IAPA Scholarship

Hydrological Design of Permeable Asphalt Concrete Pavement

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Introduction

Permeable asphalt 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 used as roads, airports runway and taxiway, racetracks, and parking lots, among other applications. Asphalt concrete pavement is design and constructed to runoff water on the surface and do 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 permeability in asphalt concrete allows water to drain through the pavement. The composition of the permeable asphalt concrete pavement layers is uniquely designed to take in water, meaning that the layers have holes for water to pass through. Many people interchange the words between pervious, permeable, and porous. For this application, they have all interpreted the same way. However, porous means having holes in space to allow water in, but those holes are not always connected. Permeable refers to the connection between the holes that allow water to go through them. The difference between conventional and permeable pavement is just the permeability aspects of the pavement.

Figure 1 shows a typical cross-section of permeable asphalt concrete pavement [1]. The different layers of the pavement are crucial to have a working permeable pavement. The first layer is the pervious pavement, which contains porous asphalt concrete. 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. The filter course is usually used 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. Underneath the filter course is a filter blanket, which makes sure that fines do not penetrate the subgrade into the reservoir course. 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.

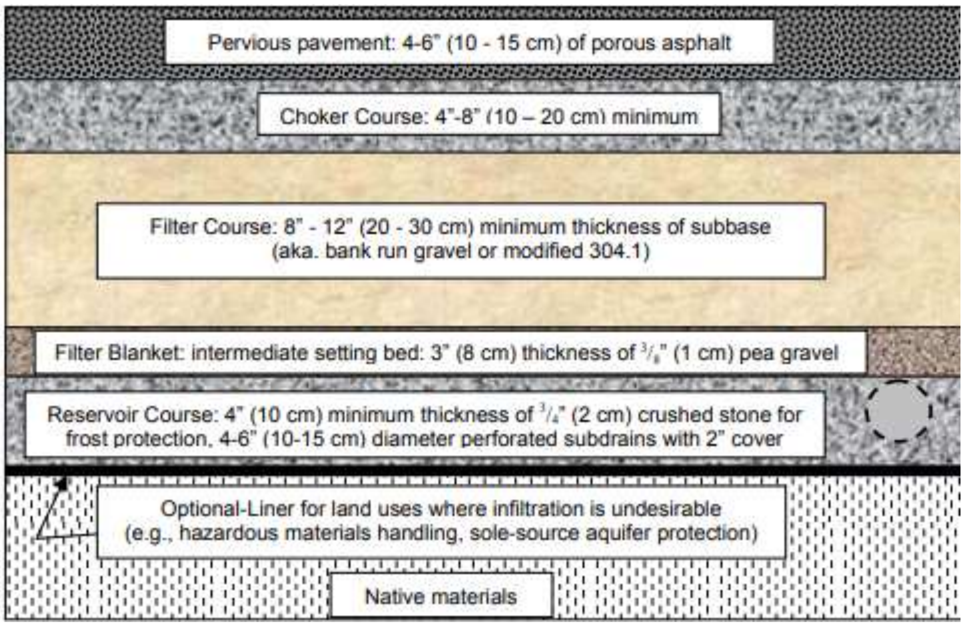

Figure 1 Cross Section of the Pavement [1]

Objective, Scope, and Limitations

This research paper is done to understand the hydrological design of a permeable asphalt concrete pavement. Most of the designs for asphalt concrete pavement is a structural design or geotechnical design. However, the hydrological design is the additional design step for the permeable asphalt concrete pavement. Permeable pavement can be design with or without underdrain. This hydrological design is done considering underdrain, means the water retained in the reservoir layer will infiltrate in the soil. There are two approaches to design a permeable pavement, one approach is to determine the time to fill out the reservoir layer, and another approach is to determine the time of water infiltration to subgrade. In this study, filling time is calculated for permeable asphalt pavement. Bradley University is used as an example water shade area to perform the hydrological design.

Hydraulic Design Method

The hydraulic design is on the premise that in specific rainfall events, the pavement will take in as much water as possible. When the layer is filled, there will be some ponding that will probably runoff 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 for 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].

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

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

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

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

where
d_p = Depth of the reservoir layer (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 storm (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 layer (day) – typically 2 hours or 0.083 day
V_r = The void ratio for the reservoir layer (0.4)

There is one assertion when it comes to the reservoir layer: 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. The drainage area is another essential parameter that needs to be found. The website StreamStats from the USGS 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, converts to 1,115,136 square feet. According to the equation, the area of the pavement is needed to calculate the treatment volume. Google map was used to measure the areas of all the pavements.

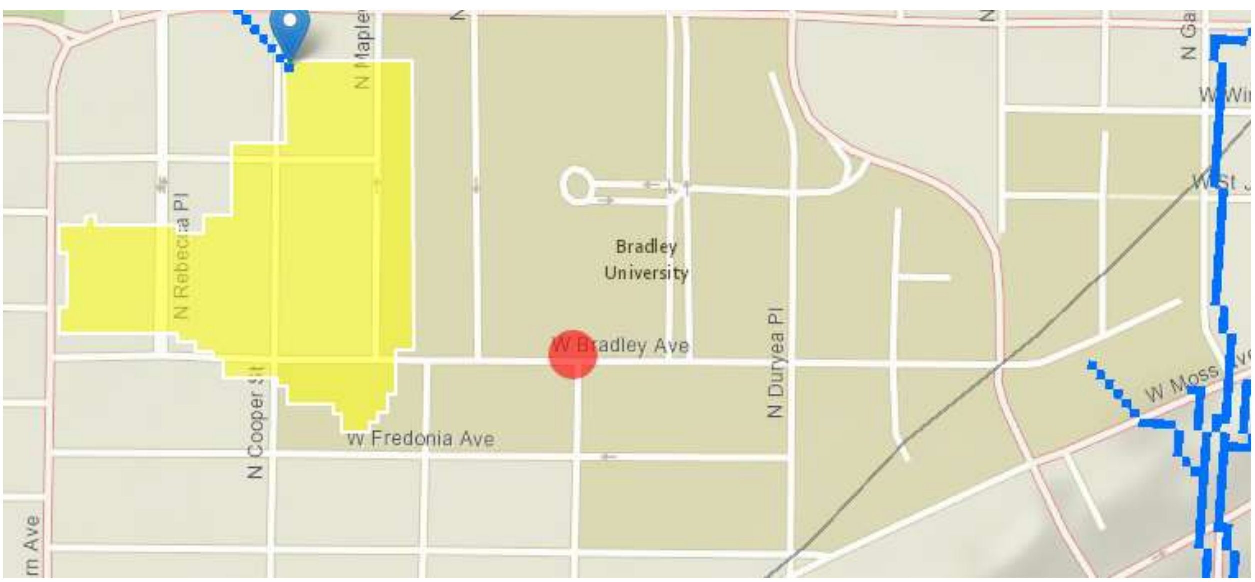

Figure 2 StreamStats [3]

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
$R = 5.12$ unitless
Using Eq. 4 with added constants of i = 3.66 feet per day, t_f = 0.083 days and V_r = .04 unitless
d_p =2.47 feet
So, the reservoir layer has a depth of 2.5 feet.

The initial assumption is that the permeable pavement will not have an underdrain and will be allowed to drain through the soil. The full reservoir layer will be unable to carry more water in this rainfall event and will surcharge. This design is ideal if, in addition to permeable pavement, there was another green infrastructure to alleviate 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 Applications 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 below), 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 the map of Bradley 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 were 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.

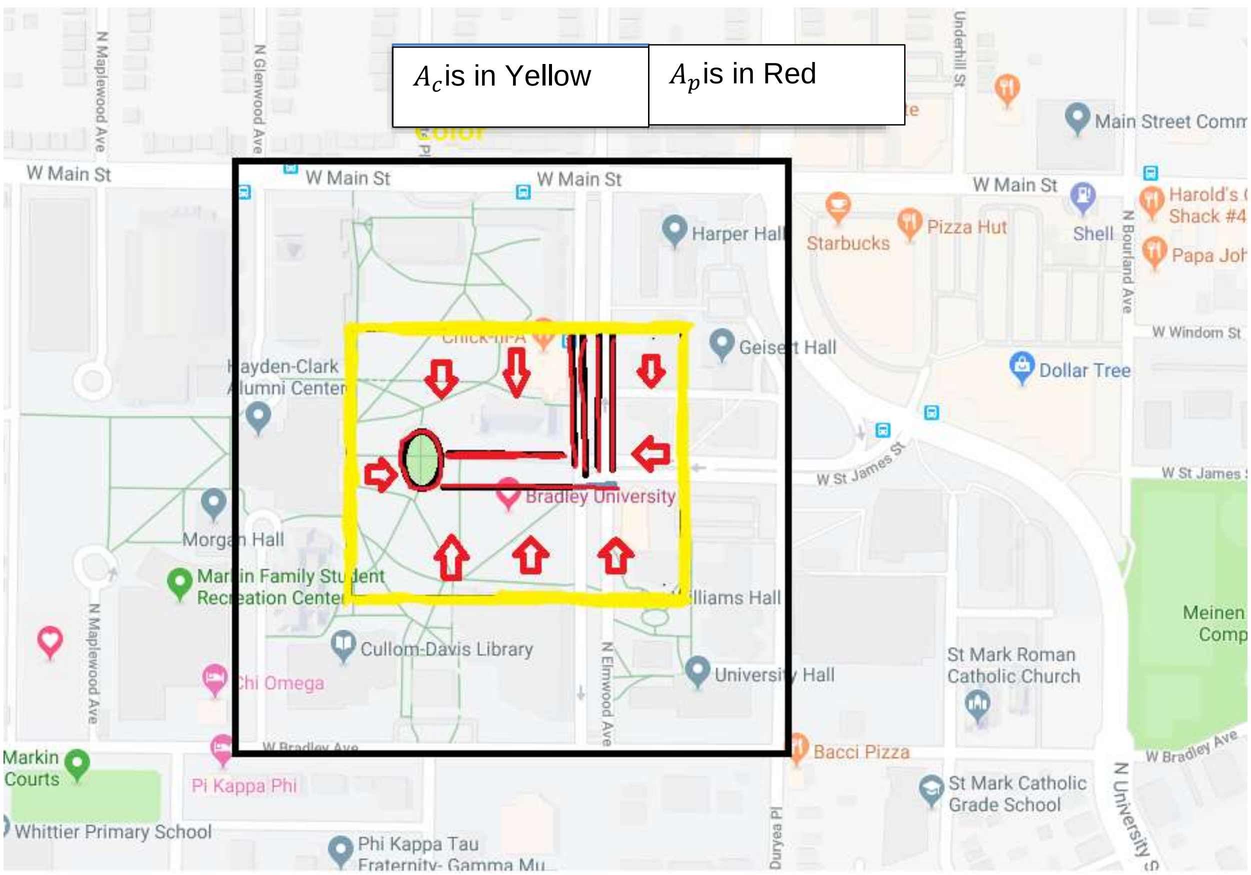

Figure 3 Map of Bradley

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 layer of the pavement will be 2.4 feet. Referring to the previous example the depth is 2.47 feet from the surface to the reservoir layer because it is ideal to design for a ten-year storm. The total pavement cross section is 4.88 feet. The rainfall intensity in Peoria is historically 2.9 in/hr., which takes into consideration the duration of most storms around the Bradley area last for about an hour. All of the Structural and Geotechnical layers are assumed from 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 layer 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 [7]. Given how close this gauge is to the 1-inch mark, we will assume 1 inch for the rainfall per hour. 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 is a crucial component to ensure porous asphalt works effectively as a best management practice. Among five layers, the reservoir layer design is the main focus of the study. The underdrain is not considered in the reservoir layer, 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 the better way to prevent this from happening.

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