The Application of Porous Concrete

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Abstract

The southwest region of the United States is stressed for potable water and needs to positively utilize its current water resource. With the urban environment being mostly made up of concrete, it is now crucial to assess its development and application. The concrete used today is a mixture of cement, water and aggregates and is not permeable. The non-permeable property of common concrete prevents natural water absorption by the earth and greatly inhibits water to percolate back into the local water table. As concrete, has developed, porous concrete has been discovered. Porous concrete or pervious pavement is made in the same way that concrete is made with cement, aggregate, and water, but the aggregate used in porous concrete creates pores that allow water to pass through. By allowing water to pass through concrete, urban development will result in greater ground water recharge.

As global warming intensifies weather patterns across the planet, Tucson, Arizona will experience heavier rainfall seasons. As the world's climate changes, Tucson will experience heavier monsoon rain fall events. With heavier rain fall events urban flooding will become more of an issue. Grey infrastructure is needed to manage flooding caused by heavy rain fall. Porous concrete can be used as an effective way to manage storm water.

This capstone has undertaken an extensive range of literature reviews to identify where porous concrete can be used for storm water harvesting. The literature reviews range from climate change to the benefits of storm water harvesting. Porous concrete allows storm water to infiltrate through it and back into the local aquifer and directs storm water into retention ponds for treatment and reuse. Porous concrete is a low impact development (LID) building material, which will turn urban development into Sustainable development. Porous concrete if used correctly for storm water harvesting can reduce potable water stress, reduce pollutants found in

local waters, and reduce the strain on current storm drains. The required maintenance associated with porous concrete is minimal and not costly, therefore will be only briefly explained throughout this research. While porous concrete has a wide range of benefits ranging from water percolation to the reduction of the heat island effect, this paper will focus on its use as a means of storm water harvesting.

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Introduction

The urban environment is mostly made up of concrete materials (PCA, 2016). This is a problem because it leads to increased flood risks during storms. Climate change will exacerbate this issues because of stronger storms (Jardine, Merideth, Black, Black, LeRoy, 2013). Better storm water management is key and porous surfaces is one highly effective solution.

Storm drain engineering in urban developed areas has been focused on redirecting rainfall into a system of drains and pipes, away from streets and properties hence averting urban flooding. Although this design has the positive effect of preventing floods inside the urban area, it also creates lost opportunities for water harvesting and is costly to maintain. This methodology by design sends water to areas where it is difficult to reclaim and adds to the erosion in the areas where all this collected water is finally released. One way to address this lost opportunity for water harvesting is to implement porous materials in these impervious urban areas. **Porous concrete**, also known as pervious pavement, is a type of concrete with high porosity and can be a solution to the problem of Urban flooding (Neithalath, Sumanasooriya, & Deo, 2010). Using Porous concrete could give the benefit of harvesting some of this previously lost rainfall during storms while still preventing urban flooding.

Water harvesting is the practice of collecting and storing rain water (Lancaster, 2016). Water harvesting can have a substantial effect in reducing urban flooding by diverting the water off streets and into catchment systems. Harvesting storm water could increase the green space of an area therefore reducing the Urban Heat Island effect or the higher temperatures found in urban areas due to an overabundance of paved surface. The green space can be increased at a lower cost because the potable water required for that space will be greatly reduced. While the heat absorption is not much less than that of regular concrete, the increase in green spaces that porous concrete helps create will have a benefit in Urban Heat Island reduction. The increased Green space will also have an immediate positive impact on the microclimate of that urban environment which can be seen in human thermal comfort. As previously discussed using porous concrete has tremendous benefit

This capstone will focus on using porous concrete in street design and construction. Porous concrete is like standard concrete. Standard concrete is a mixture of Portland cement aggregates and water. Porous concrete differs in that it contains little or no fine aggregates such as sand. The aggregates used in porous concrete determines the level of porosity and the porosity determines the size and number of voids that are deliberately integrated into the concrete. The high porosity of the concrete allows water to pass through it (Neithalath, Sumanasooriya, & Deo, 2010). The permeability created in porous concrete can allow storm water to pass through it at a rate of three gallons per minute, per square foot of surface area minute (Tennis, 2004).

Porous concrete can be instrumental in helping cities and regions adapt to some of the impacts of climate change. The rate of storm water absorption could prevent flooding in most heavy storms. The water that passes through porous concrete is typically collected in a gravel pit created below the surface, which creates an opportunity for storm water collection to be filtered. Figure 1 illustrates the main components that make up a section of porous concrete applied to 2nd street that accommodates several transportation methods that could benefit from its installation, located in Tucson, Arizona. Since the concrete allows the water to percolate back into the local water table naturally, it allows the concrete to work as a filtration process. The filtration process that occurs with the use of porous concrete helps to prevent the collection of pollutants that arise from rain water collected from impervious surfaces. Pervious Pavement will be instrumental in sustainable development, but its application needs to be further defined.

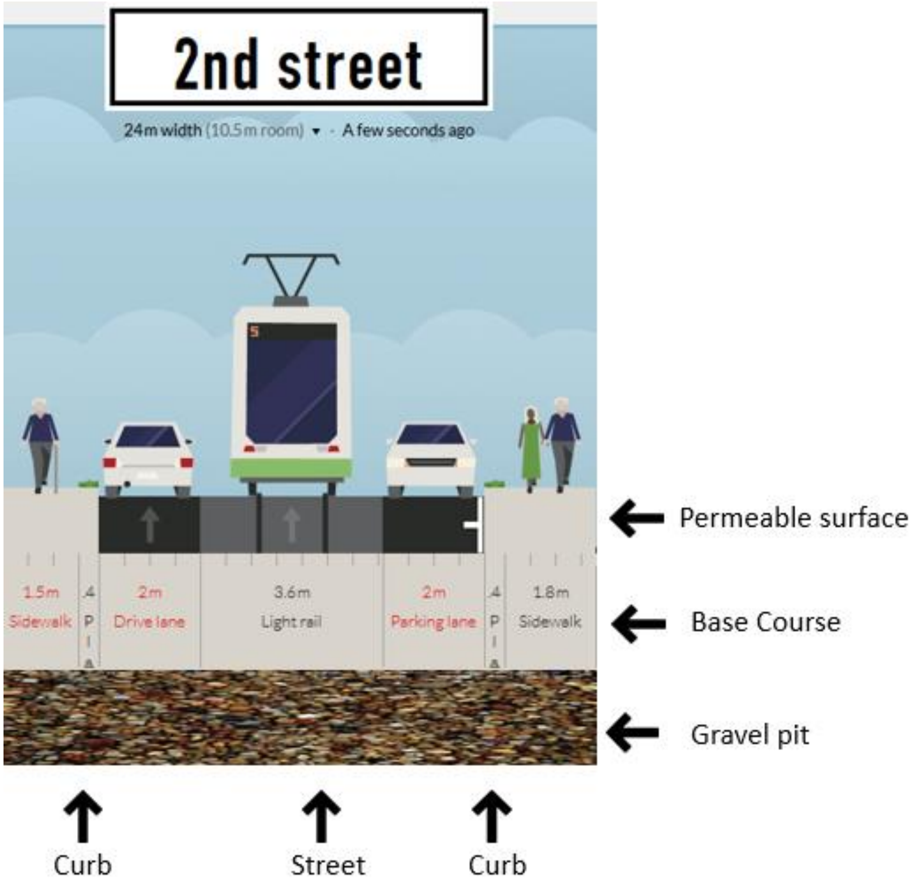

Figure 1 Street cross-section showing the components that second street is divided into.

Pollutants can collect on the surface of the impervious concrete that is used today. When there is a heavy storm, these pollutants are washed into storm drains or local waters. Porous concrete will reduce the amount of pollutant collected. The reduction of storm water flowing into storm drains helps keep storm water pollutants from flowing into groundwater. The use of pervious pavement for curb cut out will allow storm water to flow into green spaces along a sidewalk in cities. The city where porous concrete is used could see a reduction of potable water for irrigation and a reduction in urban flooding.

The runoff from impervious surfaces can cause urban flooding by overwhelming a sewage storm water system. Storm water can collect in places that do not have a storm water infrastructure in place. An urban area without a storm water system in place will be prone to flooding. The population in urban areas can grow so fast that storm water drainage systems are not installed to support the population. The high stress of population growth will make the use of porous concrete an important facet of urban and sustainable development. A system that is properly developed could see a reduction of pollutants in local water, a reduction in damage caused by heavy storms, and a reduction in global warming. Therefore, the application of porous concrete needs to be considered.

Porous concrete can be used for many applications, but is primarily used as a paving material. Special attention to where and how porous concrete is used needs to be taken into consideration so that porous concrete can assist in addressing urban flooding and global warming. This capstone presents optimum application of porous concrete as a means of storm water management.

Literature review

Current Trends

As problems with Urban Development are identified, a look back into the trends of the past will be necessary so that the problems can be addressed properly. Once the trends are identified, the correct plan of action can be put in place to address problems. The Urban Environment is covered in more and more impervious surfaces (Jardine, 2013). A trend that this capstone has identified is the use of concrete in the Urban Environment. Concrete is a commonly used building material in Urban Development. As more and more concrete covers the surface, less water can return to the local water table (Celio, Scott, & Giordano, 2010). Another trend that is creating a problem in Tucson is population growth.

The population in urban areas can grow so fast that storm water drainage systems are not installed or the increase of impervious surfaces overwhelm the storm water sewage system that is in place (Klemas, 2015). The high stress of population growth will make porous concrete an important aspect of urban development. These issues could be addressed by observing the problem areas of a city and determining whether porous concrete is a good method to address urban flooding. Strategically designed and placed. Porous concrete would be a major step in the reduction of erosion, pollution, and urban flooding

The urbanization of Tucson is the reason why porous concretes application needs to be understood. Porous concrete can reduce the amount of impervious surface found in the urban environment. Porous concrete can not only reduce the number of impervious surfaces, but it can increase the amount of green spaces found in a city says the Concrete Network. It can do this because the green spaces will not use as much potable water. The water from storms can be channeled into tree roots and landscaping with porous concrete (Network, 2014).

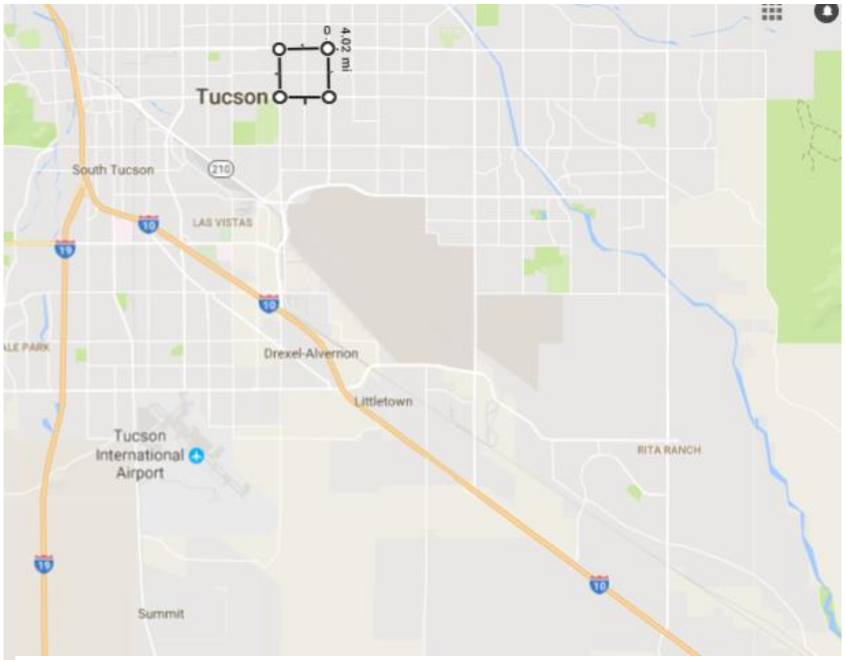

Figure 2 - 1 square mile in Tucson

When looking at Tucson from North Alvernon Way and North Swan Road for the west and east boundaries, and by East Speedway and East Broadway on the north and south boundaries, 33 % of the surface is paved (Davis, 2012). That means that 33 % of the surfaces in this area are impermeable. This limited area only represents one quarter of the square footage of Tucson. The impermeable surfaces in Tucson have created the problem of urban flooding. The use of concrete creates a missed opportunity for storm water harvesting and promotes urban flooding. These trends cannot continue because a place like Tucson, Arizona is stressed for water. Urban flooding can be linked to climate change (Climate Change, 2016). The application of porous concrete could be a solution to the trends identified.

Porous surfaces

Pervious or porous concrete has been around since 1852 (Obla, 2010). Pervious concrete was originally started in Europe because of a cement shortage. In Europe, it is called Gap graded concrete. Since there was no need to explore this building material in the past, the United States lost interest (Obla, 2010). The interest in this building material has just recently been renewed per Obla. The current application of pervious concrete is as a paving material for surface. New possibilities are being discovered and explored as it is more widely used.

Concrete

Concrete is a basic mixture of paste and aggregates according to the Portland Cement Association (PCA). The paste is mixed with water and spread over a surface. Once the paste hardens through a process called hydration, it forms the concrete we see commonly used in urban development. Concrete is commonly used in urban development because when wet it is easy to deal with and once dry has the strength needed for sidewalks and roadways. The most commonly used concrete is ready mix concrete. Ready-mixed concrete is used in all aspect of construction because it is cheap and can be used in many ways (Syverson, 2008, p.3).

The concrete most commonly used creates an impervious surface in urban environments. These impervious surfaces have an impact on water quality and flooding. The urban environment is growing and as we develop, we are paving over more of the environment. A solution to the problems created by impervious surfaces is porous concrete. The concrete used in urban development has the potential to make an impact on the problem of global warming.

Benefits of Porous Concrete

Climate change is happening and the problem will continue to grow along with the human population's growth. The globe surface temperature is hotter in the southwest region of the United States than in the past 2000 years (Jardin, 2013, p. 88). Not only has the temperature of the planet increased, but the frequency of weather events has as well (Lahmers, Castro, Adams, Serra, 2016). Additionally, more intense rainfall is occurring, even in locations projected to be drier (Jardin, 2013. P. 188). Much of the climate change that has taken place on Earth is due to the human race's creation of greenhouse gases (Lahmers, et al., 2016). Greenhouse gases naturally exist in our atmosphere, the burning of fossil fuels contributes additional greenhouse gases in the atmosphere, which allows the short-wave radiation from the sun to penetrate our atmosphere but block the outgoing long wave radiation thus, disrupting the energy balance. The activity of urban development has caused climate change and storm water management has been unable to adapt with the long and more frequent storms. In 2001, the Intergovernmental Panel on Climate Change (IPCC) wrote, "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." (Chen, 2016, p. 31) The activity of urban development has contributed to climate change and storm water management has been unable to adapt with the longer and more frequent storms.

Population as a Need for Porous Concrete

The population in urban areas can grow so fast that storm water drainage systems are not installed or the increase of impervious surfaces overwhelm the storm water sewage system that is currently installed (Lahmers, et al., 2016). The high stress of population growth will make porous concrete an important aspect of urban development. These issues could be addressed by observing the problem areas of a city and distinguishing whether porous concrete is a good method to address urban flooding. Porous concrete could cause a reduction of erosion, pollution, and urban flooding.

Storm Water Pollution

With impervious concrete, many pollutants collect on these impervious surfaces. Storm water then washes the collected pollutants storm drains. The storm drains redirect the pollutants into local waters. A city can take steps to mitigate storm water pollution. Storm water will collect trash, chemicals, and other pollutants as it is harvested in storage for reuse. Therefore, storm water needs to be rerouted to a water treatment facility prior to its intended use. Once the pollutants have been removed than it can be pumped back for its intended use. Irrigation and toilet flushing will have the least strict with the water treatment. Storm water that is intended for potable water use will have the most stringent treatment process and will need flocculation, filtration, and disinfection. The storm water intended for potable water reuse must adhere to the Clean Water Act of 1972 to be considered for potable water use.

Using pervious concrete, the process of returning water to the water table is simplified as water that passes through porous concrete is typically collected in a gravel pit created below the concrete's surface. Since the concrete allows the water to percolate back into the local water table naturally, it can allow the concrete to work as a filtration membrane. The filtration process that occurs with porous concrete helps to prevent the collection of pollutants that arise from rain water collected from impervious surfaces.

Curb Cut-Outs As a use for pervious pavements

The use of porous concrete in city curbs would be a small and simple way to begin to apply porous concrete as a method to address urban flooding (Lancaster, B, 2016). The porosity created in porous concrete can allow storm water to pass through it at a rate of 3-5 gallons per minute per square foot of surface area (concrete contractors). This flow rate could prevent flooding in most heavy storms.

Allowing water to filtrate not only reduces urban flooding, but can also water the local vegetation on a site. By reflecting on the current urban areas that get flooded, a city planner can see where the use of porous concrete can be implemented to have the best results. The water harvesting done with porous concrete not only reduces the water flowing into the current sewage systems, it also helps keep storm water pollutants from flowing into local water sources. It allows storm water to infiltrate into the local water table and can help in reducing potable water use. The local vegetation can act as a natural filtration system. Brad Lancaster discussed curb cut outs as a way that water could be filtered as it permeates back to the local water table and as a method of water harvesting to reduce urban flooding.

Maintenance:

Porous concretes performance relies on the porosity and sub-base reservoir. The sub-base reservoir captures the water that passes through the surface (Tennis, 2004). Water needs to be diverted to and away from the sub-base to help restore the water cycle. The porosity is the part of the concrete that determine how much water can pass through the surface. Most pervious concrete will not require much maintenance, but if clogging of the pore structure is identified, then the concrete will require upkeep. Debris can infiltrate and clog the pore structure and stop the flow, thus defeating the purpose of the concrete. In order to keep the voids of porous concrete clear, the concrete can be vacuumed annually, the surface can be blown, or power washed. Pressure washing clogged porous concrete could restore 80%-90% of permeability to the pore structure (Tennis, 2004). The maintenance of porous concrete is still being developed because the desired pore structure can be different depending on the preferred application.

Methodology

A comprehensive literature review of academic papers on climate change (Chen, 2016), porous concrete (Ferguson, 2016), and storm water harvesting (Lancaster, 2016) was conducted to determine its effective application of porous concrete. From this the literary review done in this capstone, a cost benefit analysis was done. The cost benefit analysis will give a clear picture as to how porous concrete can be applied and more widely used in urban development. The cost of materials for concrete and porous concrete will be taken into consideration along with the costs of the effects of their use (Layard, 2005, P. 4). I will also take the life expectancy of both concretes into consideration. A thorough review of material pertaining to the use and effects of both materials will be done to determine the best applications. The literature reviews were collected by their association with the Environmental Protection Agency (EPA), the Portland Concrete Association (PCA), and climate and urban development. The benefits and application of porous concrete for pollution control and storm water harvesting were determined through these literary reviews. An understanding of porous concrete will be obtained, the need for porous concrete, and the correct application of this building material are the goals of the literary review.

This capstone on porous concrete, addresses the challenge of application of porous concrete. The Green movements have touted the capabilities of porous concrete however; it is still not widely accepted as a commonly used building material. It is often discounted because it does not have the structural strength of the concrete used today (Lian, Zhuge, Beecham, 2011). It has also been pointed out that porous concrete does not work well in colder regions (Schaefer, Wang, Suleiman, & Kevern, 2006). This paper will focus on porous concretes application in the southwest region of the United States. However, this does not rule it out for other applications. Through reviewing the existing literature, an assessment will be made regarding the effective use and application of porous concrete to address the impacts of urban flooding, climate change, and assist in more frequent application of this building material.

Procedure

This paper first took measurements of three components of East Second Street at the University of Arizona. The components that were measured are the square footage of the street, the curb and the sidewalk. The total square footage of each components was calculated. The installation cost was broken down into three categories, Low cost, medium cost and high cost are all determined by the life cycle of the porous concrete installed (Pricing Sheet, 2017).

Low = 20 years

Medium = 30 years

High = 40 years

The square footage of each component of Second Street was then multiplied by the cost of porous concrete installation to determine the installation cost. The same cost analysis was done for the commonly used concrete according to the Portland Concrete Association. The two costs along with the benefits or drawbacks of each will then be compared to determine which building material can have the best impact on urban development.

Case study

East Second Street from Park Ave. to Campbell

Figure 3. A student trying to cross 2nd Street during a monsoon.

At a presentation with Brad Lancaster, he made the point that a hundred small changes can have a bigger impact than one huge change. Second Street, which runs through the University of Arizona Campus, is subject to flash flooding during the summer monsoons. The street was recently reconstructed with a concrete and asphalt surface when the streetcar was installed in 2013. However, the reconstruction did little to address the flooding- leaving pedestrians to cross water that is often more than a foot deep which stops the streetcar as well.

The street surface is in good condition and the streetcar tracks make it difficult, and costly, to justify resurfacing the road with porous concrete before its useful life has been reached. However, the sidewalks and curbs where left unaltered and are due for replacement. These could be areas to first install porous concrete to help mitigate flooding. The section below show a series of tables which outline the costs of replacing each of the three sections of the street, broken into low, medium, and high costs.

Data and Results

The National Green Values Calculator (GVC, 2015) was used to determine the cost for each component, Sidewalk, Curb, and Street, of Second Street. The report from the GVC stated, “The National GVC compares the lifecycle costs and benefits of green infrastructure.” The most commonly used concrete per the Portland Concrete Association is Ready mix concrete. The concrete network averages the cost of Ready Mix Concrete at 93$ per cubic yard.

Water that passes through porous concrete is typically collected in a gravel pit created below the concrete surface. Since the concrete allows the water to percolate back into the local water table naturally, it can allow the concrete to work as a filtration membrane. The filtration process that occurs with porous concrete helps to prevent the collection of pollutants that arises from rain water collected from impervious surfaces. Water that passes through porous concrete is typically collected in a gravel pit created below the concrete surface. Since the concrete allows the water to percolate back into the local water table naturally, it can allow the concrete to work as a filtration membrane. Water that is diverted to storm water drains concentrates the pollutants and therefore it is hard for the natural system to break pollutants down. The filtration process that occurs with porous concrete helps to prevent the collection of pollutants that arise from rain water collected from impervious surfaces compared to those of a conventional storm water design (Jardine, 2013, p. 10). Pervious concrete will prevent the concentration of pollutants and allow the natural environment to break pollutants down naturally.

It is difficult to measure in dollars the benefits of green infrastructure and GVC only used the costs of the storm water infrastructure components to calculate the costs (Jardine, 2013, p. 10). The benefits associated with the installation of porous concrete on East Second Street near the University of Arizona campus does not take into consideration, reduced air pollutants, carbon dioxide sequestration, or the compensatory value of trees, groundwater replenishment, reduced energy use (Jardine, 2013).

Below are the dimensions taken to find the components square footage of Second street which was measured using Google Earth:

Section	Length	Width	Total
Street	3918’	45’	176,310 sq. ft.
Sidewalk	3918’	5’	19,590 sq. ft.
Curb	3918’	.83’	3,251.94 sq. ft.

Table 1-Ready Mix Installation Cost Associated

Range	Cost	Area	Total Cost
Street	$93/cubic ft.	58182.3 cubic feet	$ 5,410,953.90
Sidewalk	$93/ cubic ft.	6464.7 cubic feet	$601,217.10
Curb	$93/ cubic ft.	1073.1402 cubic feet	$99,802.03

Table 1 To calculate price per Cubic foot. The depth that the concrete will be laid at is 4 inches

Tables 2-4 -Replacement cost associated with Porous Concrete

Table 2 - Street

Range	Cost	Area	Total Cost
Low	$2.830/sq. ft.[3]	176,310 sq. ft.	$ 498,957.30
Medium	$4.330/ sq. ft.[1]	176,310 sq. ft.	$ 763,422.30
High	$12.350[2]	176,310 sq. ft.	$ 21,774,290.00

Table 3 - Sidewalks

Range	Cost	Area	Total Cost
Low	$3.400/sq. ft.[3]	19,590 sq. ft.	$ 66,606.00
Medium	$5.190/sq. ft.[4]	19,590 sq. ft.	$ 101,672.10
High	$10,000 sq. ft.[5]	19,590 sq. ft.	$ 195,900.00

Table 4 - Curbs and Gutters

Range	Cost	Area	Total Cost
Low	$13.000/linear foot[6]	3,251.94 sq. ft.	$ 42,275.22
Medium	$17.250/linear foot[7]	3,251.94 sq. ft.	$ 56,095.97
High	$29.5000/linear foot[8]	3,251.94 sq. ft.	$ 95,904.50

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[1] RSMeans. Building Construction Cost Data. 63rd Annual Edition 2005

[2] City of Oxnard, California, Streets and Waterways Division. "Street Maintenance & Repair Funding." Accessed July 2005

[3] RSMeans Building Construction Cost Data - 63rd Annual Edition (2005)

[4] RSMeans Building Construction Cost Data - 63rd Annual Edition (2005)

[5] Residential Construction and Remodeling Estimates Accessed March 2009 Web Link

[6] "Grassy Swales Fact Sheet." Accessed March 2009 Web Link

[7] RSMeans. Building Construction Cost Data. 63rd Annual Edition 2005

[8] City of nard, California, Streets and Waterways Division. "Street Maintenance & Repair Funding." Accessed July 2005

Paving cost for porous concrete on Second Street, which commonly floods in Tucson, Arizona, are detailed in Tables 2-4 above. The cost of Ready mix concrete can be found in Table 1. The initial cost of pervious concrete is typically higher than that of traditional concrete, but with the advancement of porous concrete it is quickly becoming comparable. The reason the cost of pervious concrete seems more expensive is because typical concrete is laid out in a 4-inch thickness while pervious concrete is laid out in a 6-inch thickness. It needs to be laid out thicker because the aggregate added to achieve the porosity required for water passing through needs more space. The thick design helps to account for the weak ground beneath it. The overall benefits of pervious concrete outweigh its cost.

Tucson, Arizona received an average of 7.40 inches of rain during the 2016 Monsoon season (National Weather Service, 2016). The Month of August saw 1.09 inches of Rain. This means that East Second Street from Park Ave. to Campbell received 135,770 gallons of water during August. This water is diverted with a storm water drain and the opportunity to harvest the water is lost. This streets storm water drain is overburdened and the street regularly floods. With the use of Porous concrete 135,770 gallons of water can be returned to the local water table. The benefits of Porous concrete will be a reduction in potable water use in green spaces and a reduction in urban flooding.

Arizona is vulnerable to water strains due to its hot and arid climate (Berardy & Chester, 2017). Many parts of the United States rely on Arizona for its agricultural industry. Since there is such a high demand for water in Arizona it is imported into the State. The importation of water is an energy intensive process (Berardy & Chester, 2017). The water is pumped into canals and transported into Arizona. Therefore, Storm Water harvesting cannot be a missed opportunity in Arizona.

Discussion

Figure 4 photo credit Arizona Daily Star

The Tucson, Arizona region has a monsoon season. Flooding events occur frequently during this time of year. The monsoon season typically lasts from mid-June to mid-September. During the Monsoon season Tucson receives close to half of its yearly rain fall in the 3-month monsoon season (Adams & Comrie, 1997). During monsoon season, Second Street is known by students of the University of Arizona as a street that commonly floods and is typically avoided. Since residents at the University of Arizona are aware of the problem of flooding then it should be addressed instead of avoided. If the problem of urban flooding is looked at as a water harvesting opportunity, porous concrete can be a solution.

There are 176,310 sq. Ft. of street, 19,590 sq. Ft of side walk, and 3,251.94 sq. Ft. of curbs on Second Avenue. The cost to replace the concrete in each category can be seen in Tables 1-3. Although it would be costly to replace the components of Second Street, Tucson cannot afford to miss this water harvesting opportunity. Each category of Second Avenue presents different opportunities.

All components of Second Street will contribute to increasing green space. The street will have the smallest impact on increasing the green space surrounding the street. It will have the biggest impact on returning storm water to the water table. Curbs and sidewalks will have the greatest impact on the green space around the street. An increase of vegetation can be made with a minimal increase in potable water (Lancaster, 2016). The first introduction of porous concrete on Second Street should be the replacement of the curbs. It will be the least costly and may reduce flooding in this area enough, so that it will not need to be avoided during monsoon season.

When calculating the cost of the gutters, there is also the cost of sewer tie-ins, piping, and holding areas that are part of street construction. With permeable pavement, these items are not needed. Permeable concrete is a low impact strategy that can handle storm water runoff. The City can save money on the streets because of the reduction of grading cost the streets will no longer need to be graded to direct the runoff to a storm drain because the water can pass through Porous Concretes surface and be collected in a reservoir below the surface. Permeable concrete used in sidewalks will help to increase green spaces around a walking area. These spaces will not need to be watered as often because of the permeable concrete. When you relate total cost to the benefits of permeable concrete, a lot of opportunities are presented.

Testing under environmental conditions is important. By understanding how porous concrete works under the environmental conditions of Tucson, you can see where its application is best applied. The streets that commonly flood in Tucson are easily identified by members of the community. Permeable concrete is a great substitute for traditional concrete, however, replacing all concrete will be costly. Therefore, attention needs to be paid to the small changes that can have the greatest impact. As Tucson grows, it is important that attention is given to the way Tucson develops. Just using porous concrete as Tucson develops is not enough, a list of best management practices needs to be developed. The places where it can have the greatest impact will need to be determined. The streets that flood in Tucson are well known and small changes on these streets may be able to address the urban flooding that happens.

Future areas of study

- Aggregates in porous concrete used as a bio filter
- Pollutant control practices
- Select other streets that commonly flood in Tucson Arizona
- Current Storm water treatment practices
- Porous Concretes effect on water supply

Conclusion

Since Arizona is a water stressed state (Berardy & Chester, 2017). All water harvesting techniques need to be explored. Porous concrete has a positive impact in addressing water related issues and can be a tool for passive water harvesting. From the research conducted, porous concrete can be an effective way to address urban flooding. It can also help address the water stress that Tucson suffers because of its climate and scarcity of potable water. The benefits will not only be seen it the dollar savings, but in the addition of green spaces, and potable water reduction.

It is best to begin with a long and thoughtful observation of a location before porous concrete is applied. Curb cut outs have yielded positive results as a water harvesting method and have helped with overflow (Lancaster, 2016). This study recommends the use of curb cut outs as a model for porous concrete used on the curb. The use of curb cut outs advocates for the use of porous concrete in the curb as a water harvesting application because it can have a similar impact without the aesthetic draw back. When looking at porous concrete from a water harvesting stand point, you must think small and simple in its application.

Since Porous Concrete does not have the same strength as traditional concrete or asphalt, its application needs to be taken into consideration. The areas that have lower traffic or a curb might be the best application. The strength of Porous Concrete is dependent on the pore content of the concrete. The higher the pore content, the structural strength of the concrete is weakened (Lian, Zhuge, Beecham, 2011). Since normal concrete has no pore structure it is significantly stronger. You must take the porosity and strength into consideration when determining where to apply porous concrete.

Using porous concrete as a curb will help spread and infiltrate rainwater from a heavy storm. When thinking small and simple in porous concretes application, it can evolve over time to distinguish the best possible application. Current storm water management plans are a good resource to manage the over flow from heavy storms, however, due to population growth and quick urban expansion the current storm water drainage systems are overwhelmed. Porous concrete can spread and infiltrate water, which will reduce the heavy burden on the current sewage drainage system. The infiltration of rain water due to porous concrete helps filter out pollutants naturally. These pollutants typically end up in the current sewage system and pollute local water.

This study was limited on the study of porous concrete as a pollutant filtration method. This study would benefit from research done with porous concrete and water filtration or where the pollutant ends up. Porous concrete can be used as an aid to the current storm water management system, but more research could be done to discern the best aggregate to hold and filter water as it infiltrates back into the local water table. Further research could be done into the way water flows is directed and managed with porous concrete.

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