Pervious Pavement Systems for High Traffic Roadways

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This report highlights the benefits and detriments of pervious pavement systems through research of existing knowledge and multifaceted experiments to determine the feasibility of implementing a pervious pavement system on high traffic roadways. With over 40,000 miles of highway in the United States alone and severe water crises in states like California and growing environmental and safety concerns, the need for pervious pavements is abundantly clear. The research conducted utilizes existing knowledge on pervious pavements and applies it to the application of high traffic roadways. The experiment tests four different pervious concrete mix designs to determine compressive strength and water infiltration rates. This report ultimately concludes that pervious pavement systems can be used for high traffic roadways in open areas, where water can drain from the reservoir layer without the need for auxiliary drainage. Modifying infrastructure in urban areas that would require an auxiliary drainage means is not cost effective or practical. The experiment found that the mix designs tested could not structurally support highway level traffic; however with modifications to the experiment a suitable mix could be achieved. The experiment showed that the flow rate through all four mix designs was adequate to serve as a pervious pavement.

Key Words: Pervious pavement, High traffic, Water quality, Storm water, Safety

Introduction

Pervious pavement systems have been around for over 30 years, and yet many people have never encountered one. With the abundant benefits that pervious pavement systems provide, storm water management, water quality and safety to name a few, it is surprising that they are not more prevalent in our society. In urban environments over 25% of the area is occupied by pavements and over 2/3 of the rainwater that falls comes in contact with a paved surface, striking the need for a better roadway water management system. (FHWA, 2015) As our cities get larger and larger and we continue to increase hardscapes and our presence on the planet, we need to start thinking about the long term implications of our actions and how we can take steps to better manage the world around us. Pervious pavements can help us accomplish these goals. This report will look into the feasibility of implementing pervious pavement systems on high traffic roadways in terms of cost, practicality, public safety and water quality; through the use of research and an experiment to test the compressive strength and flow through rate of several pervious concrete mixes.

Cost

A pervious pavement system is more expensive than a traditional asphalt concrete system because the placement process and the materials are generally more expensive due to the use of more Portland cement. The typical price for a pervious asphalt roadway is $4.80 – $6.00/sf and for a pervious concrete roadway $5.00 - $10.00/sf, typically 15-20% higher than traditional road surfaces. (Cal Trans. 2014) Pervious pavements are more effective in areas where the runoff can be channeled into the groundwater table. (Tennis, 2004) Open paved highways and parking lots are the most beneficial areas for pervious pavement application because limited rework of infrastructure is needed to accommodate the new system. On large viaducts and overpasses major infrastructure rework if not complete rebuild is required to accommodate a pervious pavement systems drainage need, thus rendering it infeasible due to cost.

Practicality

There are over 40,000 miles of highways in the United States today and exponentially more worldwide, the need for a better roadway system is apparent and pervious pavements offer one of the most promising options for future development. (Interstate System Design, 2002) However, one major drawback to pervious pavement systems is the need for a large reservoir area of well graded drain rock and a filter course, rendering the finished pervious pavement road surface much thicker than a traditional road surface. (FHWA, 2015) This becomes relevant when considering how traditional urban infrastructure is built, using cast in place concrete overpasses and underpasses and road surfaces that are topped with asphalt as a replaceable layer. The pervious pavement system would require extensive drainage and water management systems as well as an additional 1-2 feet of overall thickness in order to function properly on existing urban infrastructure. (Huffman, 2005) Pervious pavement systems would be better implemented in urban streets where ample drainage infrastructure is already available in the form of storm drains and sewers. Open highway areas where the runoff can be channeled into the groundwater table and limited existing infrastructure rework is required to accommodate the new system are also practical applications for new pervious pavement systems.

Public Safety

On average there are 907,831 vehicle crashes per year in the United States due to wet pavement, 16% of all vehicle crashes and 73% of all weather related crashes. On average 352,221 people are injured in these crashes, 15% of all vehicle injuries, 80% of all weather related injuries. On average 4,488 people are killed in these crashes, 13% of all vehicle fatalities, 77% of all weather related fatalities, making driving on wet pavement the most dangerous driving condition there is in the United States.(OPS.FHWA) Pervious pavement systems offer many advantages over traditional road surfaces, in the interest of public safety; they effectively remove water from the road surface, reducing or eliminating hydroplaning effects and increasing stopping ability.(Mullaney, Lucke, 2014) Pervious pavements remove water from the road surface by filtering it through the pores in the road surface and into a reservoir layer of well graded rock, from 6”-2’ thick depending on rainfall in the area. The water collected in the reservoir layer is then channeled or dispersed into the ground water table or a designated watershed away from the roadway. Removing the water from the road surface increases a vehicle’s tires ability to make contact with the roadway, reducing or eliminating hydroplaning all together. The increase in surface area and frictional contact between the tires and the road surface increases breaking ability and handling characteristics of the vehicle, keeping the passengers safer on the road. (Mullaney, Lucke, 2014)

Water Quality

“Under current provision of the Clean Water Act (CWA) and the amended National Pollution Discharge Elimination System (NPDES) all communities with populations of 10,000 or more…are required to regulate and control the discharge of urban storm water into receiving water bodies. All dischargers are also required to comply with the total maximum daily load (TMDL). If water quality standards are not met, then the water body is classified as impaired. Currently, California alone has over 7,000 impaired water bodies with identified sources of pollution that require the establishment of TMDL limitations. About 900 of the identified impaired water bodies are directly linked with organic and inorganic pollution originated from urban surfaces.” (Kayhanian, 2015)

With the current state of water quality and quantity in California specifically, it is imperative to clean and retain as much storm water as possible. Pervious pavements have been found to effectively remove contaminants in storm water runoff and improve overall groundwater quality as well as gradually replenishing the groundwater due to the slow release of stored water in the reservoir layer. “Several studies have quantified high removal rates of total suspended solids (TSS), metals, oil and grease, as well as moderate removal rates for phosphorous, from using porous asphalt pavements (Cahill, 2005; Roseen, 2012). As the percentage or hardscapes in our urban environments increases so does the pollution of storm water. Pervious pavements remove the water from the road surface reducing splash up effects and limiting the amount of foreign contaminates that the water comes in contact with as it is collected. Pervious pavements have also been noted for having reduced storm water runoff temperatures as well as other important environmental impacts such as reducing the Urban Heat Island Effect (UHIE), labeled as, “cool pavement technology” due to its high void structure and evaporation properties. (Li, 2013; Stempihar, 2012; EPA 2008). A pervious pavement system does a very good job at improving storm water runoff and with further research into microbe layers and filter screens those qualities could be improved upon even more.

Methodology

The objective of this report through research and experimentation is to analyze the feasibility of implementing a pervious pavement system on high traffic roadways with emphasis on the following:

- Cost
- Practicality
- Public Safety
- Storm Water Quality

The methodology for the above section of the report was based heavily on research, case studies and pre-existing knowledge compiled to assess the feasibility of implementing a pervious pavement system on high traffic roadways. The information was acquired through the use of the California Polytechnic State University, San Luis Obispo Kennedy Library, as well as research conducted by other notable universities and professionals around the world. The methodology for the experiment section of the report, to follow, is based on previous knowledge as well as inferred decision making to test and compare different pervious concrete mixes to determine compressive strength and water flow characteristics with the goal of determining the best option to implement on high traffic roadways.

Experiment

In order to test and compare compressive strength and water flow characteristics of concrete pervious pavement systems an experiment was conducted using four different pervious concrete mix designs, three of which being previously identified, through external research, to be effective pervious mixes. The fourth mix design being an interpolated design based on knowledge obtained while studying construction management at California Polytechnic State University, San Luis Obispo. Multiple resources suggest a typical pervious pavement mix design consisting of cement content of 600 -630lb/cyd, course aggregate 3/8" and above 2,000-2,500lbs/cyd, and water cement ratios (W/C) between .3 and .4 with a binder to aggregate ratio between .2 and .25.(Paine,1992; Cal Trans, 2014) The mix designs used, aggregates, cement, water and ratios used to conduct this experiment are found below in table 1.

Table 1

Mix designs

Mix	**Large (A)**	**Median (B)**	**Cal Trans (C)**	**Fine (D)**
Aggregate (lbs.)				
3/4"	37.5	0	0	0
1/2"	75	50	0	0
3/8"	37.5	100	75	90
1/4"	0	0	37.5	45
No. 4	0	0	37.5	0
No.16 Sand	0	0	0	15
Cement (lbs.)	33.3125	33.3125	33.3125	33.3125
Water (lbs.)	10	10	10	10
W/C Ratio	0.3	0.3	0.3	0.3
Binder/Aggregate Ratio	0.22	0.22	0.22	0.22
Slump	0"	0"	0"	0"
Outside Temp @ Cast	66°F	66°F	66°F	66°F
Mix Temp @ Cast	68°F	68°F	68°F	68°F

The four mix designs used were labeled as they appear in the table based on their aggregate composition or the origin of the design criteria. All mixes were cast on the same day under the same conditions. All casting procedures follow ASTM standards as follows:

- ASTM C1064/1064M Standard test method for temperature of freshly mixed hydraulic cement-concrete
- ASTM C143/C143M Standard test method for slump of hydraulic cement-concrete
- ASTM C31/C31M Standard practice for making and curing concrete test specimens in the field
- ASTM C39/C39M Standard test method for compressive strength of cylindrical concrete samples

All samples were field cured in sealed bags, to reduce evaporation, in a cool, dark room due to the lack of a humidity controlled room. Samples were cured per ASTM specifications and were tested in 7 day increments starting after 7 days of cure. A water flow through test was conducted on the 28th day, prior to the compressive test.

Experiment Results

Field notes were taken while the experiment was conducted; including pounds applied by the compression machine, break type and pounds per square inch (PSI) and were compiled into table 2 as follows:

Table 2

Compressive strength test results

MIX	LARGE (A)	MEDIAN (B)	CAL TRANS (C)	FINE (D)
Day 7				
Pounds	45,000	45,000	40,000	65,000
Break Type	Cone and Shear	Columnar	Shear	Shear
PSI	1591	1591	1414	2299
Day 14				
Pounds	40000	45000	45000	75000
Break Type	Shear	Shear	Cone and Split	Columnar
PSI	1415	1592	1591	2652
Day 21				
Pounds	40,000	47,000	40,000	85,000
Break Type	Cone and Split	Cone and Split	Columnar	Columnar
PSI	1415	1662	1415	3006
Day 28				
Pounds	40,000	43,000	46,000	80,000
Break Type	Cone and Shear	Columnar	Cone and Shear	Cone and Shear
PSI	1415	1521	1627	2829

Break types are described per the ASTM standard. PSI was calculated by dividing the pounds imposed by the compression machine and 28.27 square inches as the surface area of the concrete cylinders. There is no standard for flow through rates of pervious pavements, for this test an apparatus was made to hold the test specimen in its casing over a clean 5 gallon bucket with a water receptacle attached to the top of the cylinder. The base of the plastic concrete test cylinder cut and removed to expose the pervious specimen and allow water to flow unobstructed. The purpose of this test was to get a general comparison of the flow rate of each sample and as such some variables were ignored including change in head pressure and test sample water absorption. The apparatus used to conduct the experiment can be seen in figure 1 below.

Figure 1: Flow through test apparatus

The flow through test was conducted measuring water input, water output and time. The results from the flow through test can be found in table 3 as follows:

Table 3:

Water flow through test results

Mix	**Large**	**Median**	**Cal Trans**	**Fine**
Lbs. H2O Before	10	10	10	10
Bucket Weight (lbs.)	1.8	1.8	1.8	1.8
Lbs. H2O After	9.2	9.4	9.4	9.2
Time to Stop Drip (sec)	37.5	44.5	42.5	105
Flow Rate (gal/min)	1.77	1.52	1.59	0.63

Discussion

The experiment and the results in particular show some promising and some not so promising aspects of concrete pervious pavement. Based on the research highlighted earlier in this report pervious pavements need to have high water infiltration rates as well as be able to support the rigors of use as a roadway. Many things were learned as a result of conducting the experiment that would have been difficult to ascertain without it. The results of the experiment and lessons learned will be discussed.

Compression Testing

The compression testing of the cylinders yielded interesting results, while expecting that the mix designs would have lower breaking strengths than traditional concrete mixes, the test cylinders in the experiment broke far lower than anticipated. In addition to the low breaking strength, the cylinders almost all uniformly failed at near the same PSI, also interesting because they all had different aggregate make up and the same W/C ratio, cement content and binder to aggregate ratio. The fourth mix design, with the added fine aggregate performed slightly better in the compression tests, from which conclusions can be drawn.

As seen in the figure 2, three of the specimens performed almost identically in compression, being that they have the exact same W/C ratio, binder to aggregate ratio and the same amount of cement; one variable stands out, the aggregate. When selecting aggregate for the experiment, well graded rock was sourced from a local supplier in the denominations identified in table 1. Upon inspection of the broken test cylinder, the aggregate, although well graded and the correct size, contained granite. Granite has relatively low shear strength and since pervious pavements don’t have the surface area help of fine aggregate, the shear strength of the course aggregate becomes a crucial factor. It was concluded that the lower shear strength of the granite in the course aggregates created more stress in the specimen, causing other aggregates to fail before they would in the absence of the granite. The fourth mix design performed higher than the others in compression because it had more fine aggregate than the other mix designs. The fine aggregate increases the surface area that the cement acts on, which in turn lowers shear stress on the larger aggregate allowing the sample to bear more weight and fail at a higher PSI than those without fine aggregates.

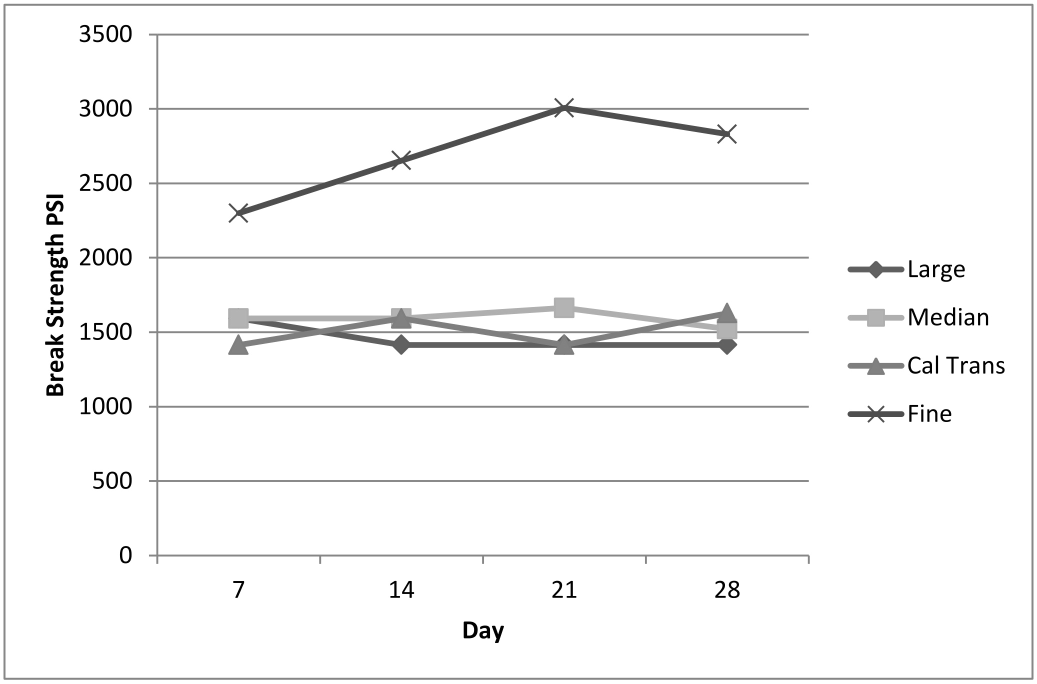

Figure 2: Compressive strength of mix designs

Flow through Test

The flow through test was conducted to determine whether or not the mix designs tested could accomplish the water permeability required of pervious pavement systems. The test was conducted ignoring the change in head pressure as the water was drained as well as the absorption of water into the test specimen as they were both irrelevant because the test didn't need to be that precise in order to get an approximate flow rate. The flow rates that were determined as seen in table 3 were very good. The large mix, with the coarsest aggregate and least amount of smaller aggregates, performed the best with a flow rate of 1.77gal/min, the equivalent to well over a 12"/hr storm.(USGS) The worst performing specimen was the fine mix, with the finer coarse aggregates and the addition of the sand, performed better than expected at .63gal/min which, despite being much lower than the large mixes flow rate, is still over a 5"/hr storm which is satisfactory for the majority of the country.(USGS)

Lessons Learned

While the experiment was overall successfully completed and valuable information gained, there are a few things that could be changed to make future experiments more successful. First and foremost, aggregate selection is key, the inclusion of granite in this experiments mix designs rendered them weaker than they could have been without the granite. Well graded, washed aggregate is essential to ensure porosity and the desired flowrates, however carefully selected crushed stone aggregates would make the tests more accurate and successful. The slump test conducted was irrelevant; all of the mix designs despite their varying aggregate contents had a zero slump per the ASTM standard test. Pervious pavement systems usually need to be compacted into place using heavy equipment, the ASTM standard test uses a rod mainly to remove air pockets and provide minimal compaction, if the experiment were repeated a method of compaction should be implemented beyond the ASTM standard test. Although not included in this experiment, a durability test in which the samples are subjected to things like tire wear and debris could be a valuable additional test.

Conclusion

Pervious pavements are more complex and require more care than a traditional road surface however the benefits of implementing them far outweigh the detriments. A pervious pavement system has many environmental benefits including storm water quality, groundwater replenishment, reducing urban heat island effect and reducing pollutants. The systems provide many increases to public safety on the roadways and could lead to a reduction in accidents, injuries and fatalities associated with wet conventional roadways. Practically, infrastructure in the United States is crumbling and needs to be updated for safety and environmental concerns. While pervious pavements are neither practical nor prudent to implement on things like bridges and overpasses, they could be very beneficial on more open highways. Anywhere the water stored in the reservoir layer can vacate without the use of auxiliary drainage, pervious pavements should be implemented. Pervious pavement systems are more expensive than traditional roadways, this additional cost is far outweighed by the environmental and safety benefits alone however it could be difficult to find additional funding. Public private partnerships could be a solution to the additional cost problem, by making the new pervious freeways toll roads, private investors would be able to help finance the initial project and would make money on their investments. Pervious pavements have been gaining in popularity and the pressure from environmentalists and the public has been gaining momentum. Pervious pavements will start to show up more and more in the near future and California will more than likely be on the forefront of pervious roadway design due to its water needs alone.

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