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Modeling and visualization of the changes of flow in the modular paver using ANSYS FLUENT

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Abstract. Increasing quantity of stormwater runoff is natural but problematic consequences of urbanization. In addressing the issue, the porous pavement usage with modular installation system has been the new alternative being experimented instead of the traditional impervious asphalt and concrete pavers. The effectiveness of porous pavement depends upon the media materials used. This study examined the potentials of an invented surface fill arrangement to be used in conjunction with the hexagonal modular system where the media tested consists of granular activated carbon (GAC), sand and zeolite. The resulting optimum bed heights of 5 cm, 5 cm and 0 cm respectively for the GAC, sand and zeolite, corroborated with the outcome of employing the optimization function, thus validating the reliability of the given arrangement. Modeling using CFD ANSYS FLUENT software and visualizing the changes in the hexagonal module filled with GAC and sand of 5 cm thickness each resulted in a flow velocity of 3.5 x 10^{-5} m/s while a physical experiment on the fixed filter bed media consisting of the two materials gave an unsaturated velocity of 3.08 x 10^{-5} m/s. The 12 % difference between the experimental and simulated velocities was considered acceptable. The results showed that GAC and sand can be used as the media for the modular paver system that treats stormwater for heavy metals contamination while serving as a practical porous pavement alternative.

1. Introduction

There are numerous porous pavement choices, each with unique benefits and drawbacks for different uses. The surface of a porous pavement may be either monolithic or modular [1]. Examples of monolithic pavement surface include porous asphalt (PA) and porous concrete (PC), while for modular surface, plastic modular pavers (PMP) and concrete modular pavers (CMP) are its most common types. Porous pavements are suitable for low traffic areas applications, such as driveways, footpaths, and car parks.

Upon contact with the porous pavement surface, stormwater tends to permeate through the voids and bedding layer, hence reducing the surface runoff volume and the risks of flooding. PMP surface layer was chosen for investigation. Figure 1 illustrates the structure of a typical PMP porous pavement. Sand, granular activated carbon (GAC), and zeolite were utilized as the fill media in the modular voids.

As for a granular material filter, the performance is dependent on the particle and pore sizes of the material. Thus, by implying the design scenarios, the numerical models of individual process were integrated to investigate the performance of porous pavement systems for effective stormwater treatment. This study focuses on the modeling and visualization of the changes in water flow in the porous pavements via the ANSYS FLUENT analysis based on the laboratory experimental data.

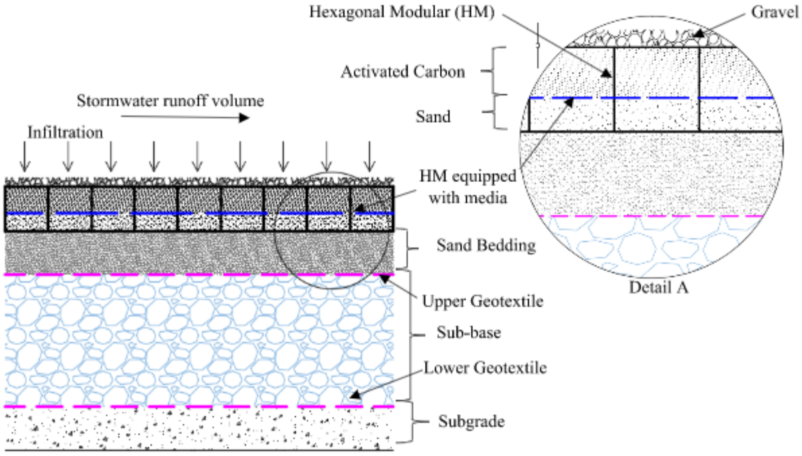

Figure 1: The structure of a typical PMP porous pavement.

2. Methodology

FluentTM is a commercially available computational fluid dynamics (CFD) package created by ANSYS Inc [2]. A structured mesh is used in the computational realm. The Blake-Kezony equation can be solved using the laminar flow feature of the software. This equation works well for simulating laminar flow since it is appropriate in situations when just a little amount of Reynolds Number is generated, which in this case is due to the fluid's flow rate through the porous material.

Numerous elements need to be considered before the simulation can be constructed. Pre-processor must first be used to generate the computer model. In order to acquire a reliable outcome, it is essential to check that the generated model closely resembles the actual pilot model. Second, the mesh and the type of mesh are generated and chosen based on how well they fit the model. The setup of the border condition follows this. It needs to be done carefully because most of the input parameters will be depending on boundary conditions. The finished mesh will then be sent so that a solver can resolve it. To calculate the flow field of the body in the solver, the solver formulation, laminar or turbulence model, and material parameters must be chosen. Before it can be solved, the boundary condition and solution control parameter must be given. The number of iterations will be chosen, but typically a high number is recommended. The iteration process will end after the count has been reached. The outcomes will next be looked over and assessed. The steps for CFD analysis are outlined as follows in Figure 2:

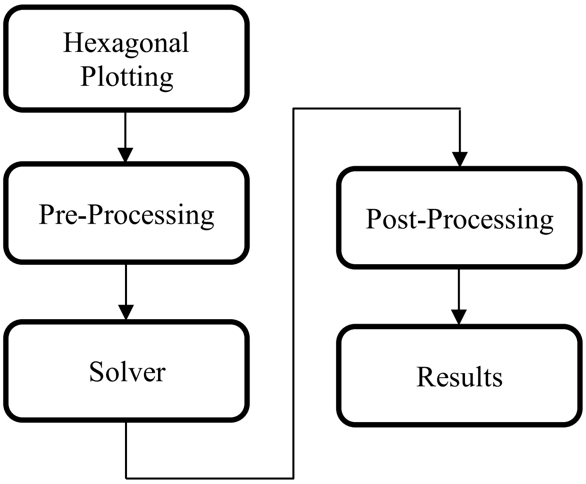

Figure 2: CFD steps of analysis.

3. Results and discussion

For the purpose of describing granular filtration processes, a large variety of models with varying degrees of complexity are available [3]. This research was done exclusively for downward vertical flow.

In Table 1 from Montgomery [4], values of sphericity for various granular media types are provided. The value of sphericity for perfect spheres is 1. The media's porosity affects sphericity. Sand and GAC had porosities that were 0.3994 and 0.4853, respectively. This indicates that the sphericity of GAC and sand had values of 0.70 and 0.81, respectively. As a result, the GAC's shape is described as crushed and sand as sharp.

Table 1: Shape factor, sphericity and porosity for granular materials [4].

Description	Sphericity	Shape factor	Typical porosity
Spherical	1.00	6.0	0.38
Rounded	0.98	6.1	0.38
Worn	0.94	6.4	0.39
Sharp	0.81	7.4	0.40
Angular	0.78	7.7	0.43
Crushed	0.70	8.5	0.48

The types of media used in this study to run the simulation were GAC and sand. The particle size of the media were between 0.063 mm to 2.36 mm. GAC and sand have low porosities which were 39.94 % and 48.53 % and can also be quantified by the effective diameter D_{10} in the order of 0.73 mm and 0.64 mm. The optimum ratio GAC and sand gave low permeability which was 0.097 cm/s and is a good permeability. As observed in Table 2 the uniformity coefficient is less than 6 thus it can conclude that the media have a uniform particle size.

Table 2: The physical characteristics of the porous media GAC and sand.

Media	Diameter effective (mm)	Uniformity coefficient (C_u)	Permeability (cm/s) 10^{-2}	Porosity (%)
GAC	0.73	2.15	5.2	39.94
Sand	0.64	1.50	6.4	48.53
GAC + Sand	-	-	9.7	-

Figure 3 displays the flow pattern when water entered the hexagonal modular. Before water passed through the porous area, the velocity of the area was represented in yellow. This shows that the velocity in the area was 4.50 x 10^{-5} m/s. However, when water passed through the porous area, the velocity decreased. The velocity drop across the porous substrate was approximately 1 m/s as can be seen in Figure 4. The velocity of the green zone was 3.50 x 10^{-5} m/s. It slowed down, straightened out, and showed a more even distribution of velocity as it moved through the porous medium. As a result, the media included in the substrate are more effective. Then, it can be seen that when the flow of water came out of the porous media area, the velocity of the flow increased because there was no more obstruction to the water. It is shown in the red area. The value for velocity in red area was 6.33 x 10^{-5} m/s. All the velocities obtained in this study are due to the physical characteristics of the media factor used. The media modelled in the model were GAC and sand. The height of the fixed bed was taken from the optimum ratio of the hexagonal column study. Media features such as size, permeability and porosity affected the velocity of water through the porous media. GAC and sand sizes are monopolized by coarse sand. The size of the coarse sand is between 0.6 mm to 2.00 mm. The hydraulic conductivity, k value for the combination of GAC and sand also showed a low value of 10^{-2} m/s. This value indicates that the degree of permeability from the combination of GAC and sand was in medium range.

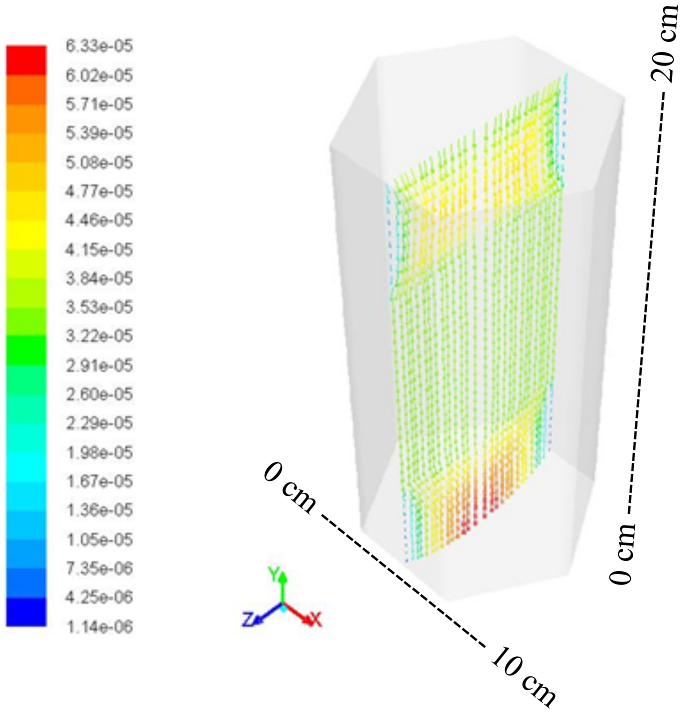

Figure 3: Velocity vectors coloured by velocity magnitude (m/s) on the x=5 plane.

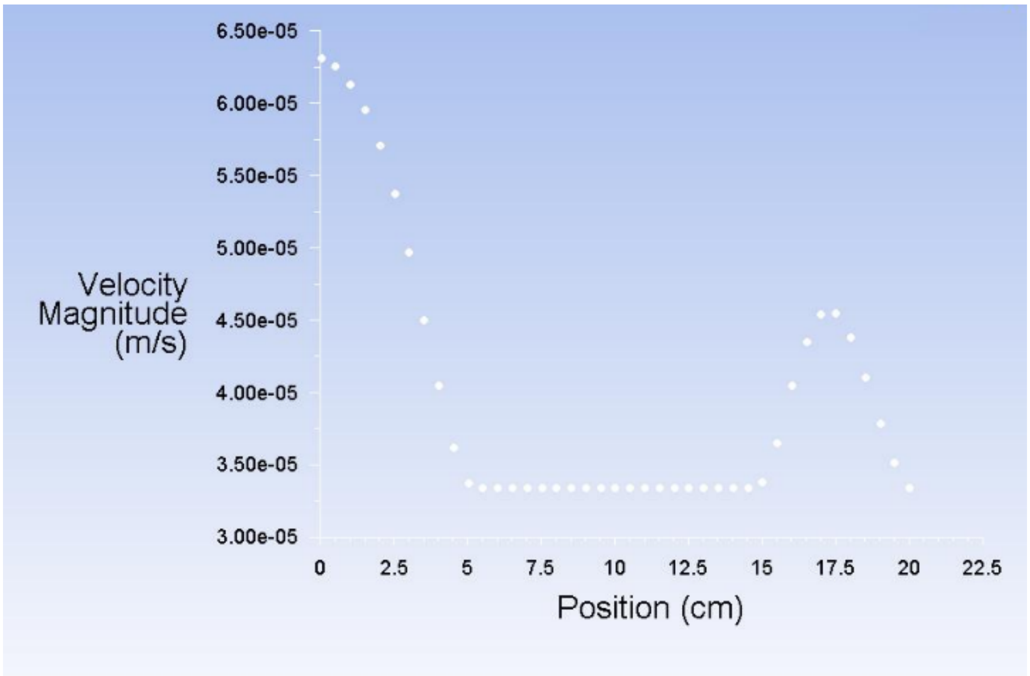

Figure 4: Plot of velocity magnitude on the porous-sand-ac line surface.

The results of simulated fluent velocity are as in Table 3. The results obtained note that the difference between the experimental and simulated velocities was about 12 % and it is acceptable because the relative error is below 20 %. If the relative error is below 10 % then it is good. The difference result between numerical study and experimental study perhaps due to numerical modelling was model for fully saturated but for physical modelling the experiment was unsaturated.

Table 3: Simulation results and the relative error.

Response	Simulated (m/s) 10^{-5}	Experimental (m/s) 10^{-5}	Relative error (%)
Velocity	3.5	3.08	12

4. Conclusion

The numerical study using CFD was performed to simulate the laboratory experimental results where water was let flow through the GAC and sand as media in the hexagonal modular unit. The simulated flow velocity was obtained for resistance factors specific to the fixed filter bed that rely heavily on the effective diameter and specific porosity of the media material. The study determined that the unsaturated velocity of the fixed filter bed media, through the experiment, as 3.08 x 10^{-5} m/s while through the numerical simulation, the velocity was determined as 3.5 x 10^{-5} m/s.

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