Qualitative Investigation of the Application of Pervious Concrete as Pavement for Stormwater Runoff Management using Hydrologic Modelling System (HEC-HMS)

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***Abstract*—Given its strategic location, numerous tropical cyclones enter the Philippine area of responsibility yearly. Through this occurrence, flooding has been one of the foremost problems particularly in the City of Manila. Given this, the researchers aim to assess the capacity of pervious concrete as it is applied as pavement through creating a pervious concrete sample and testing its capacity for compression and infiltration. Further reinforcing the analysis, the soil capacity for infiltration of the study area was also determined. Simulations depicting both the conventional and pervious concrete road were also created through the use of Hydrologic Modelling System. Through this, it was observed that there is a significant difference between both types of roads, predominantly with the behaviour of stormwater runoff with respect to the concrete pavements studied. Further analysing the hydrographs obtained from the simulations, the researchers had found that using pervious concrete for stormwater management would be certainly effective. To ensure its efficiency, several factors are to be considered such as the management of excess precipitation and the soil capacity of the area.**

***Index Terms*—Water Resources Engineering; Storm Runoff Management.**

I. INTRODUCTION

The existence of roads plays a vital role in the transportation system of a country. It directly affects society as it serves as a connection between various parts of a region through strategically constructed routes. Different sectors depend on this mode of transportation not only in the movement of people but also in the transfer of goods. However, its quality and efficiency are further tested through various causes such as its continuous contact with heavy loaded vehicles, causing road deformations, which then worsens through its exposure to stormwater.

Traffic congestion is common in the Philippines and is often the cause of delay in the transportation of goods. Through the study conducted by Japan International Cooperation Agency (JICA), it was known that these traffic jams and congested street are costing the Philippines as much as P2.4 billion a day due to lost in potential income and productivity. In connection with this is the deterioration of the quality of road pavements which also makes the delay of the transportation of goods costlier and time-consuming.

The accumulation of stormwater is known to be the most common cause of road damages. Application of stormwater runoff management will be a great help in the mitigation of flood at a specific area. In addition to this, the exposure to contaminated water among the people living in the area will be lessened thus avoiding the severe effects of waterborne and water-related diseases. Deceleration of vehicles which affects the traffic, further causing congestion will also be evaded. Damages on the roads caused by the accumulation of water could also be depreciated, thus avoiding its deterioration. Being one of the best stormwater management practices as stated by the US Environmental Protection Agency, flood mitigation could be made possible through the application of pervious concrete.

Pervious concrete is a composite material that uses the same material as conventional concrete. However, fine aggregate is eliminated in the mixture and the size distribution of the coarse aggregate is kept narrow to allow the packing of the relatively little particles. Through the production of a permeable layer, rainwater is given access to filter by passing through the pavement and then to the underlying soil, provided that the underlying soil is suitable for drainage. This material is being commonly used in parking areas and is not only capable of controlling the stormwater runoff but also a great help in the environment. Pervious concrete filters contaminants from runoff prior to its discharge to the storm sewer system. With this, the water from the drainage system in the country when it rains will have fewer contaminants before it goes to different bodies of water as reported by various previous studies on pervious concrete [1-5].

The Hydrologic Modelling System (HEC-HMS) [2] was generally formed for the simulations of various precipitation and stormwater runoff processes. This enables the quantification of the hydrologic response of a certain area of study with respect to the altered parameters. Through the software, hydrographs which can be utilized for further analysis are produced. In some cases, these outputs are also used in various programs such as the ArcGIS. Common problems solved using the data obtained included the reduction and regulation of flood, prediction of stormwater flow, as well as the hydrologic impending impact of developments.

One of the frequently flooded roads in the country is the Ricardo Papa Street As experienced by many people in the area, a few minutes of rain can immediately cause flood. The flooding which occurs in the area is apparently instigated by the great variance with respect to the road's elevation. The stormwater runoff is accrued in the area with lower elevation, thus increasing the actual level of the flood. As the stormwater incurred during the rain is left on the road, the flow of vehicles is severely affected.

The study primarily focuses on stormwater runoff management using pervious concrete as pavement. Specifically, the study tested the capacity of pervious concrete samples produced using a controlled mix. Also, this study analyzed the impact of pervious concrete when applied to the road using the numerical specifications of the pervious concrete samples created through the use of HEC-HMS.

II. Material and Methods

The study to be conducted is generally classified into two major parts: the investigation stage and the analysis stage. Initially, the researchers will be focusing on the experimentation of the pervious concrete sample. This includes the formation of the samples and its actual testing. The second stage pertains to the analysis of the data using Hydrologic Modelling System with respect to the values obtained in pervious concrete samples.

To achieve the completion of the study, the researchers divided the account into several phases. Each phase targeted specific aspects involved in the study to be conducted. This included the essential periods starting from the design development, testing of the specimen, up to the assessment of the proposed solution. The materials used in the preparation of the samples includes Portland Type I cement and aggregates. The aggregates used in the mix were dry to avoid excess water because of the aggregates' moisture content when wet. The materials used in the preparation of the samples were bought in a hardware which include Portland Type I cement and aggregates. Only aggregates having approximately half inch diameter were required in the mix so the researchers manually selected it by choosing out the aggregates that are left in the sieve. The selected coarse aggregates were then placed in a container. A few fine aggregates were also added to the mix as it can help in attaining a design with a higher strength. The researchers used 1:4.1:0.30:0.30 as the ratio by weight of cement: coarse aggregate: fine aggregate: water. Oil was rubbed on the cylindrical molds to avoid sticking the concrete to the mold and make it easier for the mold to remove as the concrete specimen hardens. The researchers mixed the cement and coarse aggregates first then followed by the fine aggregates, lastly was the water, where all follow the previously indicated ratio by weight. After adding the water, the consistency of the mixture was tested by taking a handful of the pervious concrete and formed a ball. If the formed ball out of the mixture separated and could not hold its weight, this indicated that the mixture was too dry. If pastes were sticking in the hands while forming the ball, this meant that the mixture was too wet. When the consistency is enough, the mixture is now placed in a cylindrical mold. Then all of the specimens were rodded evenly 25 times both during filled halfway and during filled half inch above the top. This was done in order to further compact the mixture and avoid unnecessary void spaces. The specimens were kept undisturbed at room temperature for a day. After 24 hours, the samples were then removed out of the molds and then placed in the curing box where it was kept until testing was to be performed. Figure 1 shows the analytical framework of this study.

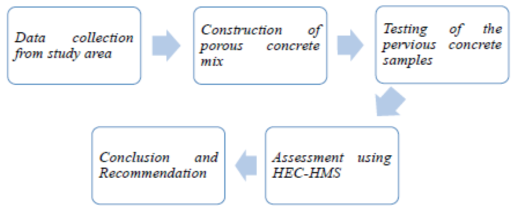

Figure 1: Research Framework

III. Results and Discussions

In order to effectively analyse the effects of pervious concrete, for this part of the study, the researchers had decided to compare the acquired results with that of the conventional condition of the road. Using the simulations created through the program HEC-HMS, the peak discharge for both conditions, together with the hydrographs defining the behaviour of stormwater runoff was obtained. The simulations were generated given the integration of the values acquired from the testing of the pervious concrete samples. This was further reinforced through the aid of the application of the various quantities acquired by the researchers through several institutions of the government. First was the infiltration rate of the pervious concrete. This was achieved through the values which were noted by subjecting the pervious concrete samples created through the permeability test. The infiltration rate of each pervious concrete sample was determined through the calculation of the values gathered from the experiment as it was applied in the equation:

$$I = \frac{K * M}{d^2 t} \tag{1}$$

where I = infiltration rate
M = Mass of infiltrated water
D = Inside diameter of infiltration ring
t = time required for measured amount of water to infiltrate the concrete
K = 4,583,666,000 in SI units or 126,870 in English system

The computed average Infiltration rate of the three samples is 9.343 mm/sec.

The rainfall intensity experienced in the study area, described in Table 1, was prepared by the Hydrometeorological Data Applications Section (HMDAS), Hydro-Meteorology Division, of PAGASA. This data was arranged in 2013 September 27, with its basis taken from 55 years of record. The values assimilated were utilized for defining the time series gage of the subbasin model created for the simulation of the two conditions of the area to be studied. These values served as the magnitude of the rainfall as it was used in the program with respect to its corresponding period of time.

Table 1
Computed extreme values (in mm) of Precipitation

Yrs	10 mins	20 mins	30 mins	1 hr	2 hrs	3 hrs	6 hrs	12 hrs	24 hrs
2	21.9	32.5	40.8	55.5	75.4	86.3	111.2	134.6	153.3
5	29.7	44.2	55.7	75.2	104.1	121.4	160	195.9	223.5
10	34.9	51.9	65.5	88.1	123.1	144.6	192.3	236.6	270
15	37.8	56.3	71	95.5	133.8	157.7	210.5	259.5	296.3
20	39.8	59.4	74.9	100.6	141.2	166.9	223.2	275.6	314.6
25	41.4	61.7	77.9	104.5	147	174	233.1	288	328.8
50	46.2	69	87.1	116.7	164.8	195.7	263.3	326.1	372.4
100	51	76.2	96.2	128.8	182.4	217.3	293.4	363.9	415.8

For both simulations, similar values for precipitation were used. The researchers used 100 % impervious for the conventional concrete pavement. As shown in the Figure 1 and 2 which states that the peak discharge on each of the roads, it can be observed that there is a significant difference between the two values. The peak discharge in the pervious concrete road is comparably lower than that of the conventional road.

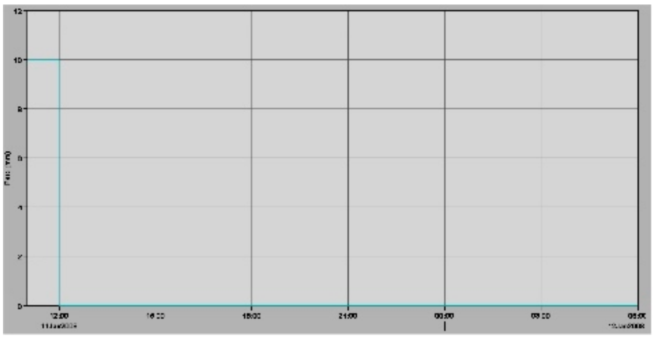

Figure 2: Soil Infiltration (Conventional Concrete Road)

Through the graphical representations in Figure 2 and 3, the behavior of water as it passes through the soil of each concrete was shown. It can be stated that due to the porosity of the pervious concrete road, it allows water to infiltrate the soil, which is in contrast to the conventional concrete which does not permit this to take place.

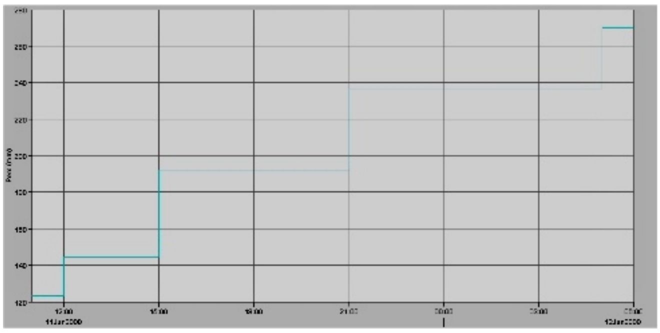

Figure 3: Soil Infiltration (Pervious Concrete Road)

The preceding graphs, Figure 4 and 5 depict the values describing the excess precipitation on each of the roads simulated. Given that pervious concrete allows water to penetrate the soil, justifies that the stormwater runoff along the area is lessened through porosity. This is in contrast to what takes place with conventional concrete roads, wherein water flow freely through the surface.

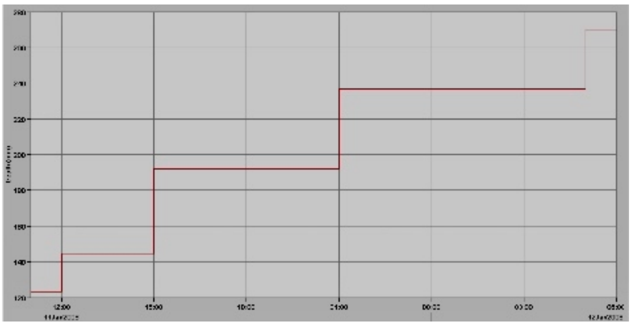

Figure 4: Excess Precipitation (Conventional Concrete Road)

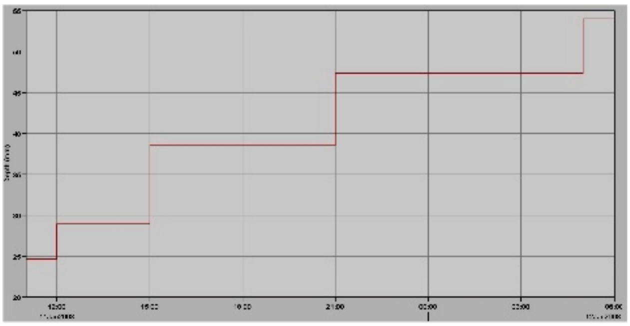

Figure 5: Excess Precipitation (Pervious Concrete Road)

For better visualization of the findings made through the simulations created, the graphs were further modified. Through the Figure 6, 7, 8, and 9, the two quantities represented were the conventional concrete pavement which is denoted as blue, and red for the pervious concrete pavement. Given modifications in the output, the significant difference acquired from both quantities can be easily observed. With reference to the graphical representation in Figure 6, it can be observed that through time, together with the increase in the rainfall intensity, the direct runoff for both roads also increase.

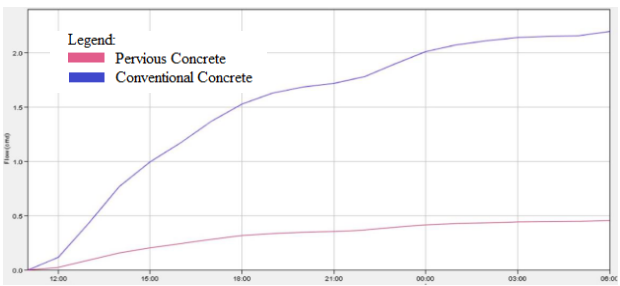

Figure 6: Direct Runoff (Pervious)

Figure 7, 8 and 9 illustrate the graphical representations depicting the trend of the behavior of stormwater runoff with reference to the various occurrences such as the precipitation, precipitation loss, outflow, and base flow. Observing the graph, it can be stated that pervious concrete has a comparably larger capacity for precipitation loss than the conventional concrete which has relatively none. It can also be seen that through the simulations, a similar level of precipitation was experienced by the two types of roads.

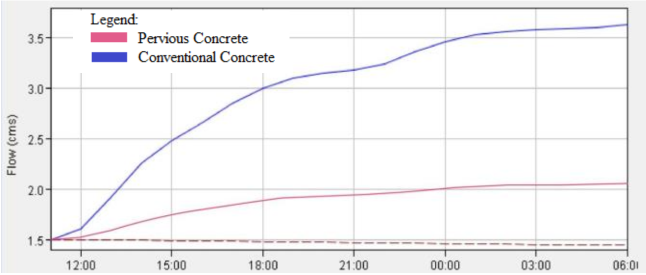

Figure 7: Summary of Flow (Pervious Concrete Road)

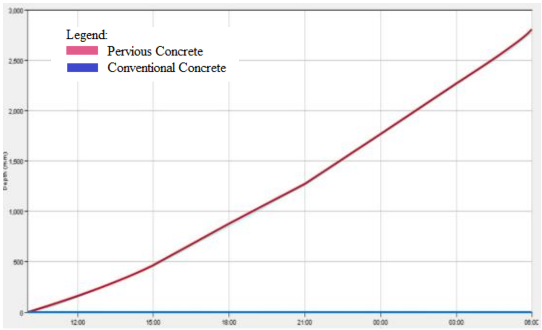

Figure 8: Cumulative Precipitation Loss (Conventional vs Pervious)

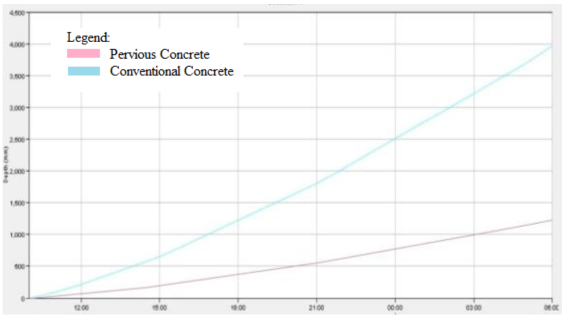

Figure 9: Cumulative Excess Precipitation (Conventional vs Pervious)

Based on the result for both simulations, it can be stated that due to the difference in porosity, the values defining the precipitation loss, excess, and peak flow depict a comparable difference. With reference to the pervious concrete, it showed a higher amount of precipitation loss, but lower values for the peak flow and total excess of precipitation, thus causing a correspondingly lower value for the runoff.

IV. Conclusion

This study aims to introduce pervious concrete and discuss its impact on the environment when applied in the design of roads in the Philippines. The researchers were able to come up with a sample, using controlled mix, and tested it. The specimen yields a low compressive strength which is due to the voids in a pervious concrete where the water passes. This suggests that pervious concrete using a controlled mix cannot probably be used on roads where large volumes of heavy vehicles are passing because it cannot withstand the stress induced by these vehicles. The Hydrologic Modelling System (HMS) is a great application of advanced technology in simulating stormwater runoff at a particular area. Through the graph produced by the HEC-HMS, a decrease in the volume of water entering per second can be observed after the placement of pervious concrete at the Ricardo Papa Street compared to that of the conventional concrete. This is significant since the volume of water coming at the portion in R. Papa Street where flooding during rainy seasons mostly occurs will also decrease. Therefore, water will be withdrawn at a shorter period of time. Traffic congestion due to flooding during rainy seasons will also decrease. The application of pervious concrete would benefit not only people living in this area but also those people who are passing here. Overall, the application of pervious concrete on highly elevated areas can reduce runoff to areas with lower elevation which can reduce flooding. In addition to this, contaminants penetrating the ground surface will decrease. This kind of pavement can be beneficial to us and also to the environment. Though this pavement may have a greater initial cost, the advantage in using this concrete is still favourable compared to its additional cost. The application of pervious concrete in the design of the roads in the Philippines could also mean that the country is coping up with the fast changing trend worldwide in the transportation system.

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