APPLICATION OF PERMEABLE CONCRETE TO REDUCE THE OCCURRENCE OF FLOOD IN INTRAMUROS, MANILA

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ABSTRACT

Urbanization has greatly increased the number of impermeable surfaces in Manila. The historic place in Metro Manila, which is Intramuros, has been prone to floods during long and short-lived intense rainfalls. One of the traditionally blamed factors besides the age-old drainage system and clogged streams was the increase in concrete pavements. Permeable concrete has been used around the world to address the problem of flooding and other negative effects such as groundwater pollution and Urban Heat Island. This study conducted several flexural strength tests and falling head tests to assess the flexural strength and permeability of permeable concrete. The data and results from the tests were compared with the data gathered from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) and Department of Public Works and Highways (DPWH) to determine the efficiency of permeable concrete in reducing the occurrence of flood in Intramuros, Manila.

Keywords: Permeable concrete, Stormwater, Rainfall, Falling head test, Infiltration

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INTRODUCTION

Nowadays, urban development has posed a threat to our natural resources. Rapid urbanization has been consuming our natural resources. It significantly lessens the percentage of pervious material in urban areas because man-made, widespread waterproof surface replace natural vegetation, which is naturally permeable and mitigates the effects of natural phenomenon like precipitation. Precipitation causes stormwater run-off to form in urban areas and this may cause flooding by overloading the drainage systems, creeks and rivers. Additionally, impervious surfaces obstruct cooling of its surface temperature by delaying the evaporation of moisture that has been trapped in the underlying soil. As a result, vast permeable area will contribute to the increase in ground surface temperature and dryness that are commonly experienced in urban areas.

More so, a study showed that one of the causes of flashflood in Metro Manila is loss of infiltration due to an increase of urban concrete which is an impermeable surface. In addition, the century-old drainage system of Metro Manila has been ineffective in handling even the short-lived heavy rains. Clogged streams have also been the obvious cause of flashflood in the metropolis as they cause the stormwater to accumulate in an area.

Permeable concrete is becoming an appealing substitute to the use of conventional concrete to construct pavements because of its capability in stormwater management and reducing Urban Heat Island(UHI) effects. It is one of the Best Management Practice strategies by the U.S. Environmental Protection Agency (EPA), as suggests in a study. Permeable concrete with proper maintenance is very efficient and has the best performance in mitigating floods. This study aims to evaluate the efficiency of permeable concrete in reducing the occurrence of flood in Intramuros, Manila.

THEORETICAL BACKGROUND

Literature Review

Rainfall data is a fundamental parameter in this study because it helps to determine the volume of stormwater in an area, because rainfall intensity directly affects the volume of stormwater runoff[6].When rainfall intensity is higher than the infiltration rate of ground surfaces, stormwater runoff will be generated. In addition, a study mentioned that the permeability of a surface is not mainly influenced by change in land use but also by rainfall intensity [6]. Impermeable surfaces decrease the infiltration of stormwater into the soil, affecting the condition and quality of groundwater. These are the major problems that increased impervious areas pose to the environment.

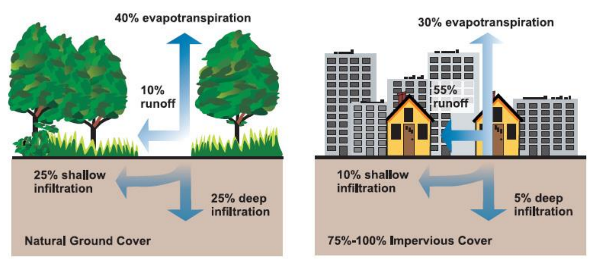

Figure 1. Illustration of where rainfall water goes

Flooding has been an agonizing problem in the cities around the world. For example, urban flooding caused damaging and life-threatening effects in the last decades in China [8]. Los Angeles, California was once affected by dangerous flooding events until they diverted the Lasagnas River (Yin, 2016). Occurrence of flooding events is more likely to increase in the future because of the increase in urban concrete and stormwater management strategies or methods have been proven ineffective.

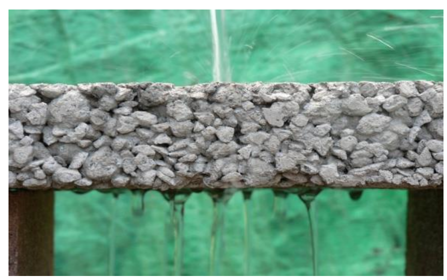

Figure 2. Permeable Concrete

Permeable concrete with proper maintenance is very efficient and has the best performance in mitigating floods. Furthermore, it has become one of the most used sustainable urban drainage system (SUDS) techniques and a best device to treat the runoff and contaminants. Infiltration capacity and contaminants removal rates are the main idea of the studies about permeable pavement or porous pavement. By the use of permeable concrete or pervious concrete, the storm water can be collected, treated, and infiltrate freely in the crushed stone base to helps increase the ground water recharge.

The mix proportions of the materials in making permeable concrete are: 0.3-4% water/cement Ratio, 0-20% fine aggregates ratio, 4-6 aggregate cement ratio and void content of 15-20%. On the other hand, there are different kinds of method which follow Darcy's law that can be followed or used to determine the permeability of a permeable concrete.

One of the simplest ways to conduct a falling head test is acquiring the penetration coefficient. An experimental study adapted this method in determining the infiltration rate of the permeable concrete cylinders. Measured volume of water is injected from the opening of a graduated cylindrical container attached to the top of the cylinder. Then the amount of time of the total volume of the water to infiltrate through the specimen is recorded. These parameters are then applied to the formula below:

$$v = \frac{V}{A\,x\,t} \qquad \textbf{Equation (1)}$$

Where:

v = permeability coefficient
v = volume of water injected
A = Area of the bottom of the graduated container
t = duration of time

Theoretical Framework

Floods in Metro Manila are traditionally attributed to century-old drainage system, to clogged streams and to the loss of vertical and horizontal infiltration of stormwater from the surface of the ground through the soil due to the loss of impermeable surfaces. Floods have been causing negative impacts to the city. Some of them are the damages that floods inflict to structures like road pavements, buildings, business establishments and schools. Traffic congestion is also one of the detrimental effects of floods, it costs PhP2.4 billion a day from the prolonged consumption of gasoline and the lost economic productivity

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This study aims to address the effect of the increasing impermeable surfaces by evaluating the efficiency of permeable concrete in reducing the occurrence of flash floods in one of the oldest and historic places in Metro Manila—"the walled city" or Intramuros. The researchers followed the standards and specifications of tests that are to be conducted, namely, ASTCM C78 (Standard Test for Flexural Strength) and falling head test. In addition, *Rational Method*was done by the researchers for estimating the design discharge of stormwater in Intramuros to evaluate the effectiveness of its existing drainage or sewer system. The simplest infiltration models, which are*Horton's Infiltration Equation*and *Green-Ampt Method,* were used to relate the reduction of run-off of permeable concrete in relation with rainfall data that were gathered from Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

METHOD

The research design of this study was experimental since permeability tests and flexural strength tests were conducted to determine the parameters of permeable concrete which were necessary for the rainfall depth reduction analysis using Horton's Equation and Green-Ampt method.

Gathering of the Data of the Design Strength of the Existing Pavements in Intramuros, Manila

Based on the information gathered by the researchers from an interview with the engineers from DPWH and their Blue Book manual, the existing design strength of the existing pavements in Intramuros was 3.8 MPa for flexural strength. Additionally, the size of the pipes of the drainage system in Intramuros, Manila, according to MMDA Flood Control Office, was only 12 inches.

Gathering of Rainfall Data from Philippine Atmospheric, Geophysical and Astronomical Services Administration

Rainfall data of extreme rainfall events such as Habagat August 18-19, 2013,Habagat August 11, 2018, Intensity-Duration-Frequency (IDF) curve, and Depth-Duration-Frequency (DDF) curve were gathered from PAGASA. These data were used in the calculation of the theoretical design of the drainage system (using Rational Method) and in the rainfall depth reduction analysis (using Horton's Equation and Green-Ampt Method) (**see Appendices C.27**, **C.28)**

Soil Exploration Data from DPWH and from the Engineering Office of the Colegio de San Juan de Letran

These data were necessary in determining what type of soil is underneath Intramuros. It can be observed that the nearest soil type from the ground surface was silty sand(**see Appendix C.4***)*.

After determining the soil type parameters for the Green-Ampt method were determined(**see Appendix C.28***)*.

Production of PC Specimens

Following the mix proportion of 1:4 cement-aggregate ratio and 0.3 water-cement ratio, the researchers made 5 batches of PC specimens, each batch had 3 beam and 3 cylinder PC specimens. Additionally, the difference between the batches was its fine aggregate percentage, starting from 0% and incrementing by 5%.

Flexural Strength and Falling Head Tests

The flexural strength tests (using Third-point method) were conducted in the testing facility of DPWH in Port Area, Manila. On the other hand, the permeability of the specimens was determined by the researchers by performing falling head test on the cylinder specimens and using the formula of permeability coefficient:

$$v = \frac{V}{A\,x\,t} \qquad \textbf{Equation (1)}$$

Where:

v = permeability coefficient (cm/s)
V = volume of water infiltrated (ml)
A = Area of the bottom of the graduated cylinder (cm^2)
t = duration from 650 ml mark to 150 ml mark (s)

Analysis of Variance (ANOVA) for the flexural strength and permeability results

A statistical treatment called Analysis of Variance was performed to determine if there was a significant difference between the batches in terms of flexural strength and permeability. Additionally, the batches which had the highest and lowest permeability and flexural strength were determined using ANOVA.

Comparison of the Existing Design to the Theoretical Design (Using Rational Method) of Drainage system in Intramuros, Manila

The size of the pipes was compared to the theoretical design using the equation of Rational Method and Manning's Equation:

$$Q = c\,i\,a \qquad \textbf{Equation (2)}$$

$$d = \left[\frac{Q\,x(8.69n)}{\pi\,x\,s^{1/2}}\right]^{\frac{3}{8}} \qquad \textbf{Equation (3)}$$

Where:

Q = discharge (m^3/s)
c = runoff coefficient
i = rainfall intensity (m/s)
a = catchment area (m^2)
n = Manning's coefficient of roughness
s = slope

According to the American Society of Civil Engineers and Water Environment Federation, the value of runoff coefficient for asphaltic and concrete pavement surfaces range from 0.70 to 0.95; a value of 0.0 means that all the rainfall is lost in the form of abstractions such as infiltration, interception, and evaporation and the value of 1.0 means that most of the rainfall will be immediately be converted to runoff. Additionally, the rainfall intensity that was used 12.3 mm/hr since the highest accumulated depth was 290 mm (**see Appendix C.27**). The total area of Intramuros, Manila was 67 ha or 670,000 m^2. On the other hand, for the Manning's Equation, the Manning's coefficient of roughness for concrete is .013 and the standard slope of the pipes is .10%.

$$Q = (0.95)(12.3)(\frac{1}{3600(1000)})(670000)$$

$$Q = 2.1747\ \frac{m^3}{s}$$

Conceptual Framework

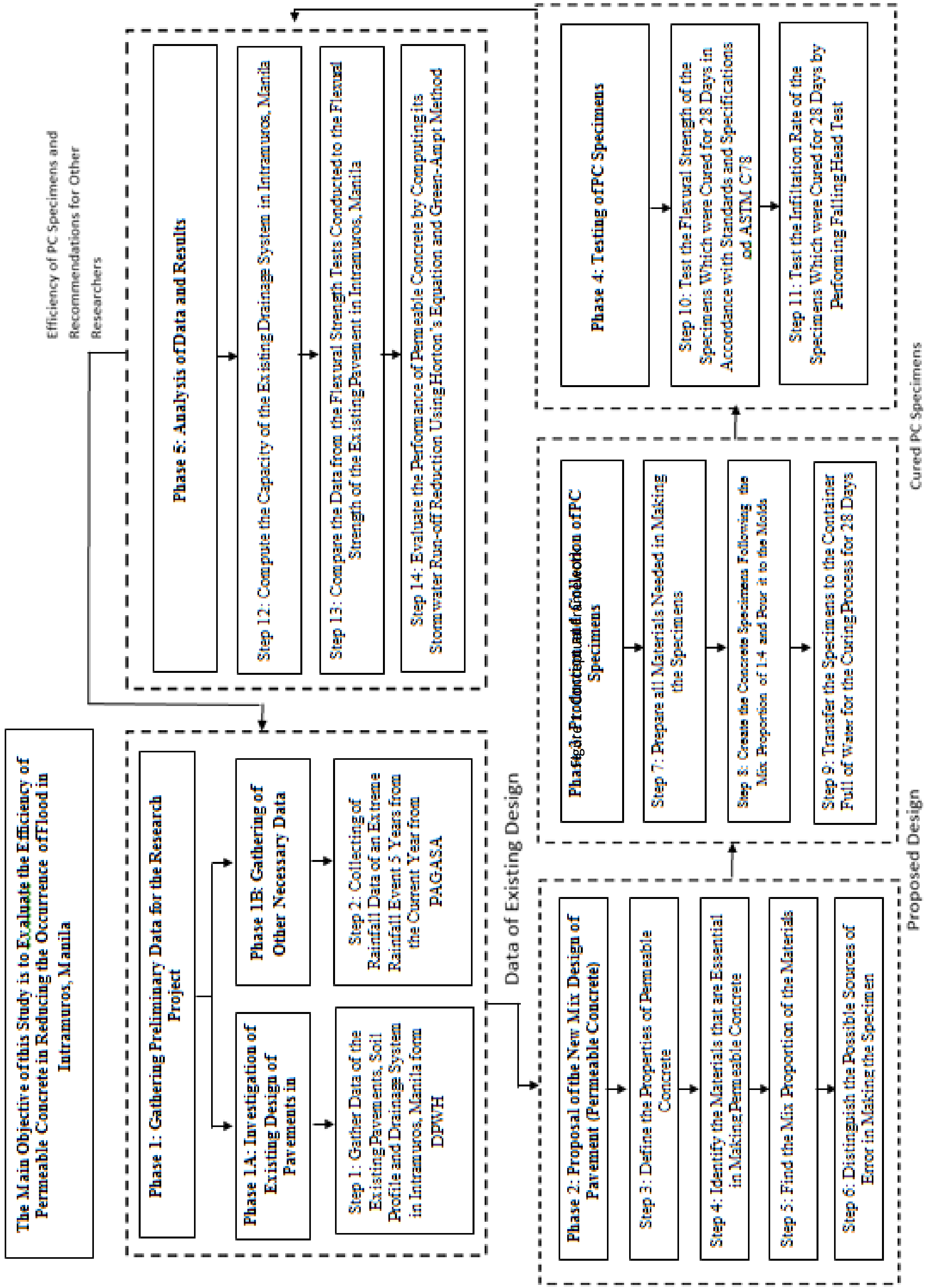

Figure 1. Conceptual Framework

$$d = \left[\frac{2.1747\ x(8.69(.013))}{\pi\ x\ .0010^{1/2}}\right]^{\frac{3}{8}}$$

$D_{theoretical} = 1.4043\ m$

$D_{design} = 0.3048\ m$

$\boldsymbol{D_{current\ design} < D_{theoretical}}$

Illustration of the Behavior of Rainfall Water in the Proposed Permeable Pavement Design

Thecross-section of the proposed design of permeable pavement by the researchers. Based on the data acquired by the researchers from DPWH, the thickness of concrete pavement under high traffic conditions is 300 mm. Consequently, the researchers still followed the standards even if the roads in Intramuros are not subjected to heavy loadings because permeable concrete pavement has lower flexural strength than conventional concrete pavement (**see Appendix C.33-C.34**.)

Rainfall Depth Reduction Analysis using Horton's Equation and Green-Ampt Method

Based on the preliminary research of the researchers, Mustafa said in his study that the United States Environmental Protection Agency (USEPA) stated that 50 % of rainfall water infiltrates the soil in permeable surfaces or natural ground covers. The mentioned assumption was used in this study, meaning that 50% of the total runoff was infiltrated by the permeable concrete then through the soil, and the remaining 50% was transported into the drainage system with the help of the cross-slope of the pavement measuring 2%. As a result, the original final cumulative depth of all the rainfall data gathered was reduced to 50%. Moreover, when analyzing rainfall depth reduction, the depth of rainfall is completely infiltrated when the rainfall intensity is lower than the infiltration rate of a medium.

After determining the maximum and minimum infiltration rate of permeable concrete by the statistical treatment used, the researchers used Horton's Equation to check if the cumulative depth of a particular rain infiltrates the permeable concrete. As shown by the tables and graphs below, none of the rainfall intensities is greater than the infiltration rate of the permeable concrete. Hence, it can be safely said that no ponding occurs. In addition, since all the run-off depth has been infiltrated by the permeable concrete, the stormwater will start to infiltrate the soil underlying the pavement; this is the reason why it was essential to determine the soil classification of soil underneath. The researchers based the parameters from the soil profile of the soil exploration conducted inside the premises of Colegio de San Juan de Letran (**see Table 2**).

Table 1

Maximum Inflation Rate, f_o	Minimum Inflation Rate, f_c	Decay Constant k
2.4637 cm/s	0.6911 cm/s	0.5 hr

Permeable Concrete Parameters for Horton's Equation

Table 2

Porosity	Time Interval	Effective Porosity	Suction Head	Hydraulic Conductivity	ΔΘ
0.437	1 hour	0.417	6.13 cm	2.99 cm/hr	0.2807

Parameters for Green-Ampt Equations

As shown in column No. 4 (**see Appendix C.18**), the infiltration capacity that was computed by using Horton's Equation was significantly greater than the rainfall intensity in column No.3 during the whole duration of rainfall. Therefore, there was no initial ponding. On the other hand, the infiltration capacity of the soil during the whole duration of rainfall was also sufficient enough to withstand the intensity of the rain. Therefore, the whole amount of rain was infiltrated throughout the soil and there was no runoff.

Computation:

$$F_{t+\Delta t} = F_t + K\Delta t + \varphi\Delta\theta ln\left[\frac{F_{t+\Delta t} + \varphi\Delta\theta}{F_1 + \varphi\Delta\theta}\right] \textit{Equation (4)}$$

$$f_{t+\Delta t} = K\left(\frac{\varphi\Delta\theta}{F_{t+\Delta t}} + 1\right) \textit{Equation (5)}$$

$$f(t) = f_c + (f_o - f_c)e^{-kt} \textit{Equation (6)}$$

To get the infiltration of permeable concrete at time t, substitute the maximum and minimum infiltration rate of permeable concrete to the Horton's Equation. At the first hour of the rainfall duration, the infiltration rate of permeable concrete is equal to:

$$f(t) = 0.6911(3600) + (2.4637(3600) - .6911(3600))e^{-0.5(1)} = 6358.45\ mm/hr$$

This means that the infiltration rate of permeable concrete was significantly larger than the intensity of rainfall; this is exactly the same with the three remaining rainfall events that were analyzed, namely, Habagat 19, 2013, Habagat 11, 2018 and a 10-year 24-hr rainfall event (**see Appendices C.19-21**). In addition, there was no accumulation or ponding of water at the surface of the permeable concrete. The stormwater runoff was infiltrated through the soil that is why the soil or the subgrade must be considered in computing the total reduction runoff. The Green-Ampt method was used in this part. To get the infiltration rate of the soil at the first hour of the rainfall, the researchers used Formula 3.2.2.

$$f_{t+\Delta t} = 2.99\left(\frac{0.2807(6.13)}{0.695} + 1\right) = 103.9269\ mm/hr$$

Since the infiltration capacity of the soil throughout the rainfall duration was greater than the intensity of the rainfall, all of the rainfall depth was infiltrated by the soil, hence, there was no ponding of stormwater runoff or occurrence of flood**.**

RESULTS AND DISCUSSION

The comparative results of the existing design of the drainage system to the theoretical design using rational method prove that the current size of the pipes was insufficient to mitigate the occurrence of flood during extreme rainfall events in Intramuros, Manila. Consequently, the results support the objective of the study to determine the efficiency of permeable concrete as additional flood mitigating measure. This was done by using rainfall depth reduction analysis using Horton's Equation and Green-Ampt method; ANOVA helped the researchers to determine the highest and minimum infiltration capacity of permeable concrete (**see Appendix C.32)**. According to the results of the analysis, the use of permeable concrete as an alternative pavement was successful in rainfall depth reduction because the infiltration capacities of the permeable concrete and the soil underneath Intramuros were significantly higher than the rainfall intensities of the extreme rainfall events (**see Appendix C.18-21**). Most of the flexural strengths of the specimens, however, were insufficient and did not pass the standards of DPWH (**see Appendix C.29).**

CONCLUSION

The main objective of this research is to determine the efficiency of permeable concrete by making samples of different batches (each different by fine aggregates percentage) and determining their respective flexural strength and permeability. The data and results were then evaluated by comparing the flexural strengths to the standards of DPWH and by calcı performance of permeable concrete in run-off depth reduction.

Based on the gathered data and results by the researchers, the capacity of the drainage system in Intramuros, Manila needs improvement because its current design is significantly small to the required theoretical design by the rational method. In addition, as shown in **Appendix C.29**, most of the batches failed the standard strength for flexural strength in concrete pavement of Department of Public Works and Highways. However, 4 samples passed the standard flexural strength of concrete pavement of the Blue book of Department of Public Works and Highways at 28 days of curing; the standard of DPWH is only at 14 days. On the other hand, in terms of reducing the run-off depth of rainfall, application of permeable concrete is efficient since it can be observed that the 50% of the runoff of extreme rainfall events namely, Habagat August 11, 2018, Habagat August 18, 2013, Habagat 11, 2018 and a 10-yr 24-hr rainfall event with an accumulative depth of 270 mm were reduced by 100%. Thus, the volume of stormwater in the stormwater drainage system is effectively reduced by 50% (**see Appendix C.18-21)**. Furthermore, the researchers concluded that the application of permeable concrete to reduce the occurrence of flood in Intramuros, Manila is not feasibile. Although it was considered to be efficient in terms of reducing the runoff depth, the flexural strength results showed otherwise since most of the flexural strength results did not pass the DPWH standards.

RECOMMENDATION

The researchers come up with four recommendations based on the scope and limitations of this study. First, for future researchers, it is highly recommended to use admixture to check if its addition can increase the mechanical properties of permeable concrete e.g. compressive strength and flexural strength.Furthermore, since the researchers of this study based the viability of application of permeable concrete only to the flexural strength standard of the Department of Public Works and Highways, the researchers recommend that the compressive strength shall also be considered. There are other permeability tests available to determine the permeability of materials; the researchers recommend that future researchers should consider using different type of permeability test in order to compare their data to this study. Finally, the researchers recommend the use of a laboratory apparatus called rainfall simulator. This apparatus can be of great help in determining the efficiency of permeable concrete in runoff depth reduction because it can be calibrated to a specific rainfall intensity of a rainfall event.

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