The Benefits of Using Porous Asphalt Pavement in Comparison with Other Forms of Pervious Pavements

Authored and Revised:
Luke Zanoni

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Draft Authors:
Andrew Boysen
Mandy Carlson
Jeremy Harris
Luke Zanoni

Draft Submitted:
University of Illinois at Chicago
College of Engineering, Department of Civil and Materials Engineering
CME 402, Geometric Design of Highway Facilities
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INTRODUCTION

Permeable pavement is an alternative to traditional concrete and asphalt in roadway and pavement design that enhances society, benefits the environment, and promotes the economy while also presenting a number of existing challenges that limit its application. Permeable pavement is one of the fastest growing technologies in sustainable roadway engineering. It is defined broadly as a surface that allows water to permeate into the subsurface. Though this technology has been utilized in different forms for about fifty years, permeable pavement as it is today was developed in the mid to late 2000's. The use of permeable pavement requires greater planning than usual, and the mix is generally more expensive due to the need of admixtures to make up for the structural shortcomings of the hardened product. Even so, permeable pavement remains a realistic and a sustainable alternative to traditional paving in roadway design.

In this report, the design basics of permeable pavement will be discussed along with certain common properties of the material. Then the three most common types of permeable pavement will be analyzed: permeable pavers, porous asphalt, and permeable concrete. The composition, benefits and shortcomings of the three methods will be analyzed along with a case study in the Chicagoland for each. The benefits of using porous asphalt will be highlighted as a final discussion of the paper.

GENERAL DESIGN

Regional Considerations

As with any aspect of roadway design, the choice of pavements at a particular location are confined by the existing and proposed site conditions. Permeable pavements can be limited by regional factors such as climate and locally available materials (Eisenberg 2015, 17). Since permeable pavements are used to mitigate stormwater runoff, climate factors such as peak rainfall and soil conditions such as infiltration and permeability factors play a part in whether permeable pavements are an adequate design choice for a particular site. While an in-depth discussion of structural and hydrological elements of design are outside the scope of this paper, a brief overview of these elements as they relate to roadway design elements is relevant.

Structural Considerations

The most important structural element that affects the selection of permeable pavement is the type of loads that the roadway is designed to carry. This relates to roadway design so far as the mode of transportation selected for a particular roadway is crucial. For example, if a portion of roadway is exclusively allocated as a pedestrian or bike path, then it need not carry the same loads as a portion of a roadway that needs to accommodate heavy loaded freight trucks. With the increased interest in adding bike lanes adjacent to or within current urban street right-of-way, permeable pavement can become a more viable roadway design choice.

One of the largest challenges to permeable pavement design is that it cannot carry the same load as typical impervious pavements. Porous pavement thickness often needs to be larger than impervious pavement sections, which limits designs that are restricted due to vertical element limitations. Also, even if a thicker section can be used, porous pavements tend to breakdown quicker under load, especially angular loads from turning movements, due to the higher pore space in the pavement. In short, these structural limitations often limit permeable pavement designs to low load areas such as pedestrian paths, bike lanes and parking aisles and lots. In limited cases, some permeable pavement designs have been somewhat effective in vehicular lanes. These cases will be discussed in greater detail in later sections (Eisenberg 2015, 17-31).

Hydrologic Benefit and Green Design Incentive

The primary incentive for using permeable pavement is to add a hydrological benefit to a roadway or site design. Recent developments in stormwater ordinances across the country have begun to require greater onsite stormwater infiltration and detention. For example, the Federal Government, under Section 438 of the Energy Independence and Security Act of 2007, requires that all federal projects over 5000 square feet to be designed to reduce stormwater runoff to pre-development conditions. In the guidance manual, produced by the US Environmental Protection Agency, permeable pavement is listed as an acceptable practice to meet the requirements of Section 438. Permeable pavements allow for infiltration into the soil below or into an underground storage facility which mitigate or remove the need for above ground detention. This could allow roadway projects to remove the hindrance of planning a road around a detention basin or acquiring land extra land for a detention basin (USEPA 2009, 21-25).

Need for Maintenance

Another aspect of design that must be considered is the type of maintenance that porous pavements require. Ongoing, consistent maintenance is required to ensure that porous pavements remain effective. If pore spaces become clogged by sediment and debris, then the stormwater benefits become restricted and even null. Another problem that can occur is organic material getting trapped in the pore spaces of pavements. This can accelerate settlement in the subgrade and hasten deterioration of the surface course (Eisenberg 2015, 37). Maintenance is conventionally not considered a primary element of design in the case of permeable pavement. This is due to regular maintenance being absolutely critical to keeping the pavement pores free of debris. The resources and education of personnel needed to maintain the pavement should be factored into the design and cost analysis. For example, roads should be designed to accommodate maintenance equipment and personnel without out extreme difficulty or undo hazard to equipment operators. Most permeable pavements come with a recommendation that inspection and cleaning take place twice a year (spring and fall) (Smith 2006, 10).

BENEFITS AND CHALLENGES

In urban areas, lack of natural land cover has led to numerous problems including flooding and the transportation of pollutants. Permeable pavement can help reduce the negative impact of impervious surfaces. However, it does have disadvantages that limit the effectiveness and eliminates some potential uses.

Benefits

Permeable pavement can reduce runoff by trapping and slowly releasing precipitation into the ground. Permeable pavement can reduce the amount of runoff and ease the demand for storm sewers. This can reduce road closure during heavy rainstorms and overall deterioration of roads from runoff.

Reduce Pollutants

Permeable pavement can reduce the concentration of pollutants by trapping them physically, chemically, or biologically. In cold climates, permeable pavement can help make roads safer by aiding in the melting and thawing of ice and snow. The same voids that make the pavement permeable also trap air that stores heat that aids in the melting and thawing on the exposed surface. In a study published in the Journal of Environmental Engineering, Roseen, Ballestero, Houle, Briggs, and Houle at the University of New Hampshire (UNH) found that porous media maintained a level of infiltration capacity that allowed it to remain well drained even during winter months. This quality not only allowed melted snow and ice to drain through the pavement, but also left the voids filled with air that can help heat the surface. This greatly reduces the need for salt providing an environmental benefit (Roseen et al. 2012, 81-89).

Permeable pavement reduces the dependency on salt, which negatively impacts the environment, to keep roads clear of ice and snow. When salt is used on roads, it dissolves with the melting ice and snow. The dissolved salt then leaches into the ground or forms runoff that can impact groundwater, rivers, or larger bodies of water like lakes. Even low concentrations of chloride, a main component of salt, can negatively impact aquatic wildlife and thus impact water quality. John Gulliver, Professor at the University of Minnesota Department of Civil, Environmental, and Geo-Engineering, cited permeable pavement as a potential solution to reducing salt use on roadways. “Permeable pavement is the only way that I know of to mitigate or to reduce our salt application, aside from everyone slowing down and putting up with less salt on the roads” (Minnesota Stormwater Manual 2018). The only time when salt could be needed is during significant snow events. Houle and the researchers at UNH found that even using salt during these events, permeable pavement can reduce the amount of salt used by up to 75%.

FIGURE 01 Porous asphalt (top) versus standard asphalt (bottom) after one hour and forty minutes (right) (Houle 2010, 1281).

Reduce Runoff

According to the USGS, permeable pavement can help “reestablish a more natural hydrologic balance and reduce runoff volume by trapping and slowly releasing precipitation into the ground instead of allowing it to flow into storm drains and out to receiving waters as effluent” (USGS 2016). This can also prevent peal discharges into a hydrologic system that can cause significant flooding concerns. Flooding roadways and paved surfaces limit access to essential services like hospitals, police stations, fire stations, and other areas linked to life safety. Keeping surfaces clear of flood water also prevents deterioration to the surface (California Department of

Transportation 2014). When runoff is reduced, this can also lead to a reduction in needed water storage facilities like retention ponds (USGS 2016).

Challenges

Permeable pavement is less durable when compared to traditional paving alternatives. It requires additional regular maintenance to ensure that pores do not become clogged. This can be in the form of vacuuming and clearing any vegetation growing through the pores.

Cold Climates

Design and operation of permeable pavement in cold climates requires additional considerations. Houle, et al, found that frost penetration can reach depths of up to eight inches, which can influence the depth of the wearing surface and the infiltration bed below. However, this is heavily dependent on the type of porous media used. Snow removal should be carefully considered such that plows do not damage the surface (Houle 2010, 1281-1298).

Ongoing Maintenance

Another potential pitfall with ongoing maintenance is the potential to accidentally perform tasks traditionally associated with conventional parking lots. This can include resurfacing, power-washing, sanding, and sealing (Operation and Maintenance of Permeable Pavement, 2018). This becomes especially critical when permeable surfaces are installed on private property. This can be mitigated through deed restrictions or other agreements that transfer along with the change of ownership.

THREE MAIN TYPES OF PERMEABLE PAVEMENT

The three main types of permeable pavement discussed are permeable pavers, permeable asphalt, and permeable concrete. Each is examined in further detail regarding typical application, specific benefits/disadvantages, and a case study.

Permeable Pavers

Permeable pavers consist of solid paving units that are connected using permeable joints. These joints are filled with permeable aggregates that allow water to flow into the open graded subbase below. In order to keep the pavers in place, the paver design usually incorporates a concrete curb edge (Smith 2006, 2). The most common type of permeable paver is the Permeable Interlocking Concrete Paver (PICP). In PICP design the paver is not permeable itself, but the joints are designed to allow water to infiltrate (Eisenberg 2015, 37). See Figure 02 below for a typical pavement section of PICP, which highlights the use of stormwater infiltration and an optional underdrain.

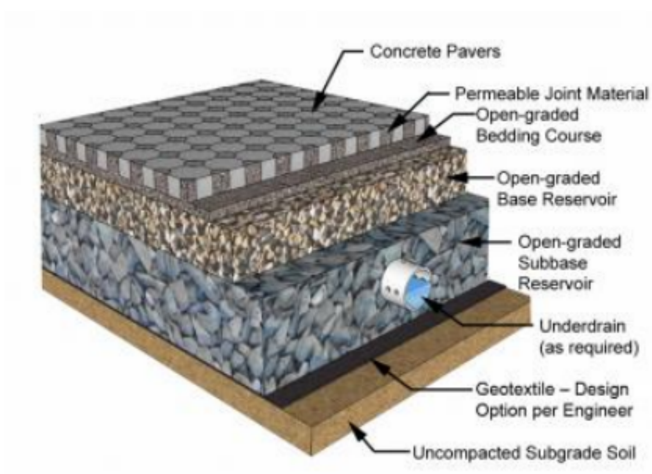

FIGURE 02 Typical cross section of a permeable interlocking concrete paver system (Smith 2011).

Alternate types of pavers include rubber composite pavers, which are extremely lightweight compared to concrete, and pervious pavers, which unlike PICP design the pavers are permeable themselves. Since both of these alternate types of pavers are better suited for pedestrian loads and are not as common as PICP, they will not be discussed further in this paper (Eisenberg 2015, 149-155).

Benefits

PICP has multiple design benefits that make it a suitable alternative to other forms of pavements. First, 5-15% of PICP surface area is open for water to infiltrate. Once water passes through the permeable joints, it can infiltrate into an underlying stone subgrade, which can be fitted with an underdrain depending on hydrological needs. PICP can replace traditional pavements in many areas including pedestrian walkways and low volume and low speed roadways. Concrete pavers is that they can be manufactured according to ASTM C936 *Standard Specification for Solid Concrete Interlocking Paving Units*, and thus can be readily manufacturer to a desirable workload. The ASTM standard ensures that the concrete pavers will be resistant to freeze-thaw and the effects of deicing salts. Also, long term observation of projects in Chicago have shown that PICP does not heave when frozen (Eisenberg, 2015, 98-100).

Challenges

The main challenge that PICP presents versus other forms of permeable pavements is its time of installation. Since PICP requires laying individual pavers, even if done by a mechanical process, the pavers will take longer to install than pouring asphalt or concrete. The length of installation makes PICP projects unideal for large stretches of roadways. Also, since pavers are often made in rectangular shapes, costs to have custom made shapes or time to field cut pavers for nonlinear roadways also increases the cost and time factors. Over the last ten years, mechanical processes have been developed that allow a square yard of pavers to be laid at a time, but these sections still have to be pre marked by a contractor or survey crew (Smith 2006, 8).

Another challenge that PICP presents is its increased cost compared to asphalt and concrete. PICP as a pavement alone can seem costly compared to traditional asphalt and concrete mixes. Costs vary depending on region, but due to prefabrication of pavers offsite both unit and transportation costs can be much higher than an asphalt or concrete mix. Though, as will be shown in the following case study, when the reduced cost in stormwater pipes and structures are accounted for, PICP can reduce overall costs (Eisenberg 2015, 105).

Lastly, since PICP joints are filled with small sized gravel, this gravel needs to be periodically replaced and filled, especially in the first year of its life. This should be considered a part of regular maintenance, but if neglected the pavers can shift due to loosening of joints. Also the infiltration of water can be impeded since debris and organics tend to fill the joints if the gravel is not replenished (Smith 2006, 4).

Case Study

Since PICP and the underlying open graded aggregate act as both a pavement and a stormwater management practice, this should be factored into cost comparisons with traditional impervious pavements. A case study focus in Autumn Trails, Moline, IL (see Figure 03 below) shows that PICP can be a cost effective solution for some low volume road projects.

FIGURE 03 PICP paver streets at autumn trails in Moline, IL (Eisenberg 2015, 107).

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AUTUMN TRAILS, MOLINE, ILLINOIS PAVEMENT COST COMPARISON IN M² (SF) 2006		
PICP	**Asphalt**	**Concrete**
\$117.85/m² (\$10.95/sf) no storm drainage	\$123.77/m² (\$11.50/sf) with storm drainage	\$161.45/m² (\$15.00/sf) with storm drainage

TABLE 01 Cost comparison of PICP with traditional pavement (Eisenberg, 2015, 107).

In the Autumn Trail project, a 3.15 inch PICP with 2-inch CA-16 bedding course, 8-inch CA-7 base course and 8 inch CA-1 subbase with underdrain was selected as the preferred option for construction. Based on cost comparisons developed by the design engineer the PICP alternative was estimated at about $10.95 per square foot, including paver, underdrain, and subgrade material. As seen in Table 01 above, with stormwater management costs in mind, PICP was actually a cheaper alternative than asphalt and concrete options. From this case study, the potential cost effectiveness of PICP is represented, even though the paver material alone may seem more expensive than a concrete or asphalt pavement per square foot (Eisenberg, 2015, 106-107).

Porous Asphalt

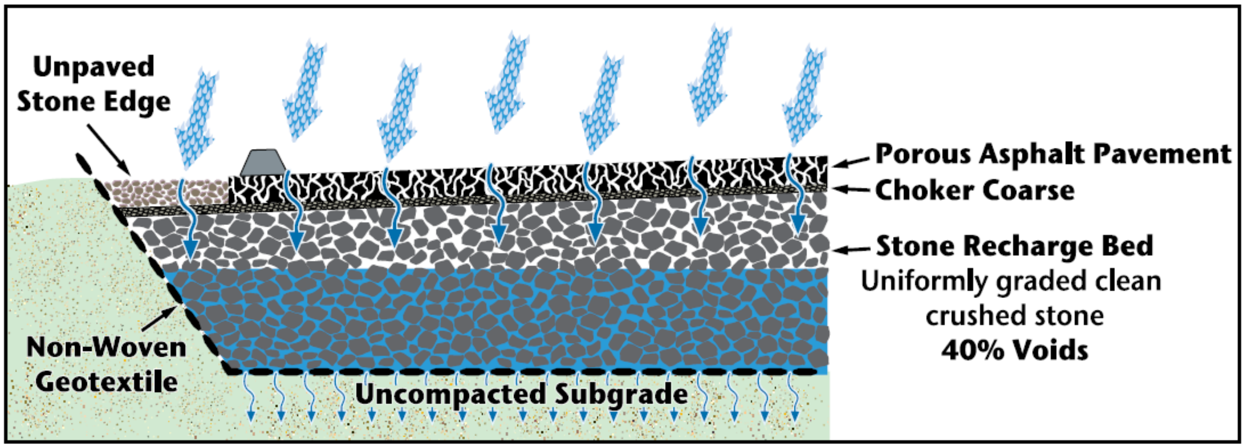

FIGURE 04 Cross section of bottom up approach of uncompacted subgrade in porous asphalt application (IAPA 2018).

As shown in Figure 4, the cross section from a bottom up approach starts with an uncompacted subgrade. The subgrade allows for the infiltration rate to be maximized. The optimal infiltration rate is 0.1 to 10 inches/hour. Next is the non-woven geotextile, which is a geotextile fabric. This fabric is designed to allow water to pass through, but also to prevent subgrade particles from migrating into the stone recharge bed. Above the fabric is the recharge bed, which consists of clean single-size crushed large stone with approximately 40 percent voids (IAPA 2018). This layer is used to temporarily hold the stormwater after a rain event so it can be slowly infiltrated into the soil below. The water held in the bed should drain between 12-72 hours. This layer also serves as a structural layer. Placed above the stone recharge bed is a stabilizing course or "choker course”. This thin layer is made up of clean single-size crushed stone, smaller than the stone in the recharge bed, in order to stabilize the surface for paving equipment. Lastly, an open-graded asphalt surface is laid over the stabilizing layer. The interconnected voids allow stormwater to flow through the pavement into the stone recharge bed where they are briefly held before infiltrating back into the ground (IAPA 2018).

Benefits

Benefits of using permeable pavement is its ability to remove pollutants from the surface water before it makes its way to the sewer systems or outflow rivers. A range of studies have shown that porous asphalt can remove 90-80% of total suspended solids TSS, significant percentages of total metals (e.g. up to 88% of lead), and up to 90% of hydrocarbons including oil and grease from vehicles. This significant reduction of pollutants while promising also leads to a need for routine cleaning of the pavement to keep the permeable benefits of the pavement from being compromised (Eisenberg, 2015, 69-70).

Permeable asphalt has many construction benefits over other forms of permeable pavements. Roads can be built faster than using other forms of permeable pavements because porous asphalt can be poured and rolled in less time than what is needed for concrete, which needs to be cut and cured. Less construction time leads to less road closure time and a reduction in labor costs (IAPA 2018).

On top of a reduction in construction costs and time, porous asphalt is cheaper and has an overall lower life cycle cost compared to other porous pavements. Porous asphalt usually is 20-50% higher in unit material costs compared to traditional asphalt. As is seen in the above PICP case study, even though unit material costs for porous asphalt are higher than tradition impervious asphalt, porous asphalt can lead to overall cheaper project costs due to the reduction in cost of storm water management system items. Also, unit costs for porous asphalt are about $2 to $3.5 per square foot for the asphalt courses while permeable concrete ranges from $2 to $6 per square foot. Thus, in most cases asphalt will have cheaper unit costs than permeable concrete costs (Eisenberg, 2015, 65, 90).

Asphalt is unique in that it is 100% reusable and has the highest rate of being reused in America. At about 99% of asphalt being reused to make new pavement. The asphalt composition can be made from byproducts as well such as the rubber from tires, glass, roof shingles, and blast furnace slag. To produce the pavement, it requires less energy and emits less greenhouse gases than concrete. So overall, asphalt has many benefits related to construction and maintenance, traffic loading, and natural pollution control as compared to concrete (IAPA 2018).

Challenges

Among all the benefits of porous asphalt there are also some challenges. For one example the porous material usually contains a higher binder content. The binder is required for durability of the mix. With high loading of trucks and cars some of the bindings may not hold up. Porous asphalt also requires thicker lifts, or layers, during construction. Based on the USDOT standards, the typical lift is one to four inches. This requires more material and compacting when in construction. The thicker lift requirements may drive the cost up if challenges arise (Matsumoto 2012).

Case Study

The purpose of Kenilworth replacing sections of their roads with permeable asphalt is to work as a better stormwater management practice. The town along the lake in Illinois has experienced devastating flooding in the past and needs a better flood control plan. The city officials decided to implement permeable asphalt because it was less expensive and stands the test of time. On average permeable asphalt will last approximately 10-20 years depending on the conditions it withstands. Below is a figure that represents the current system. They use a combined sewer system with minimal space for the rain runoff to go. The current system also allows some wastewater to escape into the lake untreated (Corona 2017).

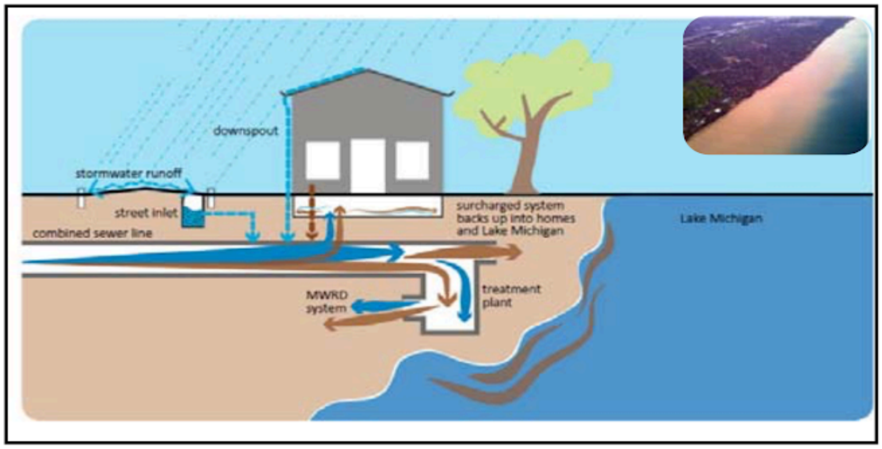

FIGURE 08 Kenilworth Green Streets Initiative (Corona 2017, 2).

After doing some modeling and running tests, it was found that the porous asphalt does indeed decreased the volume of stormwater discharge. The results are shown below (Corona 2017).

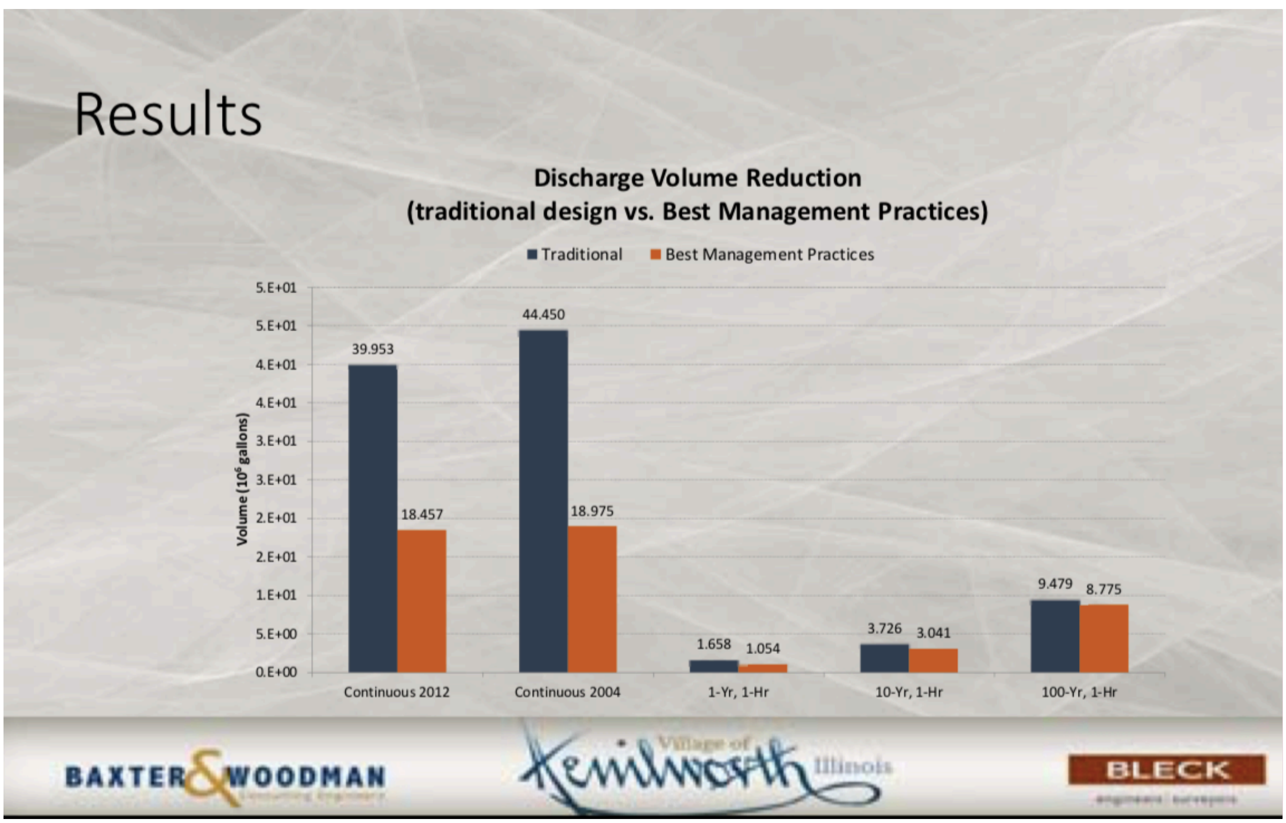

FIGURE 09 Discharge volume reduction using porous asphalt (Corona 2017, 4).

Since the numbers of the testing showed a decrease in discharge volume, the use of porous asphalt was chosen to be implemented in the town of Kenilworth. The benefits are clear, the wastewater clearly gets transported to the treatment plant and all the rainwater can be infiltrated into the storm line from the porous asphalt and storm drain. The schematic of where porous asphalt and the separated sewer system are located is shown below.

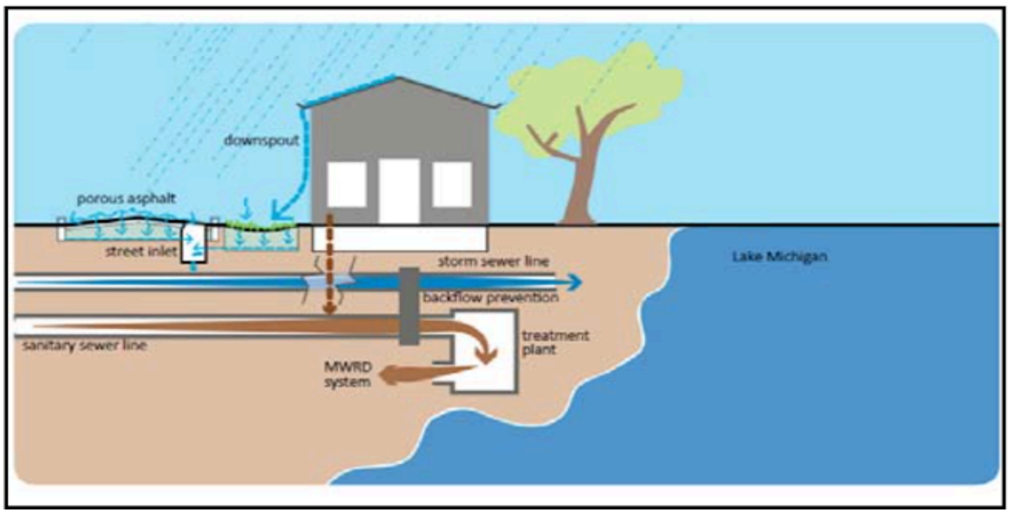

FIGURE 10 Rendering of runoff permeating through porous asphalt (Corona 2017, 5).

Permeable Concrete

Permeable concrete refers to paving consisting of porous materials most commonly cast in slabs and designed to interlock with other slabs of concrete. The earliest versions of what would come to be known as permeable concrete originated in Europe about 50 years ago. These first iterations were little more than gravel and grass roads with advances subgrades, but the technology would continue to advance rapidly and the materials and method common in construction today would first appear in the late 2000’s (Hein 2016, 2).

The most common permeable concrete is made by mixing concrete with little or no fine aggregates, and only enough cement paste to cover the particles of coarse aggregate. This leaves the final concrete with a void content of about 20 percent. This allows water to pass through the hardened concrete, but greatly reduces the structural effectiveness of the hardened concrete. Fibers can be added to the mix to help reduce the effect of the voids, and other strengthening methods such as water reducing admixtures are common. (Hein 2016, 1)

FIGURE 11 Pervious interlocking concrete pavement in Williamsburg, VA (Hein 2016, 1).

Benefits

One of the unique benefits of permeable concrete is that it is composed of high albedo material. High albedo material provides a higher solar reflective index compared to conventional concrete. The solar reflective index is a measure of how much thermal energy from the sun is reflected back in the atmosphere and how much of it is absorbed into the material. A high solar reflective index means that most of the solar energy is reflected and not absorbed. This property can greatly reduce the effect of urban heat island effect and thus can help in the lowering of energy used to cool homes in urban areas. Another form of water pollution is thermal pollution. During warmer months, stormwater runoff in urban areas absorbs heat from the concrete and transfer it to rivers, streams, and lakes harming wildlife. The higher solar reflective index can help reduce the effect of warm water pollution (City of Chicago 2010, 12).

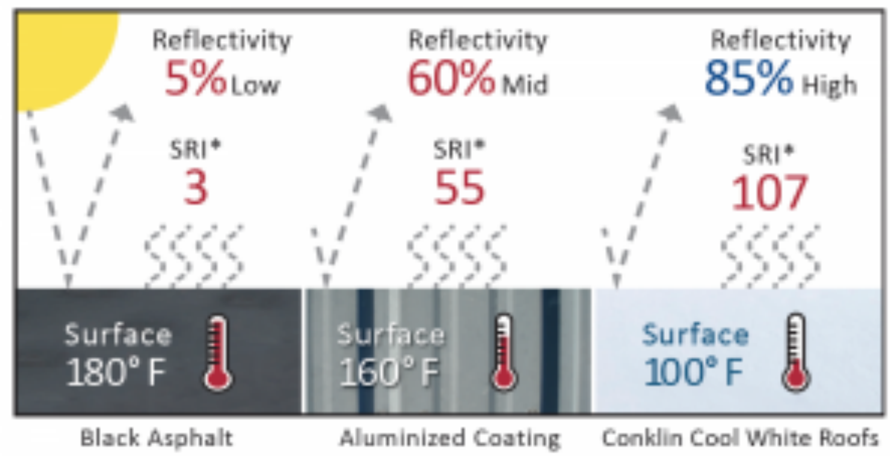

FIGURE 12 Solar Reflectivity Index (Flat Roof Solutions 2018).

Challenges

Due to the lack of sand in the concrete mix, along with the low water to cement ratio, permeable concrete has a remarkably low working time. This necessitates the use of hydration-controlling admixtures to improve working time, and viscosity-modifying admixtures to improve flow and discharge from concrete supply vehicles. The construction and placement of pervious concrete requires special attention to details such as cement hydration and compaction of the mixture to ensure the long-term durability of the concrete. These added ingredients and special construction considerations make permeable concrete more expensive than traditional concrete. The shrinkage of permeable concrete is also greater due to the void content. This requires further considerations during construction, further raising the cost (Hein 2016, 3) (ACI 2010).

Case Study

Chicago is currently experimenting with permeable concrete as part of the sustainable streets pilot project. Up to the current date, projects have included fitting alleyways with permeable concrete. Figure 13 below shows a “green alley” near Cermak Road in Chicago. Planned projects include fitting parking lanes and alleys with strips of permeable concrete to improve stormwater drainage in low load areas (Chicago Department of Transportation, 2018)

FIGURE 13 Chicago alley near Cermak Road (City of Chicago 2010).

BENEFITS OF POROUS ASPHALT OVER OTHER PERMEABLE PAVEMENTS

As already highlighted above there are two major benefits to using porous asphalt over other forms of permeable pavements. First porous asphalt, in most cases, is a cheaper solution than pervious concrete or PICP. Second, porous asphalt can be placed over existing impervious surfaces in the form of a permeable friction course overlay (PFC). This makes porous asphalt more versatile than other porous pavements. Both full course porous asphalt and PFC overlays show significant ability to remove pollutants from storm water runoff (Eisenberg, 2015, 70). One study even showed that pollutant removal of porous asphalt and permeable concrete produced similar results (Welker, 2012, 818). Coupling pollutant removal with lower prices porous asphalt provides benefits over other forms of permeable pavements.

In addition to chemical and particulate pollutants porous asphalt has been shown to reduce noise pollution effects of vehicular traffic on roadways. Porous asphalt has been shown to reduce traffic noise volumes significantly due to the porosity and the rubber or polymer modifiers used in the mix. Repeated studies have shown that PFC overlays can reduce traffic volume by 3 dBA, which translates to reducing traffic by 50%. This ability to reduce traffic volume by such a magnitude is not found among other porous pavements (Eisenberg, 2015, 70).

CONCLUSION

Though permeable pavement is a step forward towards sustainable roadways in urban environments, the lesser structural abilities when compared to traditional pavement means that it cannot fully replace current materials. As of the current date, permeable pavement has not been proven to hold up under the demands of high volume traffic areas. Permeable pavement can be used to supplement traditional pavement in areas of lesser demand however. Walkways, parking lots, alleys, and road shoulders can all be suitable candidates for permeable pavement. In general, the use of permeable pavement requires greater planning and is on the whole more expensive than traditional pavement and it also requires more maintenance than traditional roadways, further raising costs. These shortcomings are offset by the environmental and hydraulic benefits.

Rainfall permeating into the ground as it normally would instead of entering lakes and streams as runoff has a profound impact on both wildlife conservation and human sustainability. All of these considerations make permeable pavement a sustainable alternative for traditional pavement in roadway design with a number of existing challenges limiting its application. Special attention can be given to porous asphalt in that it tends to be the most economical of permeable pavements and can be used in overlay material over traditional impervious pavements, but provides similar environmental benefits as other full depth permeable pavements.

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