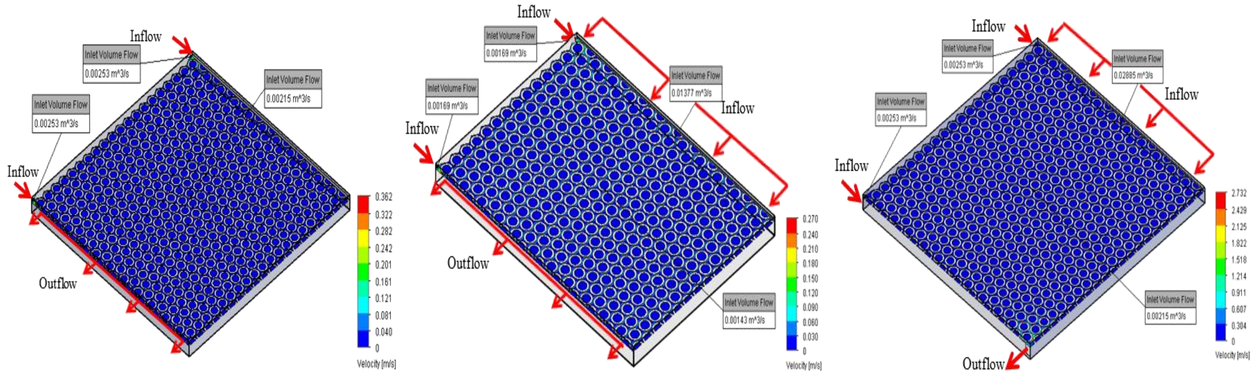
Fig. 6: Velocity Cut Plot of Part iii due to 180-minute 10-Year ARI Design Rainfall

A repetitive pattern could be observed when simulating other durations for 5, 10, 15, 20, 30, 60 and 120 minutes of 10-year ARI design rainfall events. These are presented in the following Fig 7 to 13.



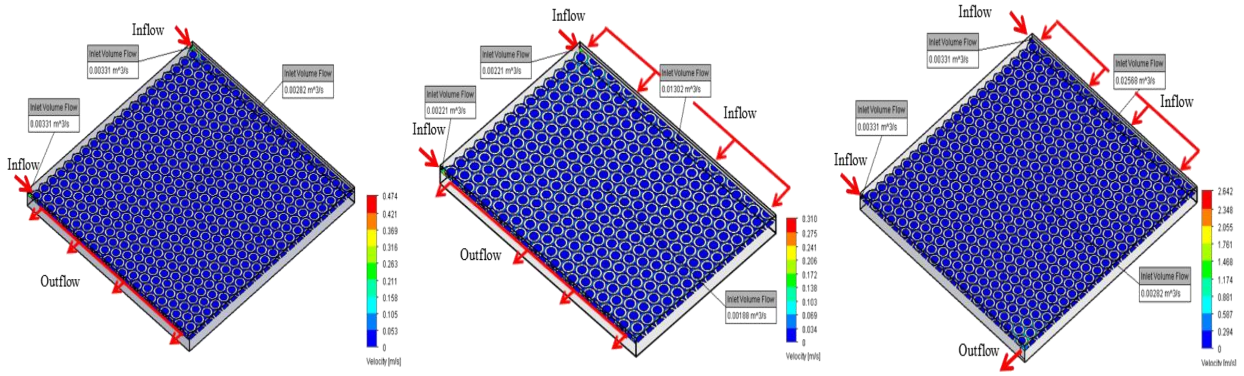
(a) (b) (c)

Fig. 7: Velocity Cut Plot of (a) Stretch i, (b) Stretch ii, and (c) Stretch iii due to 120-minute 10-Year ARI Design Rainfall



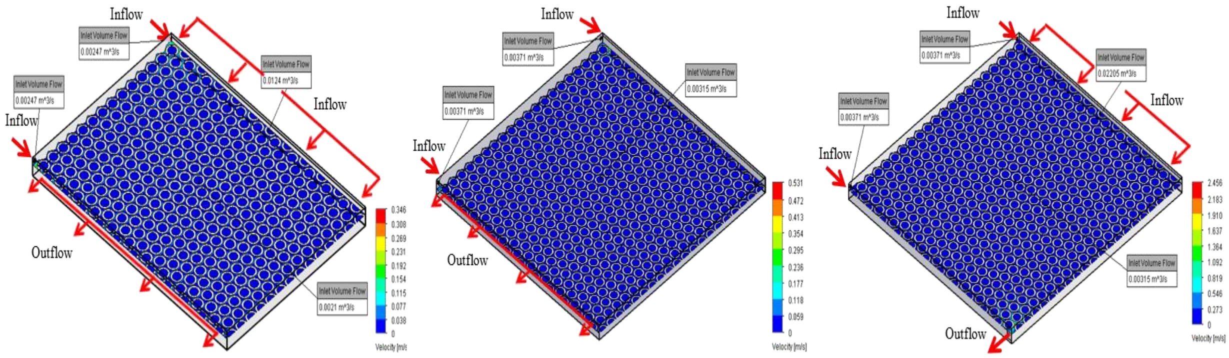
(a) (b) (c)

Fig. 8: Velocity Cut Plot of (a) Stretch i, (b) Stretch ii, and (c) Stretch iii due to 60-minute 10-Year ARI Design Rainfall



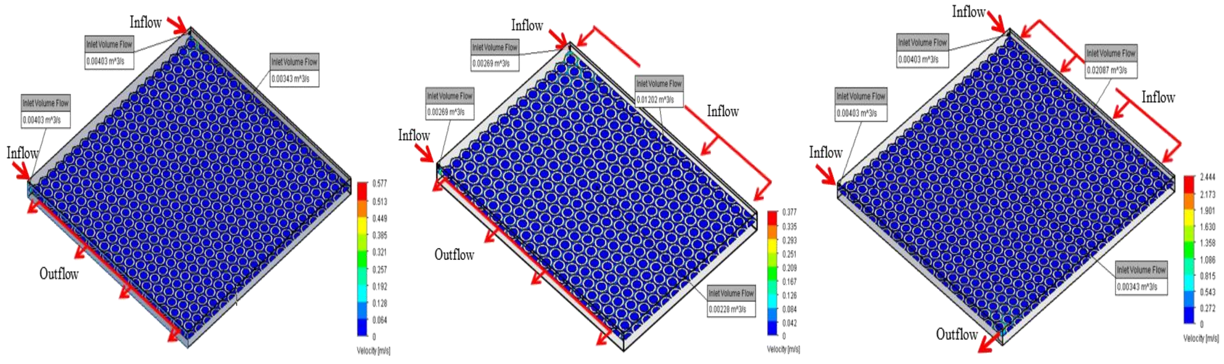
(a) (b) (c)

Fig. 9: Velocity Cut Plot of (a) Stretch i, (b) Stretch ii, and (c) Stretch iii due to 30-minute 10-Year ARI Design Rainfall



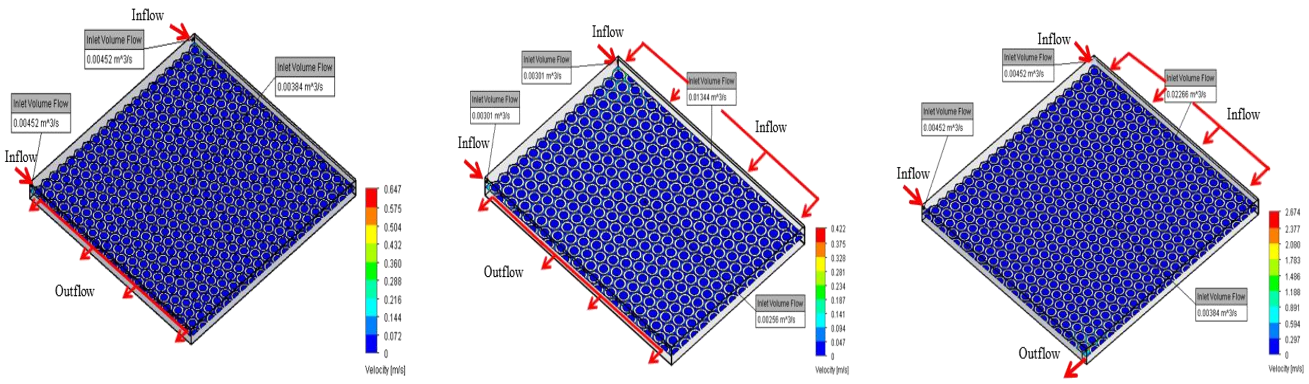
(a) (b) (c)

Fig. 10: Velocity Cut Plot of (a) Stretch i, (b) Stretch ii, and (c) Stretch iii due to 20-minute 10-Year ARI Design Rainfall



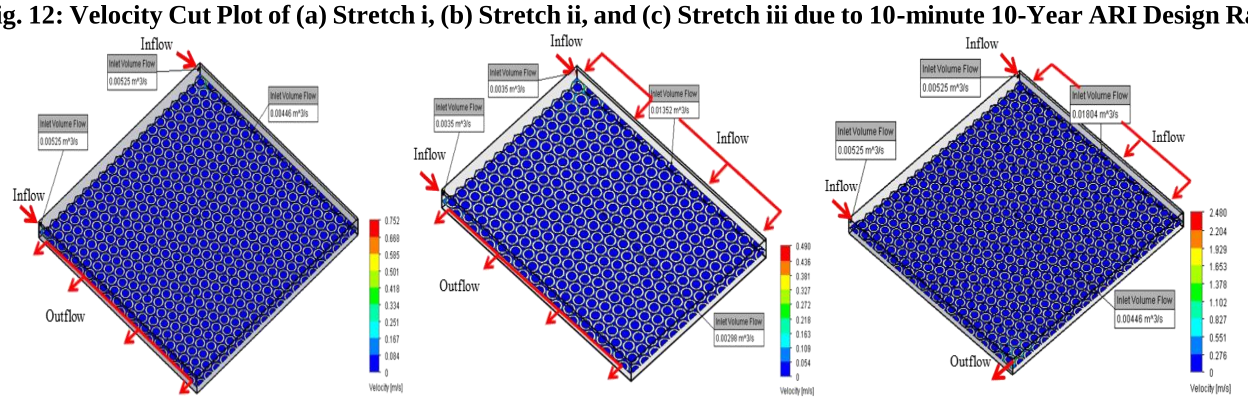
(a) (b) (c)

Fig. 11: Velocity Cut Plot of (a) Stretch i, (b) Stretch ii, and (c) Stretch iii due to 15-minute 10-Year ARI Design Rainfall



(a) (b) (c)

Fig. 12: Velocity Cut Plot of (a) Stretch i, (b) Stretch ii, and (c) Stretch iii due to 10-minute 10-Year ARI Design Rainfall



(a) (b) (c)

Fig. 13: Velocity Cut Plot of (a) Stretch i, (b) Stretch ii, and (c) Stretch iii due to 5-minute 10-Year ARI Design Rainfall

Results of flow simulation using SWMM and SW-FS are compared. The selected direction of velocities in SW-FS should be corresponding with the direction of velocities in SWMM. The comparison of velocities within the StormPav Green Pavement are tabulated in Tables 1 to 3.

Results show that the velocities modelled by SWMM are matched with the velocities obtained in SW-FS. Therefore, it enhances the reliability of both the SWMM and SW-FS models.

Table 1. Comparison of Velocities in Stretch i

Durations , minutes	Modelled velocities, m/s		Remarks
	SWMM	SolidWorks Flow Simulation	
5	0.05	0.066	Matched
10	0.047	0.066	Matched
15	0.045	0.062	Matched
20	0.044	0.061	Matched
30	0.043	0.046	Matched
60	0.039	0.035	Matched
120	0.034	0.027	Matched
180	0.032	0.02	Matched

Table 2. Comparison of Velocities in Stretch ii

Durations , minutes	Modelled velocities, m/s		Remarks
	SWMM	SolidWorks Flow Simulation	
5	0.053	0.094	Matched
10	0.05	0.079	Matched
15	0.047	0.071	Matched
20	0.045	0.065	Matched
30	0.043	0.061	Matched
60	0.037	0.058	Matched
120	0.031	0.041	Matched
180	0.028	0.039	Matched

Table 3. Comparison of Velocities in Stretch iii

Durations , minutes	Modelled velocities, m/s		Remark s
	SWMM	SolidWorks Flow Simulation	
5	0.098	0.117	Matched
10	0.092	0.111	Matched
15	0.09	0.1	Matched
20	0.086	0.092	Matched
30	0.082	0.088	Matched
60	0.073	0.083	Matched
120	0.065	0.078	Matched
180	0.059	0.069	Matched

V.CONCLUSION

We are comparing two different flow models. Each with different algorithms and structures. However, the modelled results are relatively matched. The developed SWMM model is a simplified model, in which only the effective storage volume of StormPav system is applied. While, the developed SW-FS model is the 3D modelling of the StormPav system. With the matched outcomes of both modelling methods, it is concluded that in the absence of detailed model, SWMM is simulating flow through its system reasonably well.

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