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Environmental Technology: Potential of Merging Road Pavement with Stormwater Detention

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Abstract

This study stresses on the concept of multi-functional urban land use incorporating permeable pavement integrated with underground storage. Permeable pavement that is available in the market consists of pavers and a thick layer of course aggregates that store water. Contrary to the mentioned pavement, this study tries to replace the underlying storage with blocks of concrete detention cells. Stormwater permeates through the openings of pavers and flows into the detention storage underneath. Investigation of such application is carried out using the SWMM software. Performance of a single hollow cube pavement block (0.25m x 0.25m x 0.25m) is demonstrated here. The block is virtually subjected to the worst scenarios of extreme rainfalls over a non-stop time span of three hours. Modelling outputs point to encouraging benefits of the anticipated size and storage volume are capable of capturing stormwater up to at least one hour. Thus, the system is suggested to be effective in limiting stormwater, and subsequently, promoting road structure as multi-purpose infrastructure.

Keywords: *Control at Source, Detention, Urban Drainage, Infrastructure, Permeable Pavement, Runoff, Subsurface Storage, SWMM, Water Sensitive Urban Design*

1. Introduction

In the contexts of Civil Engineering, when the lands are covered, it is known as impervious surfaces [1]-[2]. These are artificial surfaces, notoriously known to cause nuisances like flash flooding, erosion, sedimentation, degradation of water quality in urbanized areas [3]. Hence, new and exhaustive strategies are required to deal with the arising issues. Air photo depicted below shows a typical layout of urban areas, in which the dominant land uses are significantly covered with buildings and road paved surfaces.

Figure 1. Aerial view of typical urban areas (www.thefullwiki.org).

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Natural processes of water cycle in many ways are interrupted by urbanization [4]. Soil layers have the capability to adsorb stormwater and infiltrate them underground. Once the soil is saturated, only then running water is produced. On the other hand, road surface made up of tar is water resistance. Such characteristic causes running water instantly (see Figure 2).

With progressive urban developments, the need arises to reduce the growing volumes of stormwater collected in urbanized areas. This study is intended to look into "permeable pavement" in order to re-store the natural processes of adsorbing and infiltrating stormwater to soil layers. The idea is to create a model of road pavement that is strong enough to support traffic, and at the same time, capable of having a function of perviousness.

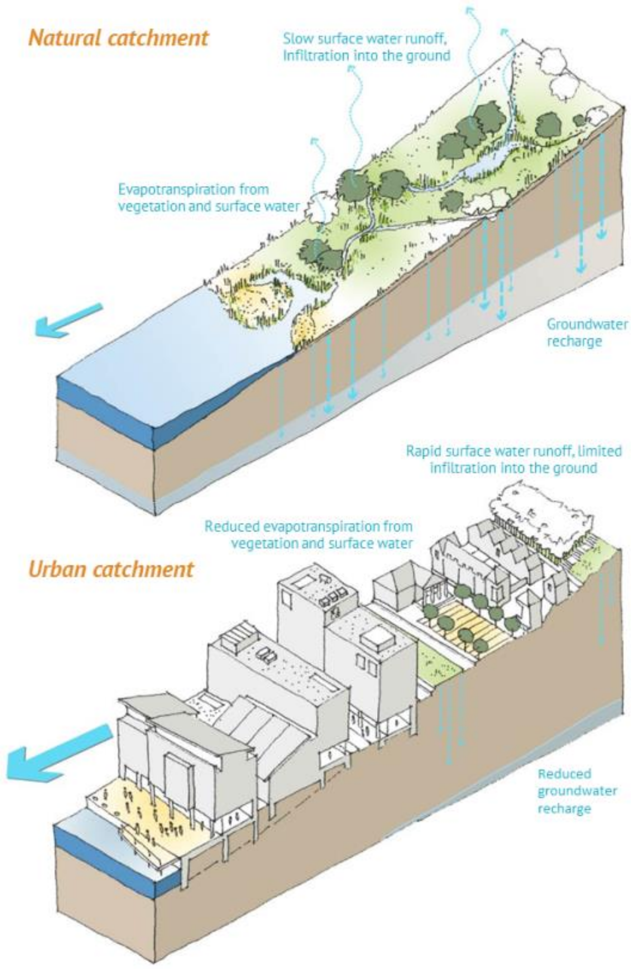

Figure 2. Natural Catchment vs Urban Catchment (www.tankonyvtar.hu).

2. Permeable Pavement

In the late 1960s, research into a new type of pavement structure was commencing at the Franklin Institute Research Laboratories in the United States. With the support of the United States Environmental Protection Agency (EPA), a permeable pavement program was developed. This pavement structure was initially installed in parking lots [5]. Such pavement is a distinct pavement type that permits fluids either from precipitation or elsewhere, to pass freely through the structure reducing or controlling the amount of runoff from the surrounding area. By allowing precipitation and

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runoff to flow through the structure, this pavement type can be applied as a stormwater management practice [6]. Since then, there are numerous studies in different parts of the world to improve the pavement type [7].

While it is not possible to reduce the number of road as it is a necessity in cities; however, adding multiple functions to road structures is possible [8]-[9], a field that is gaining significance to be researched on. Road surfaces can be altered from imperviousness to include function of perviousness.

Examples of permeable pavement are presented in Figure 3. Permeable pavement typically consists of pavers with wide joint or apertures, in which open cells are formed when the pavers are assembled in an interlocking manner and filled with porous materials allowing stormwater to permeate through. Figure 4 shows the typical cross section of a permeable pavement system. Below the pavers is a thick layer of aggregates that Ref. [10]-[11] have named it as a reservoir structure, in which stormwater is temporarily stored.

Figure 3. Examples of permeable pavement (watershedfriendlysurfacealternatives.wordpress.com, www.rwmwd.org, www.portlandoregon.gov).

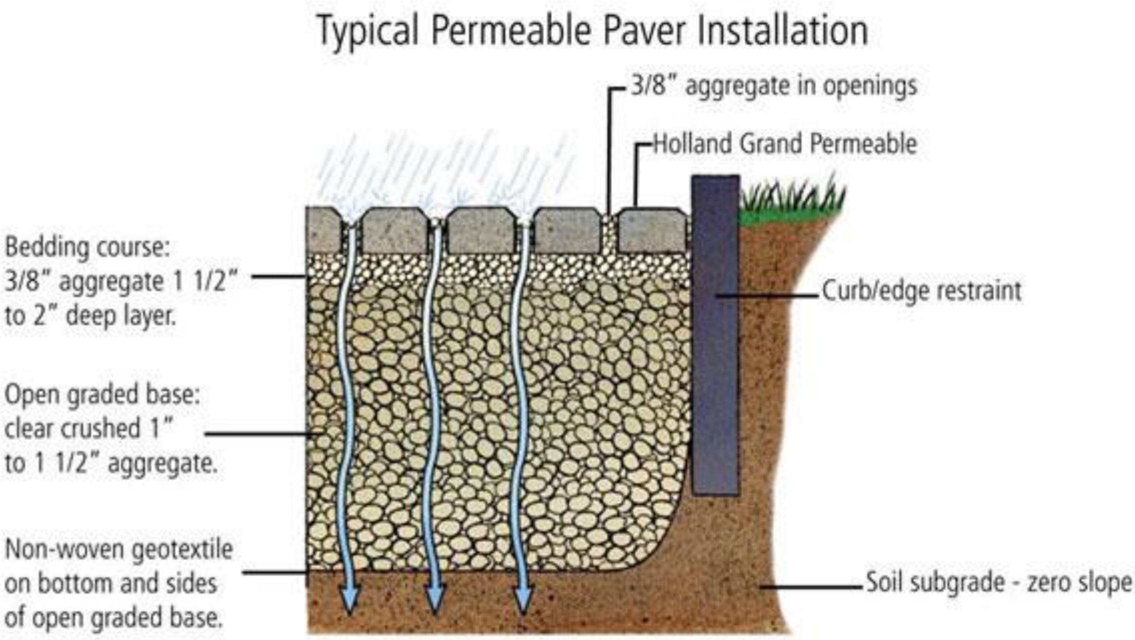

Figure 4. Typical permeable pavement design (www.usgbc.org).

Contrary to the afore-mentioned pavement type, the authors are proposing a structure of permeable pavement with openings at the surface to allow water to permeate, but the different is the replacement of the layer of aggregates with empty spaces to store stormwater, as illustrated in Figure

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5. The stored waters are allowed to infiltrate into the soil naturally [12]. However, infiltration is not anticipated in this paper as it depends on the characteristics of soil beneath the pavement unit.

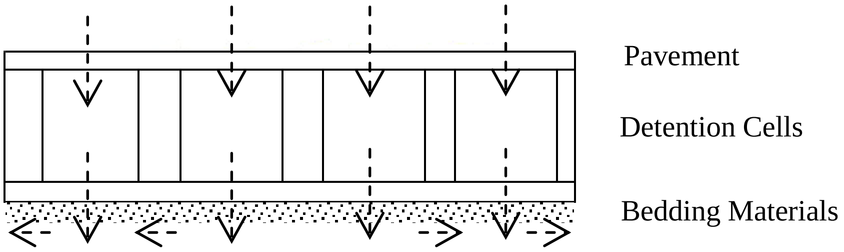

Figure 5. Proposed permeable pavement for investigation.

3. Modelling of Pavement Block

An initial storage volume and size of one unit of pavement block is estimated [13]-[14] based on the calculations for the structures to bear at least 3 tons of traffic loads (representation of load carried by a wheel of a truck), and depth of ground excavation needed. To study the behaviors of moving water on this pavement, the modeling efforts are to simulate high rainfall upon the pavement structure, thereby subjecting it to extreme climatic conditions. The software being adopted here refers to SWMM5 [15]. Figure 5 if presented in 3D form, the pavement block appears as in Figure 6. The cubes should be hollow. Interlocking cubes are easier to cast in-situ considering the factor of buildability as road structure. To cater to the pavement type under study, the authors try strategies below (see Figure 7):

a) Opening/inlet on the surface cover is modelled as a sub-catchment that intercepts rainwater and later directs the rainwater to a storage unit; and
b) Remaining surface area on the surface cover other than the opening/inlet is modelled as another sub-catchment that produces direct runoff for disposal to an outfall.

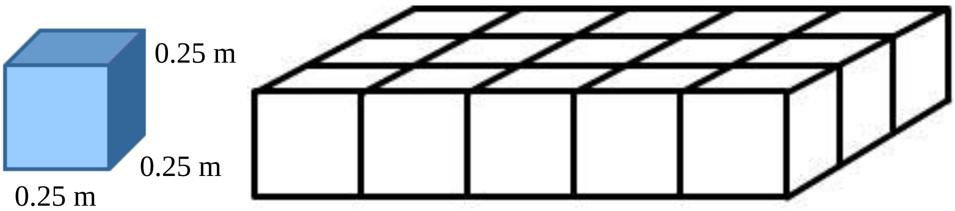

Figure 6. Frame for pavement blocks.

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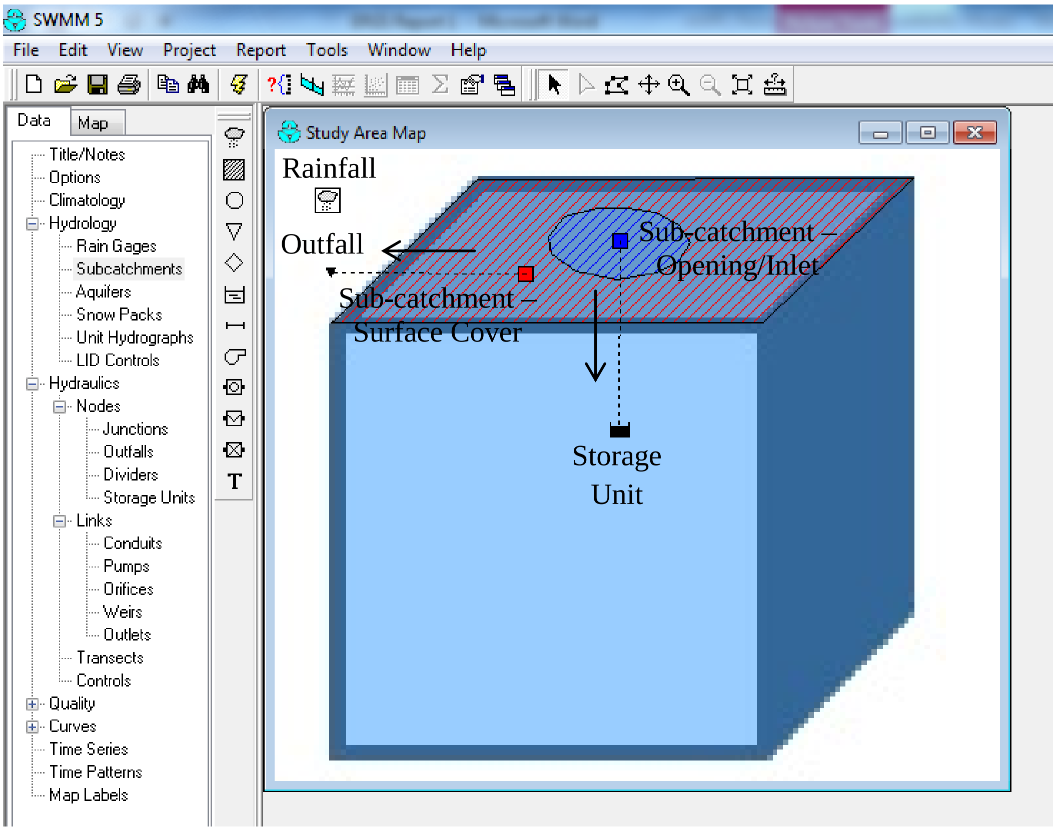

Figure 7. Developed SWMM model for the permeable pavement block.

4. Results and Discussion

4.1 Design Rainfall

To start the modelling, rainfall data need to be pre-determined as main input to the model. 10- and 20-year ARI design rainfalls are commonly used in drainage engineering practices. Therefore, the authors have computed the followings based on *Manual Saliran Mesra Alam* (MSMA) for Kuching area [16]:

Table 1. Design rainfalls adopted for modelling purposes

ARI (Year)	Time Span (hour)	Intensity (mm/hour)	Rainfall Depth (mm)
10	3	59.5	178.4
20	3	68.2	204.5

Normally rain starts light and the intensity slowly increases over a period of time until a peak; after that, the rain slowly decreases and eventually stops. Referring to Table 1, take the 10-year ARI event, rainfall of 59.5 mm/hour befalls the designated surface areas non-stop for three hours. It means a very intense rain in an uncommon scale because it is rare to have such rainfall event for long hours. The purpose is to take into consideration of worst case scenario. What is sought after here is the ability of the detention cells to withstand the onslaught of at least one-hour rain out of three-hour extremes.

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The remaining running waters are released to the environments for ecological purposes and to complete the natural water cycle.

4.2 Predicted Results on Filling Volume

The modelling results of a single pavement block are presented here, for the authors find repetitive patterns are obtained when more than one pavement blocks are included in the modelling process. Note that the surface area and storage volume of a single pavement block are 0.0625 m^2 and 0.0156 m^3 respectively. Shaded in Table 2, the readings indicate overflow in the storage of a single block. Confronted by harsh rainfalls, it takes about 1 hour 30 minutes to fill the storage full for 10-year ARI event; while it takes about 1 hour 15 minutes for 20-year ARI event. The outcomes are encouraging for it gives the research team the confidence to fabricate the anticipated size and volume for further testing. Note that also, the modelling results are based on assumptions outlined in Section 3. It is preliminary in nature and needs validation from laboratory findings to rectify the filling volume.

Table 2. Modelling results of filling volume (single block)

Time (minute)	10-year ARI Event		20-year ARI Event	
	Rainfall Depth (m)	Filling Volume (m^3)	Rainfall Depth (m)	Filling Volume (m^3)
15	0.0149	0.0024	0.0170	0.0028
30	0.0297	0.0048	0.0341	0.0055
60	0.0595	0.0097	0.0682	0.0111
75	0.0743	0.0121	0.0852	0.0138
90	0.0892	0.0145	0.1022	0.0166
105	0.1041	0.0169	0.1193	0.0194
120	0.1189	0.0193		

5. Concluding Remarks

The size (0.25m x 0.25m x 0.25m) of a pavement unit is determined by three factors below:

a) Ability to withstand a vehicle on top of it, taking the most critical, i.e. 3 tons on one wheel of a truck;
b) Ease of construction and ground excavation needed as the deeper the excavation, the pricier the cost, i.e. about 1 feet is preferable depth; and
c) Ability to withstand at least an hour out of three-hour of 10- or 20-year ARIs storms.

Critically, the model shows plausible results of ability to store water immediately during the course of storm events, which is the main focus. Imagine the large network of roads are able to apply such measure, the amount of urban runoff can be reduced significantly.

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References

[1] Booth, D.B., Hartley, D. and Jackson, R. (2002). Forest Cover, Impervious-Surface Area, and the Mitigation of Stormwater Impacts, *JAWRA Journal of the American Water Resources Association*, Vol. 38, No. 3, 835-845.

[2] Lu, D. and Weng, Q. (2006). Use of Impervious Surface in Urban Land-Use Classification, *Remote Sensing of Environment,* Vol. 102, No. 1, 146-160.

[3] Shuster, W.D., Bonta, J., Thurston, H., Warnemuende, E. and Smith, D.R. (2005). Impacts of Impervious Surface on Watershed Hydrology: A Review, *Urban Water Journal,* Vol. 2, No.4, 263-275.

[4] Marsalek, J., Cisneros, B.J., Karamouz, M., Malmquist, P-A., Goldenfum, J.A. and Chocat, B. (2008). *Urban Water Cycle Processes and Interactions: Urban Water Series-UNESCO-IHP*, Vol. 2, CRC Press.

[5] Thelen, E. and Howe, L.C. (1978). *Porous Pavement*, Franklin Institute Press.

[6] U.S. Environmental Protection Agency (1999). *Storm Water Technology Fact Sheet Porous Pavement*, Office of Water, Washington DC.

[7] Imran, H.M., Akib, S., Karim, M.R. (2013). Permeable Pavement and Stormwater Management Systems: A Review, *Environmental Technology,* Vol. 34, 2649-2656.

[8] Legret, M., Colandini, V. and Le Marc, C. (1996). Effects of a Porous Pavement with Reservoir Structure on the Quality of Runoff Water and Soil, *Science of the Total Environment,* Vol. 189, 335-340.

[9] Ferguson, B.K. (2005). *Porous pavements*, CRC Press.

[10] Legret, M. and Colandini, V. (1999). Effects of Porous Pavement with Reservoir Structure on Runoff Water: Water Quality and Fate of Heavy Metals, *Water Science and Technology*, Vol. 39, No. 2, 111-117.

[11] Legret, M., Nicollet, M., Miloda, P., Colandini, V. and Raimbault, G. (1999). Simulation of Heavy Metal Pollution from Stormwater Infiltration through a Porous Pavement with Reservoir Structure, *Water Science and Technology*, Vol. 39, No. 2, 119-125.

[12] Barbosa, A.E., Fernandes, J.N. and David L.M. (2012). Key Issues for Sustainable Urban Stormwater Management, *Water Resources,* Vol. 46, 6787-6798.

[13] Guo, J.C.Y. (1999). Detention Storage Volume for Small Urban Catchments, *Journal of Water Resources Planning and Management, ASCE*, Vol. 125, No. 6, 380-382.

[14] Al-Hamati, A.A.N., Ghazali, A.H. and Mohammed, T.A. (2010). Determination of Storage Volume Required in a Sub-surface Stormwater Detention / Retention System, *Journal of Hydro-Environment Research*, Vol. 4, 47-53.

[15] Cambez, M.J., Pinho, J. and David, L.M. (2008). Using SWMM5 in the Continuous Modelling of Stormwater Hydraulics and Quality, *11th International Conference on Urban Drainage*, Edinburgh, Scotland, UK.

[16] Zakaria, N.A., Ghani, A.A., Abdullah, R., Sidek, L.M., Kassim, A.H. and Ainan, A. (2004). *MSMA – A New Urban Stormwater Management Manual for Malaysia*, Advances in Hydro-Science and Engineering, Volume VI.

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