Hybrid green permeable pave with hexagonal modular pavement systems

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Abstract. Modular permeable pavements are alternatives to the traditional impervious asphalt and concrete pavements. Pervious pore spaces in the surface allow for water to infiltrate into the pavement during rainfall events. As of their ability to allow water to quickly infiltrate through the surface, modular permeable pavements allow for reductions in runoff quantity and peak runoff rates. Even in areas where the underlying soil is not ideal for modular permeable pavements, the installation of under drains has still been shown to reflect these reductions. Modular permeable pavements have been regarded as an effective tool in helping with stormwater control. It also affects the water quality of stormwater runoff. Places using modular permeable pavement has been shown to cause a significant decrease in several heavy metal concentrations as well as suspended solids. Removal rates are dependent upon the material used for the pavers and sub-base material, as well as the surface void space. Most heavy metals are captured in the top layers of the void space fill media. Permeable pavements are now considered an effective BMP for reducing stormwater runoff volume and peak flow. This study examines the extent to which such combined pavement systems are capable of handling load from the vehicles. Experimental investigation were undertaken to quantify the compressive characteristics of the modular. Results shows impressive results of achieving high safety factor for daily life vehicles.

1. Experimental Setup
The designed permeable pavement was constructed in 525 mm x 565 mm Perspex with hexagonal modular which was set up with hole on the bottom plate for water to pass through. Plate 1 shows the overall infiltration rig together designed permeable pavement. A rainfall simulator with 800 evenly spaced 50 mm centre to centre sprays as in Plate 3.2 was set up above the pavement surface to cover an area of 525 mm x 565 mm. Varies condition of simulated rainfall intensities were controlled by a flow meter as shown in Plate 3.3. The water flowing through the pavement was collected from underneath the pavement via a funnel connected only to the central 500 mm x 500 mm area. The infiltration area is limited to 500 mm x 500 mm to prevent boundary effects influencing hydraulic flow within the PVC box. The flat surface at the top of the funnel was screwed on to the bottom plate. There is one infiltrated holes in the middle of the bottom wooden plate (525 mm x 565 mm). The diameter of the hole is 12 mm and connected with controlled valve. This valve can be act as different condition of sub base which ranges from fully saturated to highly infiltrate area. In the boundary, 25 drainage holes were drilled on each side of the bottom plate. The pavement is constructed at a zero
slope. There are two PVC tank at the bottom of the rig, one is the water inlet storage to supply rainfall simulator and the other is to collect the outflow water. Both of the tank are connected with pipe and can be controlled the amount of water by calibrate the valves.

2. Pavement Structure
This new prototype is a new type of a pavement called Hexagonal Modular Pavement System (HMPS) [1], [2]. The HMPS is a structure of thin-walled hexagonal columns of recycled resins of polyvinyl chloride (PVC) plastic for strength, durability, and green industry benefit. Hexagonal are 10cm diameters, 5mm wall thickness, and 10cm tall. HMPS based on a simple, but impressive technology—a series of rings (hexagonal) arranged side by sides. The modular engineered to withstand significant structural loads and the grid provides stability, flexibility, and continuity for large areas. The point load pressure is transferred from the top of the hexagonal, through the fill material and modular, to the engineered base course [3], [4].

The physical model of the permeable pavement was placed in a vertical rectangular flume as shown in Plate 1 made from 20mm thickness PVC for three sides and 20mm thickness of flexi glass for front view of the model with width and length together were 525mm wide and 565mm length. In this permeable pavement, it has three different layers consists of 110mm thickness of surface layer, 300mm thickness of gravel base and 200mm thickness of sub-base layer. The sub-base layer was constructed by adding two layers of HMPS to the rig in 200mm depth. After completion of the sub-base layer, the gravel-base layer was constructed by adding washed clean cubical aggregate of 15mm
to 20mm to the infiltration rig. The surface layer of HMPS consisted of hexagonal columns of PVC with 5mm clean cubical aggregate. After the addition of each layer, the gravel was compacted using Modified Proctor Test with 95% compacted. Porosity for the surface layer was 35%, gravel-base was 40% and sub-surface layer was 92% acted as water storage.

3. Modular Pavement, HMPS
Compression test on hexagonal modular pavement system, (HMPS) have been carried out using Shimadzu Autograph AGS-X Series with loading rate of 0.005mm/min. Maximum stress obtained were 494 N/mm$^2$, maximum force were 69.7kN with maximum stroke of 3.9mm. Material used in HMPS was high-density polyethylene, HDPE. HDPE is a recycle material that been use widely due to its resistant to many different solvents such as motor oils and fuels. HDPE is highly abrasion-resistant and is unaffected by extremes in pH. HDPE was chosen as it famous in geomembrane for hydraulic applications such as bank reinforcements, geothermal for heat transfer pipe systems, water pipes and corrosion protection for steel pipelines. Figure 1 and Figure 2 shows the results from the compression test on HMPS.

High density polyethylene, HDPE is one of the most chemically inert of all plastics, and therefore is extremely chemical and corrosion resistant. This gives a significant long-term strength advantage over concrete and metal pipe. A study at California State University, Sacramento, proved that even though corrugated polyethylene had a significantly thinner wall than concrete, it was more abrasion resistant. Further, corrugated polyethylene pipe lasted 45 percent longer than concrete under more aggressive conditions.

Polyethylene has demonstrated, through testing and actual application, which it will meet or exceed life service requirements for storm water drainage applications. A service life of more than 70 years is projected in areas where corrugated polyethylene is specified.

![Figure 1. Compression test on HMPS with stress against stroke strain](image-url)
Here is the summary of laboratory test results on Hexagonal Modular Pavement System, HMPS. Physical modelled unit data made from HDPE was tested with dimension of 5 mm thickness and 100 mm diameter by 100mm high. Lab test data showed that bare rings of 72kN per modular with deflection stopped at 3.9 mm. while sand filled modular with zero deflection has 75kN per modular. Table 1 show HMPS can withstand high load with high safety factor for auto tires, truck tires, F-16 tires and fire truck outriggers. Value of sand filled HMPS with 75kN was use to compare with each items.

| Item               | Maximum load (kN) | Safety factor |
|--------------------|-------------------|---------------|
| Auto tires         | 275               | 27            |
| Truck tires        | 758               | 10            |
| F-16 tires         | 2413              | 3             |
| Fire truck outriggers | 558           | 13            |

4. Conclusion
This engineered design allows for any street-legal vehicle to park or drive on HMPS surfaces. The point load pressure is transferred from the top of the hexagonal modular to the engineered base coarse. HMPS is 92 percentage void space allowing for more decorative gravel for some of the most attractive paved surface around. This new modular pavement also makes for better runoff coefficients rates. The safety factor of loading criteria exceed over the highest truck tire pressure allowed on public highway.

References
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