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Use of Porous Concrete and Scoria Bases to Clean Groundwater Recharge

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USE OF POROUS CONCRETE AND SCORIA BASES TO CLEAN GROUNDWATER RECHARGE

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ABSTRACT

The City of Pocatello, Idaho does not currently treat its storm water, but rather collects runoff in detention basins or discharges it into the Portneuf River. Nitrates from fertilizers and petroleum products enter local waterways and ultimately groundwater supplies. Porous concrete is regarded as a green product and has storm water filtering capabilities. Idaho State University (ISU) has been studying the use of scoria (vesicular basalt) to retain petroleum contaminants which migrate through porous concrete collection systems placed on driving surfaces.

At present, ISU is conducting laboratory experiments using a physical model consisting of a porous concrete slab made with coarse scoria aggregate over a scoria base. The model is being used to determine the capacity of the scoria to retain water/petroleum fluids. Microbial bacteria, similar to those used to clean oil spills, are also being introduced and studied.

A test section was poured in October 2011 in the topographically low area of damaged parking lot on the ISU campus. A scoria leach field was placed to discharge the collected water. Monitoring wells were placed below the slab and in the leach field to measure water levels. The slab was checked throughout the winter and will be monitored during the next year. To date the porous concrete has performed extremely well, and no additional pavement/curb damage has been observed in the vicinity.

By employing scoria with porous concrete, precipitation runoffs from driving surfaces can be re-introduced to local aquifers with less pollution, preserving clean water for future generations.

INTRODUCTION AND STATEMENT OF PROBLEM

Water quality issues are increasingly important since water that is passing through a porous concrete system is not treated (American Concrete Institute [ACI], 2010), and is eventually ending up in the groundwater, which is used for drinking water and agriculture (United States Geological Survey [USGS], 2012). The ACI (2010) defines porous concrete as a type of pavement that has sufficient continuous voids that allow water to pass from its surface to the underlying soil. Porous concrete has many uses, including the ability to reduce the impact of expanding urban development by decreasing or eliminating stormwater runoff rates without tapping into any drainage system, therefore recharging local groundwater systems (ACI, 2010). With cities like Philadelphia (Duhigg, 2009) and Chicago (Saulny, 2007) revamping their stormwater management practices to implement porous concrete, it is quickly gaining popularity in the United States of America (USA) as a green, or environmentally friendly, building material.

For porous concrete to be used in an urban stormwater management application, it is generally accepting runoff from drivable surfaces such as streets or parking lots. The ACI (2010) states that porous concrete has oil contamination filtering capabilities, but only to the extent of automobiles having small oil drips. The ACI does not take into account the possibility of people dumping oil directly onto its surface or the chance of petroleum spills at gas or lube stations. These contaminants have the potential of migrating through porous concrete and into the groundwater. Since there is no water treatment plant between these contaminated runoffs and the porous concrete, petroleum pollutants pose a potential substantial problem for local groundwater systems. Wenjing, Yuling, and Huanchi (2011) conducted a study on an aggregate filter for groundwater flow using scoria, a porous light silicate aggregate of basaltic composition developed from volcanic eruption, and its ability to absorb petroleum hydrocarbons from groundwater flows. By implementing scoria into a porous concrete system, groundwater petroleum contamination can be reduced significantly (Wenjing et al., 2011). It should be noted that scoria is limited to absorbing the contaminants; it will not dispose of the pollutants.

Scoria only has the ability absorb these petroleum pollutants, and will eventually reach a maximum capacity, which means it will not be able to absorb any more pollutants. After this capacity has been reached, any more petroleum introduced will just pass through the scoria filter without being captured. Studies have been performed on different oil-degrading bacteria and plants that will "eat" petroleum and oil products (Sirotkina & Novoselova, 2005). Guerin, Horner, McGovern, and Davey (2002), studied the use of scoria in conjunction with peat to filter petroleum hydrocarbon and found that using scoria in conjunction with hydrocarbon degrading bacteria as part of a porous concrete system helped reduce petroleum contamination of local groundwater systems. However, petroleum contamination is not the only setback facing porous concrete.

Problems can arise when placing porous concrete on certain types of soils. Some of these problems deal with collapsible soils, which have small enough grain sizes that when saturated with water, the buoyant force from the water make the particles separate and settle again in different orientations causing collapse of the soil (Zoghi, Mahar, Ebrahimpour, & Katamaneni, 2010). Since porous concrete returns water directly into the soil, saturation is imminent and will cause several problems when placed on collapsible soils. Pot-holes are often associated with these types of soils. The low permeability of these collapsible soils in conjunction with the interconnected voids found in porous concrete could potentially cause freeze-thaw weakening of both the soil and pervious concrete (Zoghi et al., 2010 & ACI, 2010). By stabilizing the soil, the collapse potential can be reduced as well as the weakening due to freeze-thaw cycles.

The application of porous concrete in cold climates is another problem that is faced. The ACI (2010) expresses the need to better understand the freeze-thaw characteristics of porous concrete. Currently, the American Society of Testing Materials (ASTM) has no procedure to test the freeze-thaw durability of porous concrete, but it is important to have a procedure to follow in order to provide consistent and reproducible results. The quality of the water that is entering the porous concrete causing the freeze-thaw resistance problem is also an issue that needs to be addressed.

Stabilizing the soil beneath porous concrete will help to reduce or even prevent settlement (Zoghi et al, 2010). Studying the freeze thaw durability and researching different methods to increase the resistance to freeze-thaw weakening will help to increase the life of a porous concrete slab. Being able to treat runoff on site will help to reduce the potential of contaminating the groundwater. Merging these ideas together, a porous concrete design was established using lime and fly ash to stabilize collapsible soils, a microbial bacteria treated scoria sub-base to capture and dispose of petroleum contaminants, and a porous slab to let the water pass through to a leach field where soil collapse would be minimized.

Recently, a test site was chosen in a low spot of a parking lot on the Idaho State University (ISU) campus that did not have a drain, and was having issues with water ponding next to a dormitory building. In general, water ponding is not an issue in the USA, but due to the highly collapsible nature of the soils native to southeast Idaho, and the fact that this ponding is occurring next to a habitable building, it must be addressed to prevent damage from occurring to the building or parking lot. ISU has had several issues with saturated soil induced settlement and there have been at least two reported incidents where the soils adjacent to ISU buildings have been saturated enough to cause significant settlement and structural damage, condemning the buildings until they could be fixed (Harry, 2003 & "ISU's Colonial Hall," 2012).

<u>Importance of Investigation</u>

Porous concrete is quickly gaining popularity due to its water filtering capabilities and its performance as an environmentally friendly building material. Since porous concrete is being used as a way to control stormwater runoff in urban areas without treatment of the water, its environmental filtering/remediation potential still needs to be studied (ACI, 2010). Placing porous concrete slabs on soils that are collapsible by nature must also be addressed to prevent damage caused by these soils. By improving the performance of pervious concrete where petroleum contamination may occur by using scoria to hold the pollutants while oil-degrading bacteria can perform, groundwater pollution can potentially be reduced even more.

BACKGROUND (LIT REVIEW)

As development or expansions of cities continue, so does the installation of impermeable or watertight surfaces that affect stormwater runoff rates that are entering local waterways. By making the ground surfaces impenetrable to water, none of the water is being returned to the local groundwater systems. Instead, it is being transported via storm drains and gutters to other locations that are usually downstream from where the rain is falling. These runoffs usually are treated for pollution and cleaned before reintroducing them into another local waterway. Using porous concrete as an alternative to this stormwater management practice, local groundwater systems can be recharged with clean water (ACI, 2010).

ACI (2010) defines porous concrete as a type of pavement that has sufficient continuous voids, or a direct path through the slab, that allows water to pass from its surface to the underlying soil. Porous concrete allows stormwater runoff to infiltrate back into the groundwater locally instead of transporting it somewhere else downstream. The ACI (2010) report mentions that porous concrete is a material that can be used in stormwater management to filter some contamination, reduce post development storm runoff rates and replenish local groundwater systems. The Environmental Protection Agency ([EPA], 2010) has regulations that require the treatment of stormwater runoff before returning that water to nature, and mention that porous concrete is one of their Best Management Practices (BMPs) that will accomplish this requirement.

The ACI (2010) also reports that porous concrete has been used in Europe since the middle of the nineteenth century, but it is a relatively new technology in the USA. Since porous concrete is being recognized by the EPA as a BMP, state and local governments recognize it as a green or environmentally friendly material and are handing out subsidies for using it (Cohen & Ackerman, 2011). Since porous concrete is a relatively new technology in the USA, there is currently a lack of standardized testing procedures (ACI, 2010). There are some concerns when placing porous concrete that need to be addressed if the system is to work effectively and last long enough to be justified. This research will focus on three specific issues that need to be addressed when placing porous concrete: 1) Collapse potential of the underlying soils of the porous concrete, 2) the freeze-thaw cycle characteristics of porous concrete, and 3) the stormwater filtering capabilities.

Soil Stabilization

The in-situ, or in place stability, in addition to the saturation strength, the water-logged stability, of the underlying soils must be looked at and addressed if these soils are weak in either condition (ACI, 2010). Currently there is no standard for placing porous concrete on top of collapsible soils (ACI, 2010). Collapsible soils can be defined as soils consisting of very small soil particles that can undergo a volume change or reduction due to the buoyant force of water separating the soil particles (Jones, White, Harker, & Mahar, 2011). Investigations have been carried out on reducing the permeability, or the ability of water to pass through, of soils and increasing the compressive strength, or ability to withstand pressures acting on top of the soil. This is done by compacting soils treated with lime and fly ash, which are the same chemicals used to harden cement (ACI, 2010 & Zoghi et al., 2010). By stabilizing the soils beneath porous concrete, soil collapse can be reduced therefore reducing the potential of the porous slab settling, or sinking into the earth. Soil stabilization can also increase the resistance to freeze-thaw cycle weakening of the soil itself, or deterioration due to water expanding and contracting due to freezing and thawing cycles (Zoghi et al., 2010). This stabilization can potentially reduce frost heaves, or frost induced bumps and pot-holes in roadways and parking lots (Zoghi et al., 2010). Since porous concrete has voids for water to congregate, it is also susceptible to freeze-thaw weakening (ACI, 2010).

Freeze-Thaw Characteristics

Concrete is strong in compression, but not tension. It can withstand pressures pushing against it, but it cannot handle forces pulling it apart, therefore steel is usually used to take these tensile forces. Because porous concrete lets water pass freely through its cross section, steel reinforcing is generally not used because of its corrosive nature. The brittle nature of unreinforced concrete in addition to the voids present for water to assemble in porous concrete make porous concrete susceptible to freeze-thaw weakening (ACI, 2010). Water expands when it freezes, and if it is caught in these pore spaces within the porous concrete during a freeze event, weakening can occur as a result of the expanding water pushing the porous concrete aggregates apart in the weak tensile direction. Freeze-thaw cycle characteristics of porous concrete have been studied and evaluated as losing up to 25% of its original strength after 16 to 25 freeze-thaw cycles (ACI, 2010). Investigations are taking place on non-corrosive polyvinyl alcohol (PVA) reinforcing fibers for freeze-thaw weakening resistance in masonry mortars (White, 2012). Since porous concrete does not use conventional steel reinforcing because of corrosion that would take place when the steel is exposed to water and air, PVA fibers would be a good alternative to help increase freeze-thaw resistance in porous concrete.

There are yet other ways to help protect porous concrete from freeze-thaw weakening that do not include extra reinforcing. The National Ready Mixed Concrete Association ([NRMCA], 2004) recommends implementing three procedures when using porous concrete. They are: 1) Placing a layer of loose aggregate beneath the porous slab so that the water can drain completely out of the porous concrete, 2) using an air entrainment admixture to help protect from freeze-thaw weakening, and 3) using perforated PVC pipe in the base aggregate to help drain excess water away from the porous slab. The NRMCA (2004) goes on to state that all three recommendations are not required in every situation, but are still a good practice. The NRMCA (2004) also studied several different porous concrete slabs placed in cold climates that followed their recommendations. All of their performances proved to be effective, but the ACI (2010) still recommends that more research is needed to protect porous concrete from freeze-thaw cycle weakening in cold climates.

Stormwater Filtering Capabilities

Since porous concrete takes surface water and returns it to the groundwater, water quality is a main concern (ACI, 2010). Groundwater is water that is stored in the ground in pore spaces between soil particles as well as fissures in rock deposits (Waller, 1994). According to the USGS (2005), groundwater is a major source of clean water in the USA including 37% of agricultural water (mostly crop irrigation) and 58% of the total populations' drinking water. With large cities like Philadelphia (Duhigg, 2009) and Chicago (Saulny, 2007) implementing porous concrete into their cities, it is quickly gaining popularity in the USA. Since porous concrete is being used in the USA primarily as drivable surfaces such as parking lots and roadways (ACI, 2010), and the fact that the USA consumes over 21% of the world's oil annually (Energy Information Administration [EIA], 2012), much of which is being used to run automobiles, petroleum contamination infiltrating porous concrete is a big concern. The ACI (2010) mentions that small petroleum based spills such as oil drips from vehicles will be quickly absorbed into the surface or in the pores of porous concrete, but there is still the potential for a person disposing larger amounts of petroleum based products directly into a porous concrete system. Larger concentrations of oil will likely pass through the porous concrete and seep into the ground, eventually reaching the fresh water stores beneath the earth's surface. These pollutants can potentially cause negative effects on the public's health, including poisoning from the leaching toxins, as well as the local ecology ("Groundwater Concerns," 2012).

Water Quality

The fact that a porous concrete system does not require any water treatment before returning the water to the ground is both an advantage and disadvantage. A non-water treatment porous concrete system is an advantage because it is an economical way of controlling stormwater runoff in urban areas and returning it to the groundwater (ACI, 2010). A porous concrete system that does not treat water runoff can be a disadvantage because the water that is being returned to the ground is not being continuously tested for water quality and has the potential of letting harmful contaminants pass through the slab and into the groundwater. As stated before, this groundwater contamination can have a negative impact on the health of the public and the local ecology ("Groundwater Concerns," 2012).

Absorption.

Sirotkina and Novoselova (2005) recognized the need to capture petroleum contaminants after they have been mixed with water because of the world-wide need for clean water. There are various methods used to purify water, and the absorption of unwanted chemicals is a very efficient practice and can ensure any required level of purification (Sirotkina and Novoselova, 2005). Sirotkina and Novoselova (2005) studied many different materials that have adsorption purification properties, including scoria, which is a cheap and natural occurring aggregate.

Wenjing et al. (2012) define scoria as a porous light silicate aggregate of basaltic composition developed by volcanic eruption. This means that scoria is a natural occurring aggregate that is ready for use without any processing. Wenjing et al. (2012) recognized the need to clean groundwater because of petroleum contamination, and they conducted tests to find a material that would act as a permeable reactive barrier (PRB), which is an in-situ remediation filter for polluted groundwater that is placed directly in the path of the contaminants entering the ground. Three tests were performed to find the absorptive characteristics of scoria: 1) Removal speed of contaminants from groundwater to design an effective PRB, 2) study the absorption process between scoria and petroleum hydrocarbon pollutants, and 3) explore the mechanism of absorption that scoria possesses.

The results from the testing indicate that scoria can be an effective absorbent of petroleum from contaminated groundwater. Scoria can effectively remove almost 90% of contaminants in only two hours. As concentrations of petroleum contaminants rise, so does the absorbance of those impurities. The porous structure and mineral constituents give scoria the ability to absorb petroleum hydrocarbons regardless of other chemicals present in groundwater. This is important since petroleum hydrocarbons easily bond with other chemicals making it difficult to separate them.

Scoria has been used in the field as a PRB. One particular instance was observed by Guerin et al. (2002) where an underground petroleum storage tank was slowly leaking into the surrounding soil at a factory facility in Southeastern Australia in December of 1997. Contaminants began migrating into an adjacent river and into the groundwater further downstream. Workers quickly placed a funnel and gate PRB, which uses an impermeable barrier to redirect and funnel groundwater flow to permeable gate, where filtering material is placed and groundwater can pass through to be cleaned. In the gate portion, scoria was placed with some peat on the downstream side. Peat is another material with petroleum absorbing characteristics. Monitoring wells were installed both upstream and downstream of the funnel and gate PRB. The site was monitored for a 10-month period where the removal efficiencies varied between 63% and 96%. This means the scoria was able to remove more than half of the contamination entering the PRB and let cleaner water pass by on the downstream side.

Water Treatment.

One concern with using an absorptive material to remediate petroleum contaminated groundwater is the fact that it will reach an equilibrium state where it cannot absorb any more oil thus allowing the contaminants to pass by and into the groundwater below. Lei, Yang, Du, and Cao (2011) studied the biodegradation of petroleum contaminants by introducing microorganisms into a groundwater site that had been subjected to oil pollution for years. Lei et al. (2011) found three types of bacteria, that after introduced into the polluted area, reduced contamination concentrations up to 90%. This means the bacteria will decompose the oil contaminants giving room for the scoria to absorb more pollutants to be degraded by the same bacteria. Some concerns have risen about how these bacteria will affect the health of the public such as causing sickness or poisoning.

Paul Voosen (2010) of the New York Times reported bacteria that scientists wanted to use in the oil spill along the Gulf Coast in 2010, can potentially cause harm to humans. This harm can only occur when the bacteria is consumed by shellfish, and those shellfish then consumed by humans. Since the use of oil eating bacteria would be used in a porous concrete application that is not draining into the ocean, the threat to human health is essentially zero.

METHODS

The purpose of this study will be to evaluate the performance of a porous concrete design that is meant to be placed on a collapsible soil, in a cold climate, and in a low spot of a parking lot, acting as a drain. The ACI (2010) expresses the need for research focusing on porous concrete in a variety of situations and conditions such as applications on top of problem soils such as collapsible silts, freeze-thaw resistance and weakening, and stormwater management. The American Society for Testing Materials (ASTM) currently publishes the standards for testing different types of materials. The ASTM (2009) states that because of its porous nature, pervious concrete cannot be tested using the standards that are used for conventional concrete.

Design Methodology

Since this application of porous concrete is being used as a parking lot drain, there were some critical components of the system that need to be better understood. Since parking lot drains are responsible for large amounts of water, the presence of collapsible soils in the region needs to be addressed. Cold temperatures are another mechanism that must be looked at since weakening of the porous concrete can occur as a result of repeated freeze-thaw cycles. Finally, the issue dealing with potential petroleum contaminants passing through the porous concrete and into the groundwater, where 58% of the USA's drinking water is pulled (USGS, 2005), needs to be addressed.

Soil Stabilization

The ACI (2010) states that the soils under a porous concrete system must have a percolation rate of one-half inch per hour and are four feet thick. The soils in southeast Idaho consist mainly of wind-blown silts that are four to fifteen feet thick with a percolation rate of 0.6 to 2.0 inches per hour (McGrath, 1987). These percolation rates would work fine in non-collapsible soils, but due to the collapsible nature of the soils native to southeast Idaho, soil stabilization must take place. This stabilization would transport the water elsewhere so that it can percolate back into the ground without backing up and ponding on the surface of the porous concrete.

Zoghi et al. (2010) studied the effects of adding lime and fly ash (LFA) admixtures to southeast Idaho silts to stabilize them enough to be used as a road base. Other studies have also taken place to look at the effects of LFA on soils in other regions ("Soil Cement," 2012). By using soil cement to stabilize the soil beneath porous concrete, the collapse potential of the underlying silt will be reduced thus reducing the potential of the porous concrete slab to settle over time.

When using LFA on silty soils, the permeability of those soils is reduced (Zoghi et al, 2010). If the runoff entering the porous concrete system is coming in faster than it can be returned back to the ground, the system will overflow and ponding will occur. The water must be transported away from the porous slab and LFA treated soil beneath so that it can percolate back into the ground without causing collapse in this location as well. This can be done by implementing a leach field next to the porous slab to control infiltration back into the surrounding soil. This leach field must be large enough to accommodate the region's largest predicted storm event so that soil collapse will not occur in proximity to the leach field.

Freeze-Thaw Durability

The ASTM (2009) and the ACI (2010) have both stated the need for standardized testing for the freeze-thaw durability of porous concrete. Because porous concrete cannot use the same testing procedures of conventional concrete, other methods of testing porous concrete for freeze-thaw durability must be explored.

The ASTM D560 (2003) is the standardized test for freezing and thawing of soil cement mixtures. The ASTM C666 (2008) is the standardized test for freezing and thawing durability of conventional concrete. Porous concrete can be considered to act like a cemented soil, in that it has voids that have a permeability value and the particles are cemented together. Porous concrete cannot be tested in the same manner as conventional concrete, but it is concrete, nonetheless. By combining these two material testing procedures to incorporate the properties of pervious concrete, one can find the freeze-thaw durability of porous concrete.

Water Treatment

Porous concrete is being used to manage stormwater in urban areas (ACI, 2010). It does this by eliminating the storm drain system and returning the water to the ground on which it fell. Porous concrete has the ability to filter what is routinely found on the ground in an urban setting, and even takes into account automobiles that are leaking petroleum contaminants onto its surface (ACI, 2010), but it has not been designed to incorporate the human factor. Porous concrete allows surface water to leach back into the groundwater supplies where over 50% of the USA's drinking water comes from. It therefore must be designed for larger scale spills where high volumes of petroleum contamination can potentially enter this precious groundwater. This can be done by implementing scoria into a porous concrete system.

Scoria is a light porous basaltic rock that has oil absorbing properties (Wenjing et al., 2011). The pores that are found in scoria along with the viscosity of oil give it this petroleum absorbing ability (Sirotkina & Novoselova, 2005). At first, it was thought that if scoria were used as the aggregate within a porous concrete mix, it would be sufficient to capture plenty of petroleum contaminants. This was quickly disproven when a test batch was mixed. The cement coats the aggregates that are bound together preventing the pores on the scoria to trap the passing oil. By using scoria as a sub base beneath a porous concrete slab, more petroleum contamination can be trapped as cleaner water passes by (Wenjing et al., 2011).

Scoria will perform well as a sub base, but only if treated with a cementitious material, or binding agent (Manz, 1961). If the scoria is to be covered with cement, its absorptive pore spaces will be covered, making its oil absorbing characteristics less effective. Scoria is a light aggregate and does not take much buoyant force to lift (Manville, White, Houghton, & Wilson, 1998). If these aggregates are not confined when this buoyant lifting takes place, the scoria can migrate away and the layers above will eventually collapse. By confining the scoria and preventing it from migrating, it can perform as an adequate sub base. This scoria has trapped the oil and will not let it pass through to the groundwater, but eventually, the scoria will reach an equilibrium state where it cannot take on anymore oil or other petroleum product.

Studies have been done on using microbial bacteria to decompose oil and other petroleum containing products (Lei et al., 2011). These microbial bacteria have also been used in large scale oil spill clean-up operations like that on the Gulf Coast (Marshall, 2010). Some concerns have arisen about the effects that these bacteria might have on the health of the public, but these fears only concern the consumption of sea life that have been exposed to the petroleum degrading bacteria (Voosen, 2010), and has no effect on groundwater supplies.

By merging the surface filtering capabilities of porous concrete and scoria and incorporating oil degrading microbial bacteria, groundwater contamination resulting from petroleum pollutants can be reduced or even prevented. Incorporating this idea with LFA treated collapsible soils, a final design is proposed.

FINAL DESIGN

A test slab was poured with the final design consisting of a leach field with a perforated pipe encased in scoria and geotextile fabric, a fabric used to prevent sediment migrating into the leach field, which was connected to the scoria base course to discharge the collected water. The mouth of the leach field was surrounded by a minimum half-inch aggregate in order to prevent sediment migration into the leach field. Six inches of conventional porous concrete, which consisted of one-quarter inch to one-half inch aggregate was donated by a local concrete company. Two monitoring wells were installed in the slab to measure water levels within the porous concrete part of the system. Two other monitoring wells were placed: one penetrating the leach field as well next to the porous slab, and the other penetrating the end of the leach field.

TESTING

Water Infiltration

Since construction, water levels from the monitoring wells have been recorded. These levels help to understand how the system is working. They give an idea of the permeability of the porous concrete as well as the scoria sub base and leach field. These values can be found using Darcy's Law, which describes the fluid flow through a porous medium. By knowing the dimensions of the porous concrete as well as the amount of water coming into the system, hydraulic conductivity, which describes the ease of which water can move through pore spaces, can also be calculated.

Settlement

The settlement of the porous slab will also be monitored comparing initial measurements to those taken at the end of the study. These comparisons will show if the soil cement is performing as expected. Visual observations of settlement will take place on the leach field, since if it fails, it will be easy to detect on the bare ground.

Water Quality

Water quality measurements will also take place at the test section using standardized ASTM D3921 (2011) to test for petroleum contaminants. Samples will be taken from the surface runoff before entering the porous concrete system. More water samples will be taken from all four monitoring wells to see the progression of the water quality improving.

Concrete Properties

During construction, three testing cylinders were cast that conform to the dimensions required for ASTM C39 (2012) which tests the compressive strength of concrete. Since conventional concrete testing methods cannot be used on porous concrete (ASTM, 2009), the proposed method for testing the compressive strength of porous concrete will be used once that standard is published. Before destructive tests take place, the cylinders will be used to confirm the permeability measured in the field. The test cylinders will also be used to determine other key properties like porosity, unit weight, and void ratio that can be used for later calculations.

Since only three cylinders were cast during construction, and more than three samples are needed for the different destructive tests, the mix design will be reproduced to cast more test cylinders. These cylinders will be used to explore different methods of testing the freeze-thaw durability of porous concrete. These different freeze-thaw test methods will include aspects taken from ASTM D560 (2003) (freeze-thaw testing for soil cement) and ASTM C666 (2008) (freeze-thaw testing for concrete). These two testing procedures are explored since porous concrete is pervious and concrete at the same time, and because the ASTM expressed the need for porous concrete to have its own procedures. The test cylinders will also be used to perform tests to determine porosity (ASTM D6527, 2008). More samples will be cast using different sized aggregates to explore a mix that will drain the runoff without becoming clogged while retaining the optimum strength properties.

Maintenance

Different maintenance techniques for porous concrete will also be explored. The ACI (2010) recommends pressure washing the surface and then wet vacuuming. Since maintenance is inevitable (ACI, 2010), once the porous concrete begins to show signs of ponding, four cleaning methods will be tested: (1) Brushing the dry surface with a hard bristle broom, (2) brushing the wetted surface with a hard bristle broom, (3) pressure washing the surface only (4) pressure washing the surface and then wet-vacuuming the surface. After each of these tests, a flux of water will be introduced to bring the pond up to a measurable depth. Once a level is achieved, time and corresponding depth measurements will be taken to see how fast the puddle disappears into the porous concrete to get a rate of flow through the concrete.

Contamination

In the beginning stages of this research, a display unit was constructed using a scoria aggregate based porous concrete with a scoria sub base on top of LFA treated soil all encased in plexiglass reinforced with a wood frame. This unit will be used to test the effects of high doses of oil contamination introduced into the system. Water quality testing using standardized ASTM D3921 (2011) to test for petroleum hydrocarbons in water before and after filtration will be used.

Once initial measurements are found, oil degrading microbial bacteria will be introduced into the display unit. Water quality testing using standardized ASTM D3921 (2011) will be used again and the results compared to those that were taken before the introduction of the bacteria.

SUMMARY OF FINDINGS

CONCLUSION

REFERENCES

American Concrete Institute. (2010). *Report on pervious concrete* (ACI-522R-10). Farmington Hills, MI: American Concrete Institute.

American Society for Testing and Materials. (2003). D560, Standard test methods for freezing and thawing compacted soil-cement mixtures. Annual Book of ASTM Standards. West Conshohocken, PA. DOI: 10.1520/D0560-03

American Society for Testing and Materials. (2008). C666, Standard test method for resistance of concrete to rapid freezing and thawing. Annual Book of ASTM Standards. West Conshohocken, PA. DOI: 10.1520/C0666_C0666M-03R08

American Society for Testing and Materials. (2008). D6527, Standard test method for determining unsaturated and saturated hydraulic conductivity in porous media by steady-state centrifugation. Annual Book of ASTM Standards. West Conshohocken, PA: ASTM. DOI: 10.1520/D6527-00R08

American Society for Testing and Materials. (2009). Pervious concrete. Retrieved from http://www.astm.org/SNEWS/JF_2009/C0949_jf09.html

American Society for Testing and Materials. (2011). D3921. Standard test method for oil and grease and petroleum hydrocarbons in water. Annual Book of ASTM Standards. West Conshohocken, PA. DOI: 10.1520/D3921-96R11

American Society for Testing and Materials. (2012). C39. Standard test method for compressive strength of cylindrical concrete specimens. Annual Book of ASTM Standards. West Conshohocken, PA. DOI: 10.1520/C0039_C0039M-12

Cohen, N., & Ackerman, K. (2011, November 21). Breaking new ground [Newsgroup comment]. Retrieved from http://bittman.blogs.nytimes.com/2011/11/21/breaking-new-ground/

Duhigg, C. (2009, November 22). As sewers fill, waste poisons waterways. *The New York Times*. Retrieved from http://www.nytimes.com/2009/11/23/us/23sewer.html?_r=1&pagewanted=all

Energy Information Administration. (2012). *International energy statistics* [Total Petroleum Consumption]. Retrieved from http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=5&aid=2&cid=ww,US,&syid=2007&eyid=2011&unit=TBPD

Groundwater contamination concerns. (2012). Retrieved from http://www.groundwater.org/gi/contaminationconcerns.html

Guerin, T. F., Horner, S., McGovern, T., & Davey, B. (2002). An application of permeable reactive barrier technology to petroleum hydrocarbon contaminated groundwater. *Water Research*, *36*, 15-24. Retrieved from http://144.206.159.178/FT/1092/46449/827007.pdf

Harry, D. (2003, March 4). LDS institute damaged by suspected leak cracks, sinking pillar force closure of classes until after spring break. *The Bengal*. Retrieved from http://www.isubengal.com/2.12282/lds-institute-damaged-by-suspected-leak-1.1620973

ISU's colonial hall temporarily closed after structural assessment. (2012, January 13). *The Bannock Alternative*. Retrieved from http://thebannockalternative.wordpress.com/2012/01/13/isus-colonial-hall-temporarily-closed-after-structural-assessment/

Jones, K., White, T., Harker, K., & Mahar, J. (2011, March). *Design considerations for porous concrete applications above collapsible soils*. Paper presented at the Engineering Geology and Geotechnical Engineering Symposium, Las Vegas, NV.

Lei, Y. D., Yang, Y. S., Du, X. D., & Cao, Y. Q. (2011). Biodegradation of petroleum hydrocarbon by indigenous microorganisms isolated from an oil contaminated groundwater site. In (Ed.), *2011 International Symposium on Water Resource and Environmental Protection* (pp. 354-357). Xi'an, Shaanxi Province, China: Institute of Electrical and Electronics Engineers. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5893017

Manville, V., White, J. L., Houghton, B. F., & Wilson, C. N. (1998). The saturation behaviour of pumice and some sedimentological implications. *Sedimentary Geology*, *119*(1-2), 5-16. Abstract retrieved from http:www.sciencedirect.com/science/article/pii/S0037073898000578

Manz, O. E. (1961). *Investigation of pozzolanic properties of the cretaceous volcanic ash deposit near Linton, North Dakota* (North Dakota Geological Survey 38). Retrieved from North Dakota Industrial Commission Department of Mineral Resources website: https://www.dmr.nd.gov/ndgs/Publication_List/pdf/RI%20SERIES/RI-38.pdf

Marshall, J. (2010). Microbes munching gulf oil. Retrieved from http://news.discovery.com/earth/oil-microbes-bacteria-plume.html

McGrath, C. L. (1987). *Soil survey of Bannock County area, Idaho*. Retrieved from http://soils.usda.gov/: http://soildatamart.nrcs.usda.gov/Manuscripts/ID711/0/id711_text.pdf

National Ready Mixed Concrete Association. (2004). Freeze thaw resistance of pervious concrete. Retrieved from http://www.nrmca.org/greenconcrete/nrmca%20-%20freeze%20thaw%20resistance%20of%20pervious%20concrete.pdf

Pervious concrete pavement . (2010). Retrieved from http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=137&minmeasure=5

Saulny, S. (2007, November 26). In miles of alleys, Chicago finds its next environmental frontier. *The New York Times*. Retrieved from http://www.nytimes.com/2007/11/26/us/26chicago.html

Sirotkina, E. E., & Novoselova, L. Y. (2005). Materials for adsorption purification of water from petroleum and oil products. *Chemistry for Sustainable Development*, *13*, 359-375. Retrieved from http://www.sbras.ru/PSB/phsb/papers/CSD2005_3e_1.pdf

Soil cement. (2012). Retrieved from http://www.cement.org/basics/concreteproducts_soil.asp

United States Geological Survey. (2012). *Source and use of water in the United States*. Retrieved from http://ga.water.usgs.gov/edu/wugw.html

Voosen, P. (2010, June 17). Will bacterial plague follow crude oil spill along Gulf Coast? *The New York Times*. Retrieved from http://www.nytimes.com/gwire/2010/06/17/17greenwire-will-bacterial-plague-follow-crude-oil-spill-a-81599.html?pagewanted=all

Waller, R. M. (1994). Ground water and the rural homeowner. Retrieved from http://pubs.usgs.gov/gip/gw_ruralhomeowner/

Wenjing, Z., Yuling, Z., & Huanchi, J. (2011, September 27). Mechanism of petroleum hydrocarbon contaminated groundwater remediated by scoria. *Advanced Materials Research*, *343-344*, 72-76. doi:10.4028/www.scientific.net/AMR.343-344.72

White, T. (2012). (Unpublished masters thesis). Idaho State University, Pocatello, Idaho.

Zoghi, M., Mahar, J., Ebrahimpour, A., & Katamaneni, M. Y. (2010). *Lime-fly ash stabilization of Idaho pavement subgrade silty soils* (Idaho Transportation Department No. RP189). Boise, ID: Idaho Transportation Department.