IAPA Scholarship

Hydrological Design of Permeable Asphalt Concrete Pavement

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Abstract

The background of this paper is to design the reservoir course in asphalt concrete permeable pavement. It is important to first find the right equations to use for a design example on Bradley's campus. The motivation is to add green infrastructure to Bradley's campus to decrease runoff. The objective is to design the reservoir course and to prove that it is feasible on Bradley's Founder's Circle parking lot. The methods of design are Hydraulic Design Method from the Virginia Department of Environment Quality, or Virginia DEQ for short. Results are the reservoir course will be 2.5 feet and the overall cross section of the permeable pavement has to be 4.5 feet. The preamble asphalt concrete pavement can store 5,860 gallons of water in the 40 feet by 235 feet parking lot. The conclusion is permeable asphalt concrete pavement is a feasible option, and if implemented, would reduce the runoff on Bradley's Founder's Circle parking lot.

Introduction

Permeable asphalt concrete pavement is an efficient tool to relieve the stormwater during a rain event by capturing and directing runoff to the underlying soil. First, a distinction needs to be made between conventional asphalt concrete pavement and permeable asphalt concrete pavement. Asphalt concrete is made with aggregate and hot asphalt binder, and for this reason, asphalt concrete is also known as hot-mix asphalt concrete. Asphalt concrete pavement is used for roads, airport runways and taxiways, racetracks, and parking lots, among other applications. Asphalt concrete pavement is designed and constructed to clear off water on the surface, and it does not allow infiltration of water through the pavement structure. On the other hand, permeable asphalt concrete pavement allows water to infiltrate through the pavement structure. The reservoir course design is the largest design factor in the design of permeable asphalt concrete pavement. The focus of this paper will be the design of the reservoir course. The other courses in the permeable asphalt concrete pavement will be assumed by the structural and geotechnical design criteria.

Figure 1 shows a typical cross-section of permeable asphalt concrete pavement [1]. The different courses of the pavement are crucial to have a working permeable pavement. The depth of each course will be stated because this is only focusing on the reservoir course design, so the other courses will be assumed based on the structural and geotechnical designs.

- The first course is the pervious pavement, which contains porous asphalt concrete (It is 5 inches in depth).
- Next is the choker course. It consists of a clean, single size crushed stone smaller than the stone in the recharge bed. Its purpose is to stabilize the surface for the paving equipment (It is 6 inches in depth).

- The filter course is usually some crushed stone aggregate that provides some stability for the next courses. The filter course needs to have a high void ratio so the water can filter through it. (It is 10 inches in depth).
- Underneath the filter course is a filter blanket, which makes sure that fines do not penetrate the subgrade into the reservoir course (It is 3 inches in depth).
- Lastly, the reservoir course holds water that passes through the pervious pavement. The reservoir course is determined by how much storage and volume is needed while also making sure that it can store runoff water so it can infiltrate into the soil. The depth needs to be calculated based on the design criteria
- Under the reservoir course is the native material, or the natural soil.

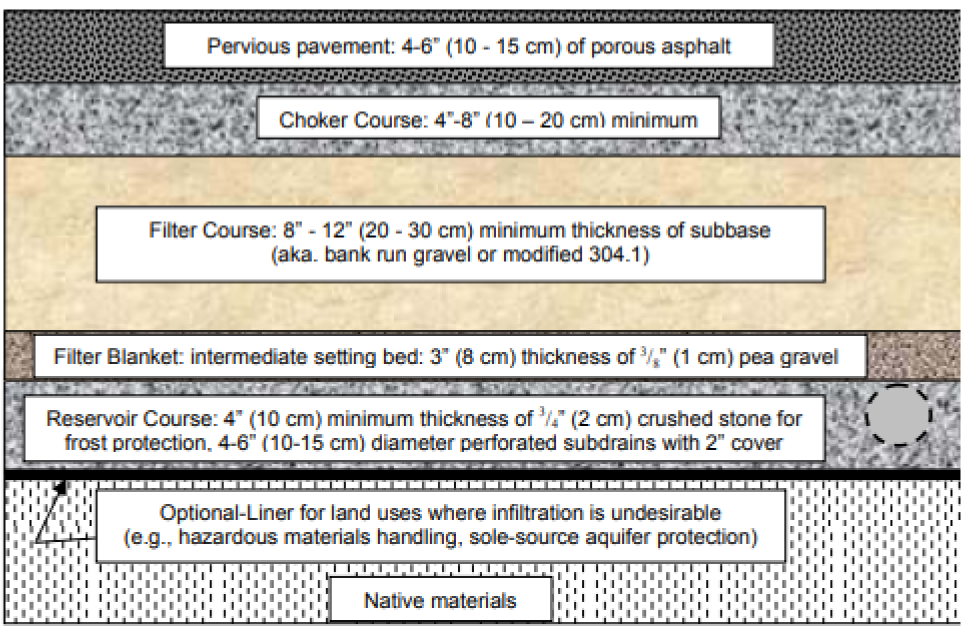

Figure 1 Cross Section of the Pavement [1]

Objective, Scope, and Limitations

The objective of this project was done to understand the hydrological design of a permeable asphalt concrete pavement. The hydrological design is the design of the reservoir course in the permeable asphalt concrete pavement. Most of the general design for asphalt concrete pavement is a structural design or geotechnical design. However, the hydrological design is an additional design step for the permeable asphalt concrete pavement. The objective of the design of the reservoir course is to prove the design is feasible to use for Bradley's Founder's Circle parking lot.

The scope and limitations are unique to Bradley's campus. Permeable pavement can be designed with or without underdrain. This hydrological design is not considering underdrain, which means the water retained in the reservoir course will infiltrate in the soil. Underdrains are a perforated pipe at the bottom of the pavement under the reservoir course, so if the course overflows, the pipe can put the water back into the system. This location has low rainfall intensities, so there is no need to have an underdrain to put the water back into the sewer system.

There are two approaches to design a permeable pavement. One approach is to determine the time to fill out the reservoir course, and another approach is to determine the time of water infiltration to subgrade. In this project, filling time is calculated for permeable asphalt concrete pavement. Some may say time to fill is a limitation, however the area being used on Bradley's campus has low rainfall intensities.

Hydraulic Design Method

The hydraulic design is based on the premise that in specific rainfall events, the permeable pavement will take in as much water as possible. When the course is filled, there will be some ponding that will probably run off into a drain that is sloped to take in the overflow. This design is economical because it needs less construction space. This application is going to be used in situations where the owner of the property does not want any ponding and wants to make sure that after it rains, the surface looks seemingly dry. Another benefit of using this method is that all of the water flows into the underlying soil instead of potentially getting clogged and going back into the system through pipes.

The following equations 1 to 4 are used to calculate the fill time for permeable pavement [2]. There is one assertion when it comes to the reservoir course: fill time. Equations 1 to 4 states the constant T_f is 2 hours. The infiltration rate for Peoria is 3.66 feet per day from USGS.

$$T_v = \frac{1.1 * R_v * A_c}{12} \quad \text{(Eq. 1)}$$

$$d_c = \frac{T_V}{A_c} \quad \text{(Eq. 2)}$$

$$R = \frac{A_c}{A_p} \quad \text{(Eq. 3)}$$

$$d_p = \frac{((d_c * R) + P - \left(\frac{i}{2} * T_f\right))}{V_r} \quad \text{(Eq. 4)}$$

where
d_p = Depth of the reservoir course (ft.)
d_c= Depth of runoff from the contributing drainage area (not including the permeable pavement surface) for the Treatment Volume (T_v/A_c), or other design storms (ft.)
R_v = .30 is constant
A_c= Contributing drainage area
A_p = Contributing permeable pavement surface area
R = A_c/A_p= The ratio of the contributing drainage area (A_c) (not including the permeable pavement surface) to the permeable pavement surface area (A_p)
P = The rainfall depth for the Treatment Volume (Level 1 = 1 inch)

i = The field-verified infiltration rate for the native soils (ft./day)
T_f = The time to fill the reservoir course (day) – typically 2 hours or 0.083 day
V_r = The void ratio for the reservoir course (0.4)

The drainage area is another essential parameter that needs to be found. The website StreamStats from the United States Geological Survey can calculate the drainage area of any parcel of land [3]. Figure 2 displays the closest drainage area from the watershed lines to Bradley University. According to figure 2, the drainage area is .04 square miles, which converts to 1,115,136 square feet. According to the equation, the area of the pavement is needed to calculate the treatment volume. Google Maps was used to measure the areas of all the pavements.

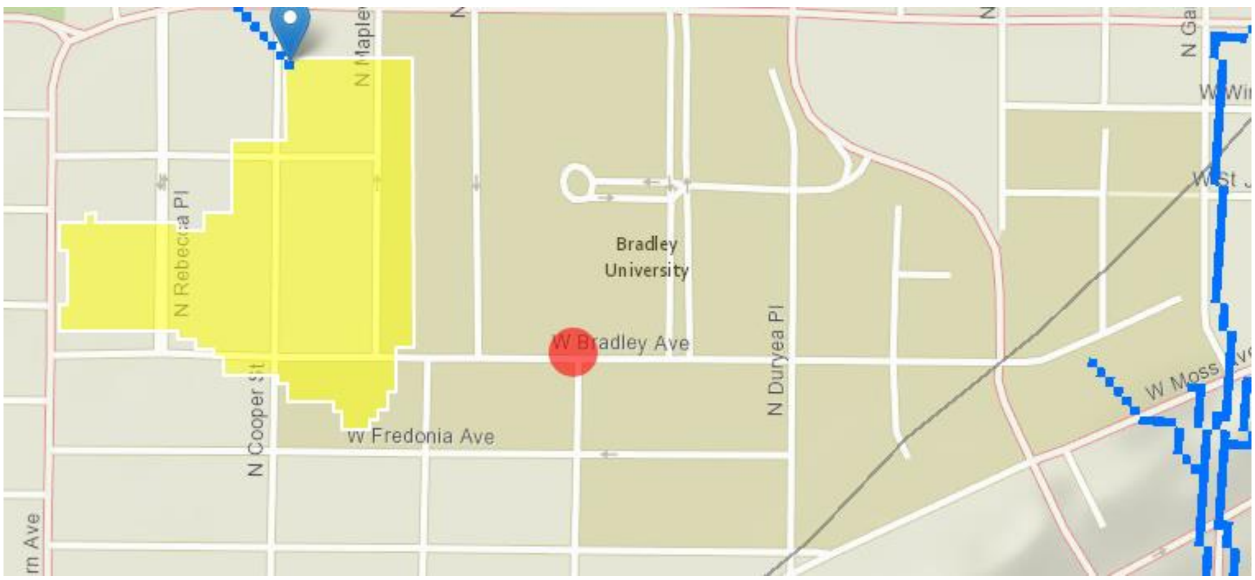

Figure 2 StreamStats [3]

The following approach is taken to calculate the drainage area.

Drainage area = 1,115,136 square feet
Area of the pavement = 217,772 square feet
Drainage area - pavement area 1,115,136 – 217,772= 897,364 square feet

Derivation
Using Eq. 1 with the constant R_V =. 30 and A_C = 1,115,136 square feet
T_V =30666.24 cubic feet
Using Eq. 2 with T_V and A_C
d_c =0.0275 feet
Using Eq. 3 with A_C and $A_p = 217{,}772$ square feet
$R = 5.12$ unit less

Using Eq. 4 with added constants of i = 3.66 feet per day, t_f = 0.083 days and V_r = .04 unit less, d_p =2.47 feet, so the reservoir course can be rounded to a depth of 2.5 feet.

The initial assumption is that the permeable pavement will not have an underdrain and the water will be allowed to drain through the soil. The full reservoir course will be unable to carry more water in this rainfall event and will surcharge. This design is ideal if, in addition to the permeable pavement, another green infrastructure alleviates the system if ponding occurs. Other reasons to select this method is that the design is affordable because it takes up less space. In an urban area, there would be potential problems with this design, such as possible conflicts with obstructing utilities or water going into the adjacent properties. Since Bradley is surrounded by residential areas, this design is ideal. Permeable pavement is meant to have low doses of rainfall because it is just a supplementary green infrastructure that is not meant to have high volumes of water that a larger green infrastructure designed to store more runoff might have.

A Hypothetical Application on Bradley's Campus

The focus of the study is limited to the Bradley campus area. The parking lot leading up to Founder's Circle at Bradley University is a great location to place permeable pavement. Flash flooding occurs and is grounds for implementing permeable pavement because there is an inability to drain the water without it. Since there is a drain at the end of the parking lot (see Figure 3 and the arrow that locates the drain in Figure 4 on the next page), it would make sense to have permeable pavement because, during heavy rainfall events, the parking lot floods due to a lack of other drain locations and the impermeable material the parking lot is currently made of. Figure 3 is a map of Bradley's campus, where the black outer box is the total watershed considered for this study. The yellow filled-in box is the contributing permeable pavement surface area, and the red lines are the area of the pavement. The red arrows are indications of where the water is flowing. However, the overflow of all the runoff would go into the drain and back into the system if a permeable pavement was used in the Founder's Circle parking lot.

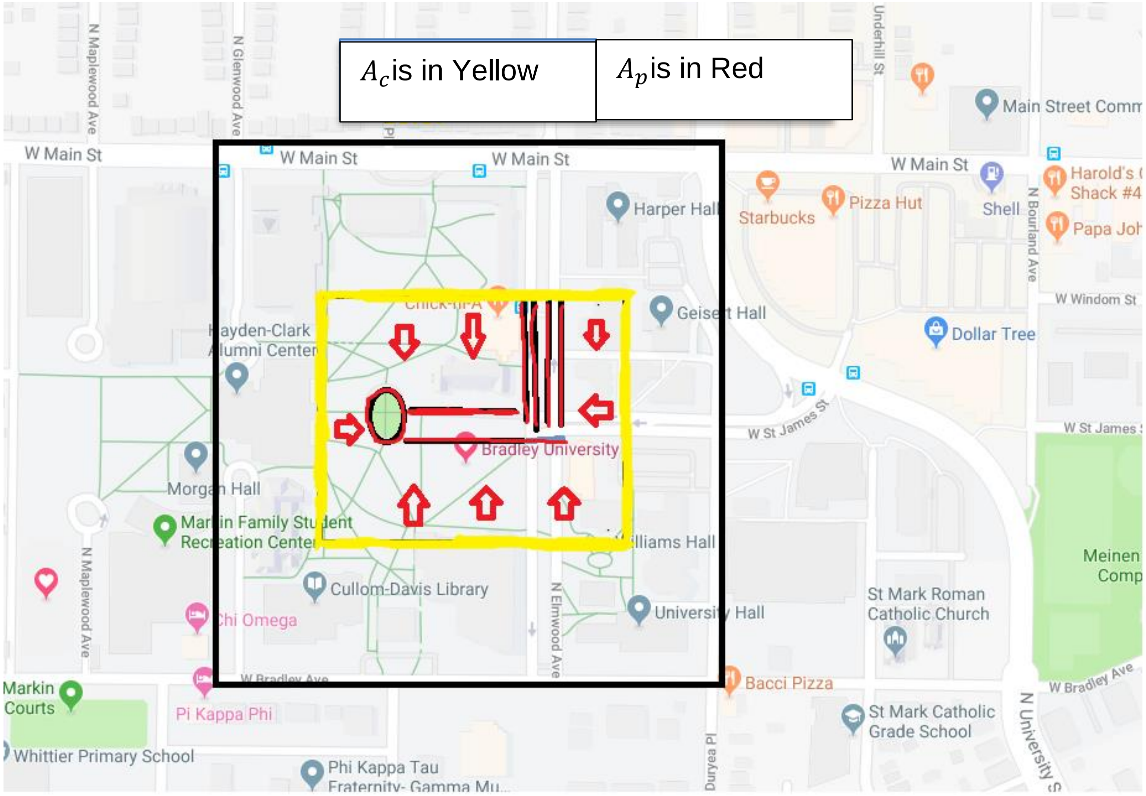

Figure 3 Map of Bradley

Figure 4 Parking lot near Founder's Circle

As one can see in Figure 4 above, the area of the parking lot is 40 feet by 235 feet, separated by 14 feet of the median. The thickness of the surface to the reservoir course of the pavement will be 2.50 feet.

Referring to the equation on page 7.

- The depth is 2.50 feet from the surface to the reservoir course because it is ideal to design for a ten-year storm. Since the project area has low rainfall intensities, designing for a ten-year storm is appropriate. A ten-year storm means that we are designing the project for a serve storm that comes every ten years.
- The total pavement cross section is 4.5 feet by adding up off of the depths of the courses.
- (5 in + 6 in +10 in + 3 in + 2.5 feet) = 4.5 feet
- The rainfall intensity in Peoria is historically 2.9 in/hr., which takes into consideration that the duration of most storms around the Bradley is an hour.

All of the structural and geotechnical courses are assumed in Figure 1. The drainage area was 0.04 square mile from the United States Geological Survey Geographic Information System Software. The storage capacity of the reservoir course is found from these parameters of the drainage area. Peoria has a stormwater utility grant program that gives a grant to green infrastructure designed to have 1 inch of rainfall captured by the United States Geological Survey Illinois cumulative rainfall map from the precipitation gauge in Fondulac Creek [5]. The gauge displays 0.93 inches as of November 26th, 2018 [7]. Given how close this gauge is to the 1-inch mark, one can assume 1 inch for the rainfall per hour. The rain gauge is the recorded data and the 1 inch is the standard based on that data. Using the United States Geological Survey rainfall calculator, the permeable pavement will be able to hold 5,860 gallons of water without surcharging [6]. These gallons of water will flow into the underlying soil instead of the storm sewer.

Conclusion

The hydrological design of porous asphalt concrete is a crucial component to ensure porous asphalt concrete works effectively as a best management practice. Among the five courses, the reservoir course design is the main focus of the study. The underdrain is not considered in the reservoir course, which considers the time to fill assumption. Permeable pavement will recharge the groundwater supply and alleviate flooding downstream. Since Bradley University is on the top of a hill, water could be flowing downtown. This is not an ideal situation, so implementing permeable pavement would be a better way to prevent this occurrence from happening.

Works Cited

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