Effects of Void Characteristics on Compressive Strength of Permeable Mortar Paver and Design Recommendation for Parking Area

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Abstract. This study aims to analyse the effect of void characteristics on the compressive strength of permeable mortar pavers and provide design recommendations for permeable mortar pavers to be applied in parking areas. In this study, the specimens were cast in steel moulds with the void percentages of 5%, 10% and 15%, and tested for compressive strength. For the design recommendations, the permeable mortar paver installation was carried out based on the result of laboratory testing and from some literature studies. The result of this study indicated that the lower the void percentages, the higher the compressive strength of the specimens. The use of plastic straws to make voids gave higher compressive strength compared to specimens with bamboo straws. For the application, the recommended form for the permeable mortar paver is a 21 cm x 21 cm squared pre-cast paving block which contains four 1 ½ PVC pipes as a void maker. Finally, field studies are necessary to evaluate the design recommendation of permeable mortar paver.

Keyword: Permeable Mortar Paver, Design Recommendation, Parking Lot

1. Introduction
As a country that has a humid subtropical climate, Indonesia has a high rainfall intensity. One of the cities that has a “fairly high” rainfall is Depok, located in West Java. According to BPS Kota Depok (Depok Central Bureau of Statistics) in 2018, the rainfall in Depok reaches 2883 mm. Even in the driest month during that year, Depok still has a lot of rainfall. As a result of these conditions will cause some puddles, even flooding if the rain is not absorbed well into the ground.

The concept of conventional drainage that is widely used has a paradigm that all rainwater immediately flows into a river or drainage channel without seeing the load and capacity of the river or drainage channel. The impact caused when rainwater is immediately flowed into the river without having enough time to seep into the ground is that the river cannot hold air because it requires its capacity. This causes an overflow of air returning to the mainland, resulting in inundation or even flooding.

China manages its city with the sponge city concept, a city development concept that has an integrated urban rainwater management system. This city concept focuses on low impact development that controls stormwater through temporary water storage, recycling, and purification of runoff water [1]. One form of application of the sponge city concept is the use of permeable mortar pavers in urban road infrastructure to reduce runoff, groundwater purification as a supplier of urban water, rainwater infiltration, and soil ecological restoration.
Based on the description above, this study aims to understand the mechanical properties of self-compacting permeable mortar paver by looking at the influence of several parameters including the void characteristics, mixing and curing methods. Furthermore, a design recommendation for permeable mortar paver applied in parking area is also discussed.

2. Literature Review
According to The Federal Highway Administration - U.S Department of Transportation [2], a permeable paver is a paver made of solid concrete with a connection that has an opening on the surface that is arranged to form a pattern. The joints and openings in the paver are then filled with aggregates that can absorb water such as gravel or earth. Besides permeable concrete paver, there is also a similar product called pervious concrete. Pervious concrete is a high porosity concrete that is used for ordinary work applications that allow rainwater and water from other sources to penetrate concrete, which then reduces runoff and increases groundwater levels [3]. The difference with permeable pavers is that pervious concrete does not use fine aggregates to fill cavities between coarse aggregates. So that, on the surface of pervious concrete, holes are created as a result of the cavity between the aggregates. The holes that make pervious concrete having ability to absorb water into the ground.

Based on Indonesian Standard, paving block is a building material composition that made from a mixture of Portland cement or a similar hydraulic adhesive, water and aggregate, with or without another admixtures which does not reduce the quality of the paving block [12]. In this study, to reach the concrete quality based on this standard, the specimens targeted to reach an average compressive strength of 20 MPa and reach a minimum compressive strength of 17 MPa.

3. Methods
3.1. Sample Preparation
3.1.1. Materials
The permeable pavers analyzed in this study were made of mortar with a water/cement (w/c) ratio of 0.4. The mix design is given in Table 1. Ordinary Portland cement produced by PT. Adhimix Precast Indonesia was used as the main binder. Bangka sand with a specific gravity of 2.31 was used as fine aggregate. Finally, superplasticizer was used to improve the workability.

| Table 1. Mix Design |
|---------------------|
| Materials | Volume (kg/m³) |
| Cement | 700 |
| Water | 280 |
| Sand | 1210 |
| Superplasticizer I | 5.25 |

Two types of straws, namely plastic (diameter of 12 mm) and bamboo (diameter of 10 mm) straws were selected as pore makers for permeable mortar paver. The number of plastic and bamboo straws used were adjusted so that the samples would contain voids with three designed percentages: 5%, 10%, and 15%. Those percentages were selected to understand the effects of porosity levels on the mechanical properties of permeable paver concrete. It was not possible to produce the samples containing voids more than 15% due to mould size limitation.
3.1.2. Casting

Casting the test specimen was carried out using a square mold of 150 x 150 x 150 mm. To keep the straw upright during the casting process, a pore-maker cast with an iron bar was used. Iron bars and platers were used to hold straws and iron bars respectively. The number of iron bars as a hole maker was adjusted to the percentage of voids from the test object.

Before inserting a straw into an iron bar, the iron bar was smeared with oil first. After inserting the straw into the iron bar, then the hole maker was inserted horizontally against the square mold. This is done so that the position of the straw remains symmetrical and there is no damage to the straw.
### 3.2. Sample Making Process

There were seven different casting methods during manufacturing of test specimens with several factors including mixing time, air temperature, sand conditions, mixture volume, amount of cement, water, sand, and superplasticizer used. The test specimen was made using a pan-type concrete mixer. First, the sand and cement was dry mixed for 30 seconds. Water mixed with 0.75% of superplasticizer were gradually added into the mixture and mixed for a further 3 minutes. Finally, the mixture was transferred to a bucket and then poured into the molds. The cast samples were covered with a plastic sheet for the first 24 hours before demolding. The examples of hardened specimens with plastic and bamboo straws are shown in Figure 7 and 8.

![Figure 7. Specimen with Plastic Straw](image1)

![Figure 8. Specimen with Bamboo Straw](image2)

The specimens were cured for 28 days in two ways, namely water cured by immersing the specimens in water and moist cured by wrapping the specimens using plastics as shown in Figure 9 and 10.

![Figure 9. Water Curing Method](image3)

![Figure 10. Moist Curing Method](image4)

### 3.3. Compressive Test

Procedure for compressive test specimens was carried out in accordance with ASTM C 109 / C 109M – 99 [4]. This procedure was carried out by placing the test specimens onto the test machine. Compressive testing was carried out from the top and side of the specimen to analyze the effect of
specimen positions. To get the compressive strength, the total pressure is divided by the surface area of the test piece from the side pressed.

![Figure 11. Side part of compressive test](image1)

![Figure 12. Top side of compressive test](image2)

3.4. Design Parameter

To be applied to a parking area, the designed paver must meet the eligibility standards. According to SNI 03-0691-1996 [5], the paver applied to the parking area is categorized as a quality B paving block, which means it must have an average compressive strength of 20 MPa and a minimum compressive strength of 17 MPa. Apart from the strength factor, the paver should have no cracks so it is not easy to be brittle even though it is pressed using a finger.

4. Result and Discussion

4.1. Compressive Test Result

The results of compressive strength testing with different void percentages can be seen in Figure 13 and 14. The average compressive strength of the specimens tested from the top-side test with a void percentage of 5% was 30.29 MPa, a percentage of voids of 10% was 27.47 MPa, and the percentage of voids was 15% by 24.42 MPa. The average compressive strength of the specimens tested from the side test with a void percentage of 5% was 27.58 MPa, a percentage of voids of 10% was 22.48 MPa, and the percentage of voids was 15% by 11.14 MPa. The average calculation results can be caused by voids made from plastic straws and bamboo straws making the mortar does not fully fill the holes contained in the test specimens. In addition, the more the number of straws filling the mold, the position of the straws getting closer to each other so that when the casting process of the mortar does not meet the mold in full. From Figure 13 and 14, it indicates that the specimens with plastic straws have a greater compressive strength than the specimens with bamboo straws. It is probably because the bamboo straws as a pore maker tend to swelling and shrinking as it absorbs water during the curing periods until it affected the specimens itself. Hence, the quality of the concrete has been decreased. [10]
The effects of curing methods on the compressive strength of permeable mortar paver can be seen in Figure 15. It showed that the average compressive strength of the specimens cured in the water produce higher compressive strength compare to the specimens with moist cured. This finding is in line with the pervious study confirming that the specimens cured in water will experience better hydration process due to sufficient humidity and vapor pressure compared to the moist cured [11].

4.2. Design Analysis
In making designs for permeable mortar pavers, several references are needed as a benchmark in their application in parking areas. The benchmark is needed as a consideration whether it can be applied in Indonesia, especially Depok. Apart from literature studies, the design of permeable mortar paver is also considered from the results of laboratory tests.

4.2.1. Infiltration Design
Data from the FTUI Rain Station from 2003 to 2018 shows that the rainfall in Depok is 4.99 mm / hour. Based on Depok City soil data, soil types in the subgrade layer in Depok City are red latosol soils with the ability to absorb water of 5.47 - 19.18 mm / day or 0.23 - 0.80 mm / hour. The data shows that subgrade land is not sufficiently permeable. According to Credit Valley Conservation [6], to build a permeable mortar paver with this type of soil, an infiltration system in the form of a perforated drainpipe with a flow restrictor is required. The pipe is installed in the subbase layer with a minimum slope of 0.5% towards the outlet.

4.2.2. Subsoil
In order to function properly, the soil layer must be changed in the installation of permeable mortar paver. On top of the subgrade layer is a non-woven geotextile layer which functions to prevent the migration of subgrade soil layers to the subbase which can cause clogging. In the subbase layer coated coarse aggregate with a diameter of 63 mm (ASTM No. 2), base layer coated with coarse aggregate with a diameter of 20 mm (ASTM No. 57), and the bedding course layer coated coarse aggregate with a diameter of 5 mm (ASTM No. 8). This arrangement was chosen to make the stormwater to drained into the pavement and then streamed into the drainage outlet without being clogged. According to
Credit Valley Conservation [6], this layout can be useful in a high density area that have limited space for stormwater best management practices (BMP).

**Figure 16.** Cross section detail 1

**Figure 17.** Cross section detail 2

### 4.2.3. Permeable Mortar Paver Fabrication Method

To achieve good quality permeable mortar paver, high quality materials are needed. From the results of laboratory studies, the cement used to get good quality concrete is the type of Ordinary Portland Cement (OPC) cement and the fine aggregate used is Bangka sand.

There are 2 methods that can be applied to parking lots, namely the in-site and pre-cast methods. Based on the installation method, the in-site method tends to be faster than pre-cast method because the casting process is carried out directly on site so the paver transfer process is not carried out. When viewed from the installation of the hole / pore maker, the in-site method will tend to be more difficult than the pre-cast method because in the in-site method, the casting area will be broader compared to the pre-cast method so that it will increase the risk of hole makers not being perpendicular. When viewed from the mix-design mixing method, the in-site method has more risks of being wrong than the pre-cast method. This is because in the pre-cast method, the mixing process is carried out in accordance with the predetermined mix-design volume so that the quality of the concrete is better maintained. Whereas in the in-site method, mixing is done not based on a predetermined mix-design volume but only based on the dose / comparison. From these statements, in the application of permeable mortar paver on the parking lot using the pre-cast method.

For the selection of pre-cast shapes from permeable concrete pavers, there are 2 choices of shapes, namely pre-cast floor slabs and pre-cast paving blocks. Pre-cast concrete itself has a definition as a concrete that has been printed and maintained in a location that is separate from the installation location [8]. When compared to pre-cast paving blocks, pre-cast floor slabs are better able to withstand compressive strength due to reinforcement. However, the permeable mortar paver function that is able to drain puddles from the surface into the ground, the pre-cast floor slab is considered less effective because the reinforcement contained in the pre-cast floor slab will obstruct the flow of water. In addition, with the reinforcement, the hole-making pipes will certainly collide with each other so that the molding process will be difficult and risky to crack. From these considerations, permeable mortar paver was chosen in the form of a pre-cast paving block.

For the shape and dimensions used, a rectangular paving block of 21 x 21 cm was chosen with a thickness of 8 cm. The reason for the thickness of the pre-cast paving block used is 8 cm in order to meet the standard dimensions of the paving block written in SNI 03-0691-1996 [5], which is a minimum thickness of 6 cm. The dimensions of the pre-cast paving block chosen are 21 cm x 21 cm to adequately fit the hole in the pre-cast paving block and the required percentage of voids. In the permeable mortar paver design plan in this study, for an adequate percentage of voids by 15%, 1 ½ inch PVC pipes needed amounted to 4 pieces with a surface area of 21 cm x 21 cm. In the fabrication process, the mold used is of course also the size of 21 cm x 21 cm with a thickness of 8 cm adjusted to the permeable mortar paver design plan.
4.2.4. **Permeable Mortar Paver Pore Maker**

From the testing results in the laboratory, the next step is to design a parking area with a permeable mortar paver. For the application of permeable mortar pavers as pavement parking lots, pore makers are needed that are able to withstand vehicle loads and are also able to absorb puddles optimally according to their main function. The hole maker used in permeable mortar paver in this study uses media in the form of pipes or straws. The reason that for making holes must use media in the form of pipes is to avoid clogging. Because the potential blockage of permeable paver will be greater if the hole has a high tortuosity [7]. Tortuosity is a measure of geometric complexity in porous media [9], which in this study is a permeable paver. After conducting laboratory experiments, it can be concluded that both bamboo and plastic straws are not strong enough to withstand vehicle loads and absorb standing water simultaneously. That is because the diameter of the straw is small and the number of straws is large because it is adjusted to the minimum percentage of holes, causing gaps between the straws that are very tight, thereby reducing the quality of concrete. To overcome these deficiencies, PVC pipe was chosen as a pore maker because the larger diameter of the PVC pipe makes the gap between pipes not so tight that it does not reduce the quality of concrete. Apart from the diameter of the hole, PVC pipes were also chosen because PVC pipes considered to be stronger and more durable compared to bamboo straws and plastic straws. The reason for not using stainless steel straws or iron straws even though the material is considered stronger than PVC pipes is because the price of iron straws tends to be more expensive than PVC pipes so it is less economical. Unfortunately, due to COVID-19 pandemic that happened in Indonesia and the implementation of large-scale social restrictions (PSBB) in West Java, the research was stopped so that there are no laboratory results that using PVC pipes.

In its manufacture, 1½ inch diameter PVC pipe was selected. This is based on the calculation of the ratio of hole area to paver area measuring 21 cm × 21 cm so that a void ratio of 15% is obtained. From the calculation of the void ratio, obtained the appropriate number of PVC pipes as many as 4 pieces. The number of pipes as much as 4 pieces was chosen because with 4 PVC pipes, it would be effective to drain the water without having to cause objects/loads on it to fall into the hole. Examples of objects that have a direct impact on permeable mortar pavers in a motorcycle parking area are the standard motors used to support motors. With a PVC pipe diameter that tends to be smaller, causing the standard risk of the motor to fall into the pipe hole is much smaller. For anchoring PVC pipes during fabrication, a hole punch is needed. The orifice mold used to hold the PVC pipe has the same concept as the orifice mold used in the manufacture of laboratory test specimens. The difference lies in the type of iron rod used. The iron rod that serves as a barrier to PVC pipes is a 32 mm diameter concrete steel with 100 mm length. The concrete steel used is 32 mm in diameter to be able to hold the 1½ inch diameter PVC pipe. The length of concrete steel measuring 100 mm is adjusted to the thickness of the permeable mortar paver design of 80 mm.

![Figure 18. Recommendation Design of Permeable Mortar Paver](image-url)
4.2.5. **Curing Method**

After determining the installation method, the next step is to determine the treatment / curing method. There are 2 choices of treatment methods, namely using water curing method and moist curing method. From the laboratory results, the curing method in water was chosen because the compressive strength produced is better than the moist curing method.

4.3. **Design Recommendation**

The form used in permeable mortar paver is a pre-cast paving block with a dimension of paving block of 21 cm x 21 cm x 8 cm. This is to meet the minimum thickness standard of paving blocks listed in SNI 03-0691-1996 [5] which is equal to 6 cm and also to meet the required percentage of voids which is equal to 15%. The chosen hole maker is PVC pipe due to its larger dimensions compared to bamboo straws and plastic straws so that concrete will be better able to absorb standing water. The size of the PVC pipe is 1 ½ " and the number of pipes as much as 4 was chosen due to the ergonomic factor of the paver so that the permeable mortar paver's ability to absorb water continues to function without having to make objects on the surface of the paver easily fall due to pipe holes.

The paver treatment process is chosen by using water because of the results of laboratory tests, samples using water treatment methods show greater compressive strength compared to plastic treatment methods. The maintenance process is carried out after the permeable mortar paver has finished printing.

There are several layers needed to allow the permeable mortar paver to work optimally according to its function. The subgrade layer is coated with geotextile so that the aggregate in the subbase is not mixed with the original soil which can cause clogging. Then on top of the geotextile, there is a subbase layer that is filled with 63 mm diameter rough aggregate. At the subbase layer, an infiltration system is installed in the form of a perforated pipe with a flow restrictor. This is because according to Depok city land data, Depok subgrade land is not sufficiently permeable. After the first subbase layer has been filled in accordance with the plan, then the subbase layer is filled with 20 mm diameter aggregate. Subbase layers use aggregates of specific size so that the pool of water that is on the surface can flow properly and then continue through the infiltration system in the subbase layer. Then, the subbase is then coated with a layer of bedding course with 5 mm aggregate filled before the permeable mortar paver is installed. In addition to spreading the load to the extent of the bedding course, the bedding course can also be used to drain puddles on the surface to be passed on to the subbase layer.

![Figure 19. Top View of Permeable Mortar Paver Parking Lot Recommendation Design](image)

![Figure 20. Cross Section View of Permeable Mortar Paver Parking Lot Recommendation Design](image)
Figure 21. Infiltration Mechanism of Permeable Mortar Paver

Based on Figure 17, explains the infiltration mechanism of permeable mortar paver. Stagnant water found on the surface enters the soil through a PVC pipe in a permeable mortar paver. Then, the puddle will undergo a screening process from the bedding course layer to the subbase layer. Stagnant water that passes through the subbase then enters the perforated pipe located in the subbase layer. At the outlet end of the pipe, a flow restrictor is installed.

5. Conclusion

The purpose of this study is to analyze the influence of void characteristics, mixing and curing methods on the mechanical properties of permeable mortar pavers. The results of this study indicated that the smaller the number of void percentages, the higher the compressive strength of the specimens compared to specimens that have a higher number of void percentages. For the specimens with plastic straws as a void maker produced higher compressive strength compared to the specimens with bamboo straws. Another factor in this study was curing method. The specimens cured under water would produce higher compressive strength compared to the specimens with the moist cured. In its application in the real world, the recommended design for the permeable mortar paver is a 21 cm x 21 cm squared pre-cast paving block containing four PVC pipes with a diameter of 1 1/2 as a void maker.

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