University of Southern Queensland

Faculty of Engineering and Surveying

Investigations into the Effect of Contaminants on Permeable Concrete Effectiveness during its Life Cycle

A dissertation submitted by

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Abstract

Permeable concrete (PC), also referred to as porous or pervious concrete, is a specific type of concrete with a high porosity that ultimately allows for water and gas permeability. As permeable concrete is not commonly used in developments for construction of pavements, car parks and driveways in Toowoomba. It is therefore, necessary to understand the implications of the long-term benefits of using permeable concrete. This project explores both the positive and negative implications of using permeable concrete in new construction developments.

Small scale testing was carried out in a USQ laboratory. Therefore, this type of testing is not as representable as large scale applications, such as new housing subdivision development or completed pavements. The clogging potential was examined in four pervious concrete cylindrical samples using various aggregates: sand, clay and stormwater. Pressure cleaning and vacuuming was used to clean the clogged specimens after each use. The permeability was determined following clogging applications. This report is aimed at developing an understanding for what influences clogging of the pores/voids in PC which ultimately leads to permeability reduction.

Results reveal that a reduction of permeability is strongly associated with sediment types, porosity and tortuosity. Evaluation showed that sand significantly impacted the occurrence of clogging. Furthermore, in comparison clay and stormwater runoff had no significant impact of clogging. However, literature review suggests that clay may eventually accumulate and build up under the PC sub surface. Most information from research is currently derived from small scale tests and not in-situ testing of larger areas.

The integration of pervious concrete into new housing developments around Toowoomba, or any city, should be encouraged by planning sections of local government to add as a condition for new developments that PC be incorporated for use on roads, driveways and footpaths. However, long-term wide scale investigation into PC and the phenomenon of clogging and site location is recommended.

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CHAPTER 1
INTRODUCTION

1.1 Introduction

Permeable concrete (PC), also referred to as porous or pervious concrete, structurally has a high porosity used for concrete pavement application that allows water from precipitation and other sources to pass directly through, thereby reducing runoff from a site and allowing groundwater recharge. Permeable concrete is traditionally used in parking areas, residential roads and pavements. PC application is suitable for both construction and to protect ground water quality. However, the use of PC is not wide-spread within Australia. The growing populations of cities require an increased surface area of land to be devoted to impermeable development which inevitably leads to expensive costs in the augmentation of existing drainage infrastructure.

The synthesis of pervious concrete is relatively similar in nature to normal concrete, however uses less water and no fines (sand) is almost entirely removed. The utilisation of Portland cement as concrete leads to an increase in greenhouse gases. Environmental friendly substitutions are available such as: partially replacing Portland cement with fly ash, natural possolans and ground granulated blast furnace slag. Furthermore, another alternative concrete may include geo-polymer mixes. However, environmentally friendly concrete is not the focus of this project as PC could be easily made to produce similar or better results using the environmentally friendly alternatives to conventional Portland cement.

The construction and development of PC is to ultimately reduce the amount of pollutants to reduce volume to receiving waters. The porous structure of PC allows for diffusion of water, vapours and gases. However, research and literature review has revealed that the long-term use of PC leads to a phenomenon referred to as ‘clogging’. Experiments using contaminants such as sand, clay and stormwater runoff demonstrates a reduction in permeability.

This chapter will provide an overview of the common applications of permeable concrete such as; construction of low-traffic roads, driveways and pavements etc. PC has shown sufficient strength for use in light traffic road applications, however, not motorways. This is due to the correlation between permeability and density.

1.2 Applications of Permeable Concrete

Permeable concrete is suitable for a variety of residential, commercial and industrial applications (Scholz & Gradowiecki, 2007). However, PC is confined to light duty and infrequent usage; therefore, the capabilities of this system allow for the use in low traffic areas. Although, PC can have adequate compressive strength, the increase in density decreases permeability (Kearsley & Wainwright, 2001). Therefore, suggesting why permeable concrete is uncommon. This will be discussed later in the chapter review and report findings.

Common applications of permeable pavement systems include;

- Residential, service and access driveways
- Roadway shoulders, crossovers and fire lanes
- Slope stabilisation and erosion control
- Golf courses
- Parking lots
- Pedestrian access
- Bicycle and equestrian trails; and
- Land irrigation

(Scholz & Gradowiecki, 2007).

PC has the potential to be used in new subdivisions, streets and footpaths. PC is recommended for replenishing underground aquifers and act as an environmental filter.

The evolution of permeable concrete is recognised for storm water management and is influenced by increased urbanisation and changing weather patterns (Scholz & Gradowiecki, 2007). Furthermore, PC has been established as a solution for pollutant control concerning surface runoff from areas such as roads and parking lots or other locations where contaminated water may infiltrate into underlying soil. As harmful pollutants such as hydrocarbons and heavy metals have the potential to endanger soil and groundwater resources (Scholz & Gradowiecki, 2007). Therefore, the structure of PC can allow for the collection and control of both stormwater runoff and pollution.

1.3 Research Objectives

Permeable concrete, used for roads, pavement and carparks etc. will eventually lose the ability to absorb surface runoff due to clogging of concrete pores. This project focuses on the causes of such clogging by using laboratory testing and analysis. This project involves the use of storm water runoff and the accumulation of soil, sand and clay within PC pores. The analysis will assist in identifying what type of maintenance is required to keep the surface pervious and what contaminants are detrimental in reducing the life cycle of permeable concrete.

1.4 Research Approach

This study will investigate the clogging effect on several permeable concrete specimens. These samples will be subjected to clogging caused by various sedimentation materials, such as storm water, sand and clay. The clogging and permeability tests will be conducted using the falling head test apparatus. The *in-situ* clogging conditions will be simulated as the samples are subjected to various sedimentation loads. The evaluated results will represent measured values of permeability before and after clogging. Maintenance methods will then be tested on the specimens to determine how effective vacuuming and pressure blasting is.

1.5 Conclusion

Permeable concrete can be used as an alternative in constructing roads, parking lots and other areas of traditional pavement. However, PC applications are limited due to a decrease in structural strength. Permeable concrete is appropriately designed for low traffic areas or use in lightly trafficked areas with not too many heavy commercial vehicles. Due to the porous structure, permeable concrete is suitable to limit environmental implications of stormwater runoff and pollutants. PC has been developed to reduce runoff rates and growing volumes of storm water collected in urbanised areas. (Scholz & Gradowiecki, 2007). The structure of permeable concrete will be further evaluated in the following chapters.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Permeable concrete has been widely used in infrastructure especially in urbanised areas. With the support of the Environmental Protection Agency (EPA), PC is used for low traffic residential areas, parking lots and driveways (Ferguson, 2005). Permeable concrete has several environmental benefits to improve urban drainage systems, control of stormwater runoff, supplementation of underground soil, water and heat reduction (Thorpe & Zhuge, 2010) (Ferguson, 2005). Materialistic properties and porous structure allow for permeability of fluids and air.

2.2 Environmental Benefits

Permeable concrete has been successful in retaining large volumes of water runoff and pollutants on site. The high porous structure of PC allows diffusion of water, vapours and gases. Several large scale studies has revealed that PC consistently reduces concentration of pollutants, supports supplementation of underground drainage systems and increases skid resistance in cold and/or wet conditions (Dietz, 2007) (Hood, et al., 2007) (Davis, et al., 2006).

Bioretention areas, or rain gardens, are structurally designed for stormwater retention that is potentially beneficial for aggriculture (Dietz, 2007). This can be used in either residential or commercial settings to increase groundwater recharge and limit pollution. Laboratory examination over a 6-year period revealed that water quality is significantly improved in areas with permeable pavement (Hood, et al., 2007). Concentration of pollutants such as copper, zinc, lead, ammoniacal nitrogen and nitrate were signifanctly lower in, infiltrate water (Dietz, 2007).

However, environmental concerns are associated with groundwater contamination (Dietz, 2007). For residential areas, polluntants such as petroleum residues from vehicles, heavy metals and pathogens are of concern (Hood, et al., 2007). Dietz suggests that treating stormwater from high traffic areas may provide a good margin of safety in regards to groundwater contamination (Dietz, 2007).

2.3 Properties of Permeable Concrete

Permeable concrete is a mixture of water, Portland cement, uniformly graded coarse aggregates and little or no fine aggregates with some additives (Tennis, et al., 2004). Permeable concrete uses the same materials as conventional concrete, with the exceptions that the fine aggregate, such as sand, is typically eliminated and the size distribution of the coarse aggregate is kept narrow allowing for little particle packing (Tennis, et al., 2004). Traditional cementitious materials as in Portland cements may be used in PC.

Appropriately designed PC may reduce the amount of pollutants reaching receiving waters, by allowing water to infiltrate into the subsurface layers. Permeable pavement allows stormwater to quickly infiltrate the surface layer to enter a high-void aggregate base layer, which forms a detention reservoir. The captured runoff is stored in the reservoir until it either percolates into the underlying subgrade, or is routed through a perforated underdrain system to a conventional stormwater conveyance (James & Von Langsdorff, 2003).

Permeable concrete systems comprise of four distinct aggregate components; concrete/pavers, unsaturated zone of base material, saturated zone of base material and sub-grade. Geotextiles with a fibre area weight of 60g/m^2 are used to prevent sand from migrating into the base of PC and can also be used to retain and grade oil. (Scholz & Gradowiecki, 2007). There are certain factors dependent on the properties and proportions of materials used when placing PC such as density and porosity, permeability, strength and durability (Tennis, et al., 2004). Smaller aggregates produces higher mechanical strength, but with decreasing permeability. Angular aggregates produce less density, higher voids, permeability and lower strength compared to rounded aggregates. (Kevern, 2006).

2.4 Pore Structure of Permeable Concrete

The engineering properties of PC, such as strength, durability and permeability are influenced by the number, type and size of pores present. The pore structure of pervious concrete includes four factors which are pore volume, pore size, pore distribution and the connectivity of the pores (Montes, et al., 2005). Permeable concrete has interconnected pores and, therefore, the porous structure of PC allows for the percolation of water through the matrix and into beneath the subsoil (Mishral, et al., 2013)(Refer Figure 1 & 2). Total porosity and pore size distribution are determined to evaluate permeability (Song & Kwon, 2007). Therefore, permeability can be influenced by total porosity and hence rate of permeability is influenced by pore size distribution.

Figure 1 shows the effect of binder to cement ratios, stronger connection with the aggregate leads to smaller voids. Less cement paste leads to larger voids however a balance between the two needs to be found for strength & permeability. A water to cement ratios of around 0.30-0.35 seems to be the best ratio from literature review.

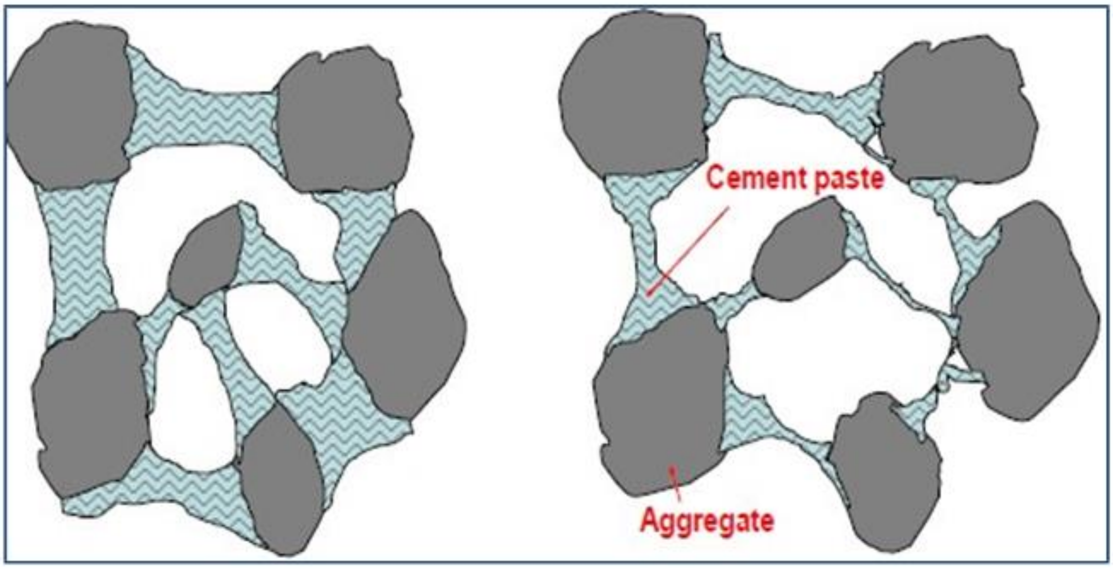


Figure 1: Higher binder to cement ratio (left) and lower binder to aggregate ratio (right) (add reference) (Tong, 2011)

Figure 2: This picture depicts the porous structure of a permeable concrete sample, thus revealing its relation to permeability (Yukari, 2009).

The porous structure of concrete also permits the ingress of CO_2, chloride, O_2 and moisture into the concrete leading to corrosion of reinforcing bars (Song & Kwon, 2007). However, the PC discussed in this report contains no reinforcing steel due to the fact that tensile strength is not a large factor in pavement use.

Furthermore, the unique surface texture of permeable concrete in comparison to traditional pavement provides enhanced friction for vehicle tires and skid resistance, therefore, preventing driving hazards in severe weather conditions.

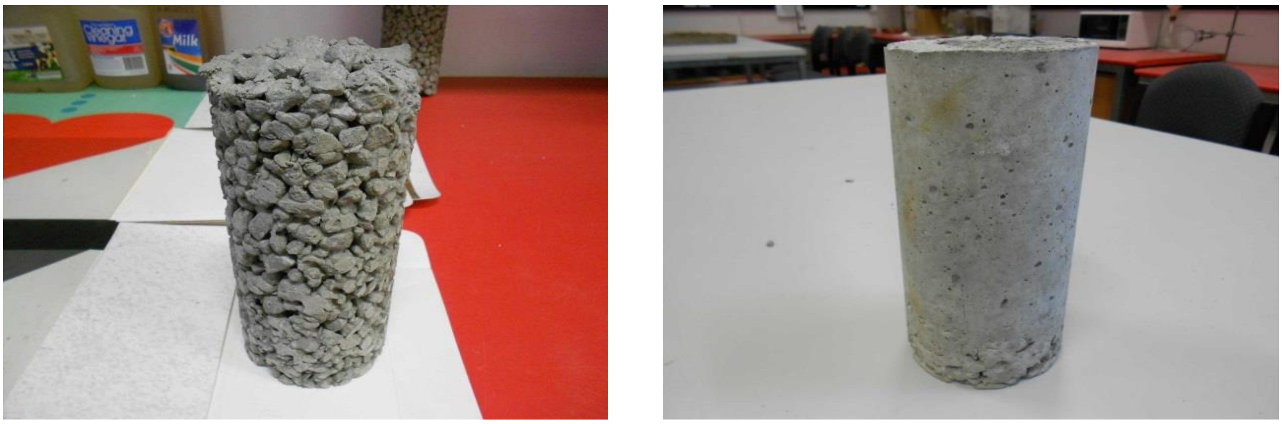


Figure 3: Shows the different appearance and surface of permeable concrete (left) compared with conventional concrete on the (right) photos from USQ laboratory

2.5 Benefits and Limitations to Permeable Concrete

The main advantage of permeable concrete is the ability to reproduce flow reduction and water quality improvement of natural surfaces and assisting infiltration of water into soil to replenish groundwater (James & Von Langsdorff, 2003). When comparing performance of permeable concrete to traditional pavements found that discharge rates from permeable pavements were significantly lower, by 30% of peak rainfall, and the time of concentration was greater by about 5 to 10 minutes (James & Von Langsdorff, 2003).

Another important advantage is the ability to reduce the amount of overland flow reaching receiving waters, thereby reducing peak flows in rivers and streams. Furthermore, permeable concrete may not only be suitable for addressing the negative impacts of stormwater runoff, but also pollutant collection in urbanised areas. Permeable pavement can facilitate biodegradation of oils from vehicles and decrease urban heating (Thorpe & Zhuge, 2010). Thorpe and Zhuge then goes on to state that PC also has the ability to reduce noise resulting from impact of tyre and pavement (Thorpe & Zhuge, 2010).

However, issues associated with permeable concrete involve hydraulic and mechanical problems. Due to the decreased density, and therefore, decreased strength, PC can only be used in low trafficked areas, such as small residential suburbs, driveways or parking lots (Scholz & Gradowiecki, 2007). Furthermore, the infiltration of stormwater runoff and pollutants after time will cause clogging of the pores, and therefore, reducing permeability (Mishral, et al., 2013) (James & Von Langsdorff, 2003). Ferguson suggested that permeable concrete may be impractical for public streets due to clogging materials (Ferguson, 2005) (Refer to Figure 3). Lastly, the life cycle of PC is much lower than traditional concrete, and therefore, the regular upkeep may be unpractical and expensive (Scholz & Gradowiecki, 2007).

Figure 4: Permeable concrete showing blocking of the pores termed clogging (Tennis, et al., 2004)

2.6 Financial Implications

PC costs, in contrast to conventional paving systems is approximately 25% more expensive (Scholz & Gradowiecki, 2007). This includes various upfront costs such as;

- more concrete is required PC normally requires pavements to be thicker than conventional concrete 150mm & 100mm respectively.
- PC requires a subase designed to drain the water seeping through the PC especially over clay bases to alow the water to slowly filter into the ground.
- Site preparation and site permeability need to be factored into the estimate

2.7 Porosity of Permeable Concrete

Porosity is a function of the mixtures, mixing materials and finishing and compaction procedures that influence the sum of entrained air voids and the voids within the space, the formula for this method is mentioned below (Kearsley & Wainwright, 2001) (Refer to Equation 1). Porosity can be used in conjunction with permeability. If the porosity is high and the pores are interconnected the permeability is also high, however if the pores are discontinuous the permeability of the concrete is low although the porosity is high. (Kearsley & Wainwright, 2001). Research suggests that porosity is largely dependent on the dry density of the concrete sample.

Furthermore, porosity affects hydraulic performance, or strength capacity, of permeable concrete. The typical range of total porosity is 15% to 30% as insufficient hydraulic performance and weak mechanical properties may be caused if porosity is lower that 15% and higher than 30% (Montes & Haselbach, 2006).

Volume of water is expressed in kg/m^3. Can be influenced by the volume of air entrained which suggests not all voids can be filled with water allowing permeability. Therefore, permeability increases with porosity and by reducing density. (Kearsley & Wainwright, 2001).

$$Ptotal(\%) = (1 - \frac{W2 - W1}{\rho x V})\ x\ 100\% \qquad (1.0)$$

$$Popen(\%) = (1 - \frac{W3 - W1}{\rho x V})\ x\ 100\%$$

$$Pclose(\%) = Ptotal(\%) - Popen(\%)$$

P open = Total porosity, %
P close = Closed porosity, %
*W*1= Weight immersed, (kg)
*W*2= Dry weight, (kg)
*W*3= Saturated surface dry, (kg)
V= Normal sample volume based on dimensions of the sample, (m^3)
ρ = Density of water, (kg/m^3)

Equation 1: Formula to find Porosity

2.8 Tortuosity

Tortuosity of a porous medium is a fundamental property of the streamlines, or lines of flux, in the conducting capillaries (Hajra, et al., 2002). Tortuosity is the effects of porosity and pore characteristics on permeability, therefore, is strongly related to the method in which water flows through an indirect path into permeable concrete

(Mishral, et al., 2013).Tortuosity commonly used to describe diffusion through a porous medium by determining the ratio of the flow of water divided by the direct path Le/L (Mishral, et al., 2013) (Refer to Figure 4).

Furthermore, tortuosity can be an indication of infiltration rate; as porosity increases, tortuosity decreases. Permeability increases with pore size and porosity, however, permeability decreases with increases in tortuosity (Mishral, et al., 2013) (Refer to Figure 5).

High tortuosity indicated the more distance between two points in concrete, which required more time for liquid to flow through. Tortuosity is also defined as a structural factor and a purely geometrical independent of the solids or fluid densities factor (Dullien, 1992).

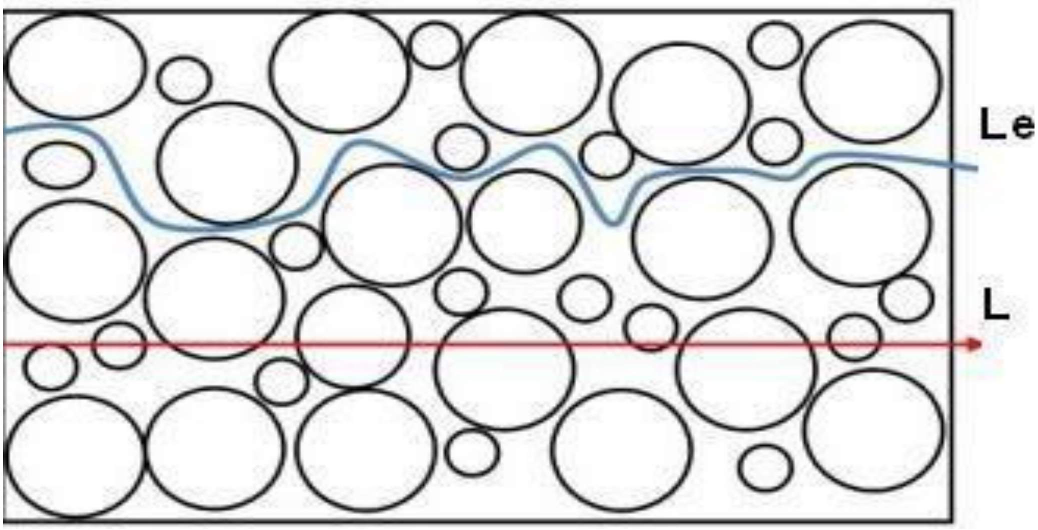


Figure 5: Shows the different paths of water flow where L is highly unlikely but the flow will mimic Le. (Mishral, et al., 2013)

$$\alpha = 1 - r(1 - \frac{1}{\emptyset}) \quad (2.0)$$

α=Tortuosity

r = $\frac{1}{2}$ for spheres

∅ = Porosity

Equation 2: Formula to determine the relationship between porosity and tortuosity

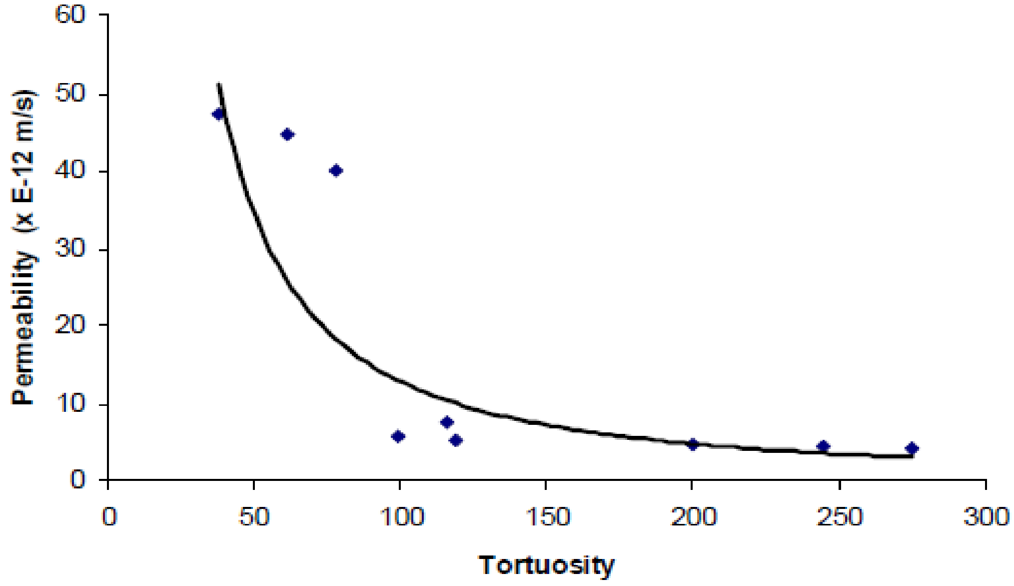


Figure 6: Reveals the relationship of permeability and tortuosity (Mishral, et al., 2013)

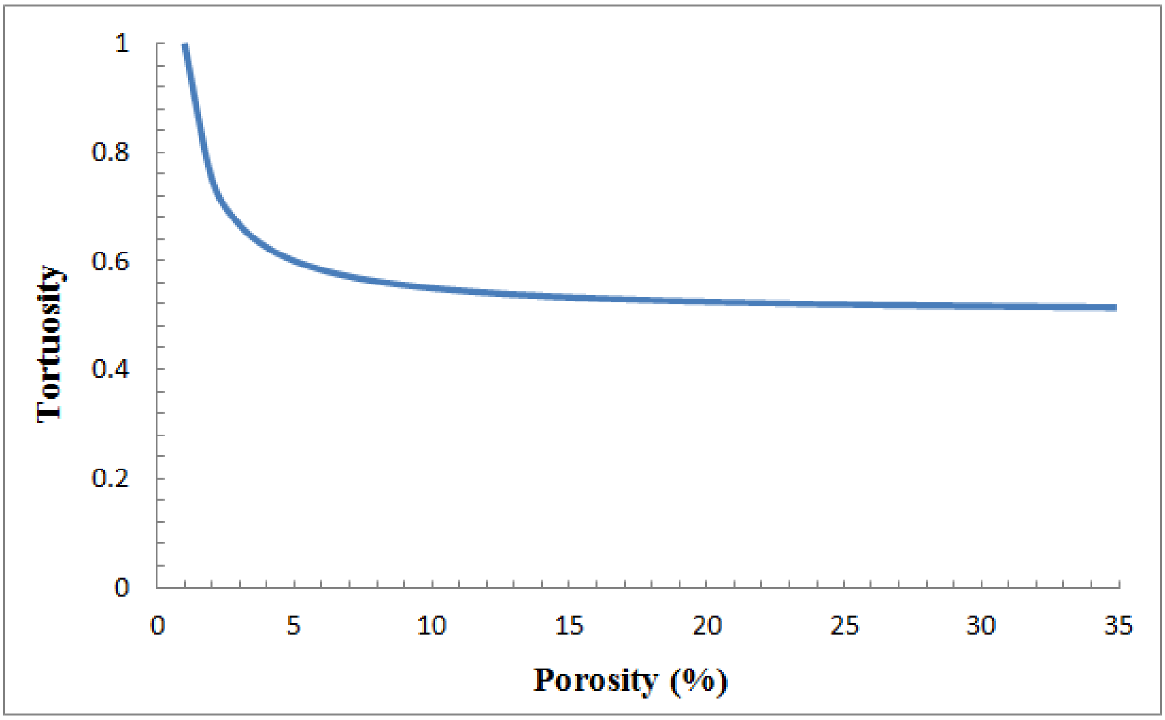


Figure 7: General relationship between porosity and tortuosity a minimum value for tortuosity is taken as 0.5 (Tong, 2011)

2.9 Water Permeability

The measurement of permeability is the flow of water through voids in the concrete usually measured in mm/s. Generally, the void content of PC is between 15% and 25% and the water permeability is typically about 2-6mm/s (Huang, et al., 2010). Permeability is used as an indication of the ease in which fluids, gases or vapours can enter into and move through the concrete or as an indication of the quality of concrete (Kearsley & Wainwright, 2001). However, permeability is influenced by the density of PC, therefore, effecting concrete strength values. Research suggests that permeable concrete compressive strength ranges from approximately 5MPa to 35MPa, which is of adequate compressive strength for the pavement systems being proposed.

There are two opposing influences upon permeability: size and volume obstructions can reduce permeability but interfacial effects and aggregate properties can increase permeability (Kearsley & Wainwright, 2001). Furthermore, the movement of water through porous pavement can be controlled by surface runoff, infiltration through pavement stones, percolation through unsaturated stones, lateral drainage at the base and deep percolation through the sub-grade. (Scholz & Gradowiecki, 2007) (Refer to Figure 6).

Permeability, k in mm/s, expresses the velocity of liquid in a porous medium in water-saturated conditions (Borgdwardt, 2006). Permeability measurements are based on the theory of Darcy's Law and the assumption of laminar flow within the pervious concrete using the falling head test (Neithalath, et al., 2006).

Figure 8: A picture depicting the differences between Permeable Concrete and traditional asphalt. Note the obvious differences between the foreground and background that represents the accumulation of stormwater runoff and pollution on traditional concrete. (Lake George Association, 2012).

2.10 Falling Head Test Method

The Falling Head Test (FHT) is used to estimate the hydraulic conductivity of permeable concrete (Neithalath, et al., 2006) (Refer to Figure 9). The falling head test measures the time taken for water to drop from its initial determined starting point to its final level. The coefficient of permeability (K) can be calculated according to Darcy's Law;

$$K = \frac{A_1 l}{A_2 t}\log\left(\frac{h_2}{h_1}\right) \quad (3.0)$$

$A_1 = Cross - sectional\ area\ of\ the\ specimen$

$A_2 = Cross - sectional\ area\ of\ the\ tube\ (95mm)$

$l = length\ of\ specimen\ (150mm)$

$t = time$

$h_1 = initial\ water\ head\ (290mm)$

$h_2 = final\ water\ head\ (70mm)$

Equation 3: Darcy's Law accurate for laminar flow when pore size is greater than 6mm flow conditions within sample move more towards transitional flow on the Moody Diagram

The hydraulic conductivity (K) of a porous material is determined by the arrangement of particles, pores and their relative sizes. The intrinsic permeability (k) of a porous medium can be through of as a measure of the frictional resistance to a fluid flowing through it. Therefore, the hydraulic conductivity related to intrinsic permeability is;

$$K = k\frac{\rho g}{\mu} \qquad (4.0)$$

Equation 4: Montes and Haselbach established a relationship between hydraulic permeability and porosity using the Konzeny-Carmen equation; (Montes & Haselbach, 2006).

$$K = \frac{\emptyset^{3p}}{Fs^2(1-\emptyset)2} \qquad (5.0)$$

$k = permeability$

$\phi\rho = porosity$

$Fs = generalised\ factor\ to\ account\ for\ different\ pore\ shapes$

$\tau = \text{tortuosity}$

$S_0 = Surface\ area\ of\ pores$

Konzeny-Carmen equation can be simplified to;

$$Ks = \alpha\ [\frac{\rho\hat{}3}{(1-\rho)\hat{}2}] \qquad (5.1)$$

$Ks = hydraulic\ conductivity$

$\rho = porosity$

$$\alpha = \frac{gCo}{vAs}$$

$= gravity$

$= empirical\ constant$

$= kinematic\ viscosity\ of\ water$

Equation 5: Konzey-Carmen Equation takes into account more variables and shows good accuracy with measured values.

2.11 Clogging

Permeability is an important parameter of permeable concrete since the material is designed to perform as drainage layer in pavement structures. However, Huang et al suggest that during the life cycle of PC addition of sand and soil can lead to the reduction in permeability which can be comparable to the general requirement of drainage (Huang, et al., 2010). The entrapment of minerals and organic fines into pores of concrete cause a phenomenon known as clogging. Commonly known sediments or clogging materials include, soil, gravels, leaves, sand and debris.

Research suggests that permeable concrete is prone to clogging within three years subsequent to installation (Scholz & Gradowiecki, 2007). Clogging of voids causes a decrease in porosity, and therefore, a decrease in permeability. The clogging effect of pervious concrete may be defined by a whole pavement system as the permeability of concrete decreases lower than the permeability of underlying soil due to clogging (Chopra, et al., 2010).

Furthermore, Mallen conducted research on PC over a 21 month period and results revealed that the permeability effectiveness was reduced by 97% due to clogging by sediments and organic matter (Mallen, 2006). Therefore, clogging may manifest through changes associated with decreased surface permeability and decreased storage capacity (Neithalath, et al., 2006).

The main causes of clogging include;

- Sediment being ground into permeable concrete by traffic before being washed off;
- Waterborne sediment drains onto pavement and clogs pores; and
- Shear stress caused by numerous breaking actions of vehicles at the same location resulting in collapsed pores. (Scholz & Gradowiecki, 2007).

This project will investigate the requirements to increase the life and effectiveness of permeable concrete and the limitations of clogging.

2.12 Conclusion

There is a wide variety of applications of permeable concrete, most commonly including the construction of residential roads, driveways and parking lots etc. All of which appear to have environmental advantages concerning stormwater runoff and pollution control. However, PC is not as strong as traditional concrete and the frequent maintenance proves to be expensive. It is important to investigate the limitations of clogging and tortuosity on permeability and to develop solutions to increase PC quality.

CHAPTER 3

RESEARCH DESIGN

3.1 Research Methods and Materials

The objective of experimental work is to examine the effects of clogging on pervious concrete at different design void ratios. Additionally, research more extensive than this will provide suitable solutions to limit the effect of sediments on clogging and increase PC life cycle. This research will focus on the use of permeable concrete use in developments in the Toowoomba region, thus testing will incorporate soils found in the local area. Toowoomba is not a highly polluted city, and therefore, this research will exclude contaminants due to pollution, chemicals, tyre wear and other clogging sediments. Experimentation will focus on turbidity from stormwater runoff, clay, sand and the associated issue of clogging from these contaminants.

This chapter will outline the appropriate test parameters and materials used. The design principle of this study is to stimulate the occurrence of clogging of permeable concrete in the laboratory. The simulation will attempt to reduce permeability of permeable concrete due to the clogging effect. Evaluation and important findings will be presented and discussed in Chapter 4.

Research was conducted in Laboratories based on the USQ Toowoomba Campus with approval from the project supervisor.

3.2 Literature Review

The literature review was conducted using Google Scholar using key word phases pertaining to the subject matter;

Permeable/Pervious/Porous Concrete, Permeability, Porosity, Clogging, Tortuosity, Falling Head Test, Portland Cement Pervious Concrete, Performance of Permeable Concrete, Permeable Concrete Review, Clogging, Pore Structure of Permeable Concrete etc.

3.3 Permeable Concrete Sample Materials

The PC samples were provided by USQ PhD student Krishna Mishra and use the following aggregate sizing. Gradations included #8 (passing of aggregate from 4.75mm of sieve and retained on 2.36 mm sieve), #4(passing of aggregate through 9.5mm of sieve and retained on 4.75 mm of sieve) and 3/8"(passing of aggregate through 12.5mm of sieve and retained on 9.5 mm of sieve). Using single size of aggregates or blending them together with a percentage of 25, 50 and 75% by their weight can also get the porosity between 15 to 30%. Using single size of aggregates or blending them together with a percentage of 25, 50 and 75% by their weight can also get the porosity between 15 to 30%. Tan et.al (24) concluded from their theoretical model and experimental results that by keeping the gradation narrow and by limiting the number of aggregate sizes, the voids could be larger. (Mishral, et al., 2013) or in table format below;

Passing Sieve	Retained Sieve
#4 (4.75mm)	#8 (2.36mm)
#3/8" (9.5mm)	#4 (4.75mm)
#1/2" (12.5mm)	#3/8" (9.5mm)

Table 1: Narrow graded aggregate used in PC samples

(a) 0.25 Too dry

(b) 0.30 Mix still to dry

(c) 0.35 Best compromise for PC

(d) 0.40 Too wet

Figure 9: Mould ability of pervious concrete at different water/cement ratios using the hand test (Yukari, 2009).

Samples were wrapped with cling wrap several times and then overlayed with duct tape on the sides. The ends of the samples were left uncovered to allow water to percolate through. The PC samples are prepared and ready for Falling Head Apparatus testing. Stormwater runoff was collected from receiving waters into Lake Annand, Toowoomba. Clay was collected from a Hodgson Vale property south of Toowoomba. Sand was purchased from a local landscaping supplier and all three conditions will be sampled.

3.4 Test Methods

Student was given samples for this study and use of the testing apparatus for permeability. The constants in the tests will be; water to cement ratio and aggregate to cement ratio. Laboratory testing was performed to measure clogging of material in permeable concrete. Samples were tested with different clogging approaches such as; sand, clay, and stormwater.

3.5 Porosity

Permeable concrete samples were dried in an oven for 24 hours at 110^0 Celsius. Following this, samples were then weighed to obtain a dry weight. A bucket of water was zeroed on scales; the buoyant mass was obtained by submerging the sample (Refer to Figure 10). Saturated surface dry sample is found by weighing the sample after it has been submerged. Using both these methods will determine the closed porosity or the water left behind that is locked into the sample.

Figure 10: Finding the submerged weight of a sample by placing sample in a bucket of water for 60 minutes then taking a reading from the scale

3.6 Permeability

Permeability of the PC samples will first be conducted using clean tap water. The clean tap water will be setup as the benchmark on how PC should behave in a perfect world without impurities blocking permeability. The PC samples will then be tested with local stormwater runoff to see the difference in permeability when dirty water is used. If time allows testing of sand and soil will be carried out. Testing of all samples will be carried out by the falling head method as shown in figure 9.

3.7 Clogging

The specimens were subjected to sedimentation load for *in-situ* stimulation of clogging. The clogging procedure was repeated five times for each test and then the mean found.

Once all testing are carried with the three methods below the amount of clogging can be determined.

- Storm water
- Clay
- Sand

The as mentioned earlier will be used to determine the rate of change of permeability with respect to time k = A/t , *k* in mm/s, with A & t relating to cross sectional area and time respectively. To clog the samples the equivalent of 0.5m will be poured into the graduated cylinder for each test phase.

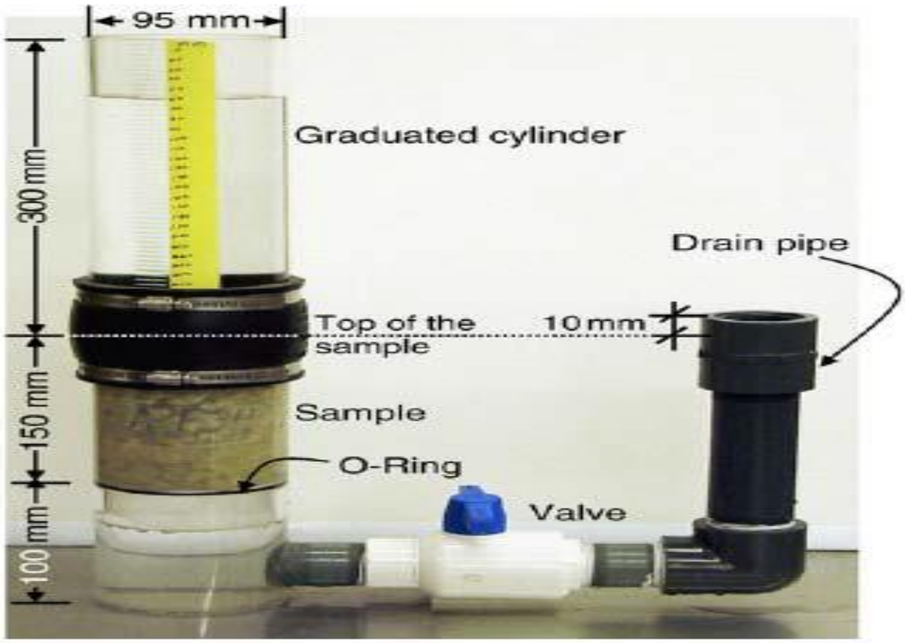


Figure 11: Permeability testing by the falling head method (Neithalath, et al., 2006)

Using the Falling Head Test (FHT) Method an initial starting head on the clear graduated cylinder at 200mm and a finishing head of 50mm will be used. The time taken for tap water to percolate through the specimen between start and finish heads will be completed five times and then the mean taken.

Results will be tabulated and graphed and a solution found that either single out which is the main clogging culprit or distinguish a pattern of one or more variables that will link PC samples by differing aggregate types, porosity values, density and permeability.

3.8 Maintenance

Once the specimens have been clogged the next step will be to prove how effective maintenance methods will be. Cleaning methodologies include pressure washing, vacuuming or a combination of the two (refer to figures 17 & 18). This will be performed on specimens that become significantly clogged and to ensure minimal aggregate contamination from subsequent tests.

3.9 Data Collection and Analysis

Mathematical formulas used are mentioned in Chapter 2 Literature Review under the appropriate subtitle. Data will be collected from experiments pertaining to porosity, permeability and clogging. Analysis graphing will be done using statistical programmes such as SPSS, GraphPad Prism and Microsoft Excel.

3.10 Risk Assessment

Risk assessment was used to examine activity, location or operational system in order to control hazards and manage risk. This process involved a series of basic steps;

1. Who is involved?
2. Identify Hazards
3. Analyse possible consequences. Is there a potential of injury or damage?
4. Assess the risk. Analyse the probability, frequency and severity.
5. Method of action. Removing or reducing any possible risks.
6. Implement control. Redesign and safety audit.

Judgement of risk was determined on a scale such as;

- Extremely slight, or practically impossible
- Very slight or very unlikely
- Slight
- Significant or possible
- Substantial or catastrophic

Assess the likelihood and consequences from the hazards or risks					
	Consequences				
Likelihood	Insignificant No injury, 0 - low $ loss	Minor First Aid injury, low - medium $ loss	Moderate Medical Treatment, medium - high $ loss	Major Serious injuries, major $ loss	Catastrophic Death, huge $ loss
Almost Certain is expected to occur at most times	H – 5	H – 4	E – 3	E – 2	E – 1
Likely will probably occur at most times	M – 6	H – 5	H – 4	E – 3	E – 2
Possible might occur at some time	L – 7	M – 6	H – 5	E – 4	E – 3
Unlikely could occur at some time	L – 8	L – 7	M – 6	H – 5	E – 4
Rare may occur in rare circumstances	L – 9	L – 8	M – 7	H – 6	E – 5

Code: E – Extreme Risk, **H** – High Risk, **M** – Moderate risk, **L** – Low risk

Table 2: Risk assessment table as used in many local and state government departments

By using an already established council based risk methodology table, concerns were put into the likelihood and consequence table and from this formed the basis of how high the risk was and ways/solutions to mitigate the risk to a lower level.

Each risk that was believed to be an issue to USQ staff or student was raised and a solution sought to minimise or eliminate altogether.

Risk ID	Risk Event description	Likelihood	Consequences	Overall Risk Rating	Priority
1	*Access for undertaking work in laboratory*	*Likely*	*Insignificant*	*M-6*	*Low*
2	*Students understanding of using laboratory equipment needed to complete project*	*Likely*	*Major*	*E-3*	*Extreme*
3	*Working with ovens and handling heavy items from oven*	*Likely*	*Minor*	*H-5*	*High*

4	*Working with chemicals & other dangerous goods*	*Likely*	*Moderate*	*H-4*	*High*

Risk ID	Risk Event Description	Mitigation Strategy	Likelihood	Revision of Consequence	Overall Risk Rating
1	*Access for undertaking work in laboratory*	*Plan suitable times with Laboratory manager*	*Unlikely*	*L-9*	*Low*
2	*Students understanding of using laboratory equipment needed to complete project*	*Student has previously been inducted and is to provide own PPE to cover tasks that require protection*	*Unlikely*	*L-7*	*Low*
3	*Working with ovens and handling heavy items from oven*	*Proper PPE Gloves, shoes, safety glasses*	*Unlikely*	*L-7*	*Low*
4	*Working with chemicals & other dangerous goods*	*Proper PPE & Student understands where to seek help in case of emergency*	*Unlikely*	*L-7*	*Low*

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Introduction

This chapter will outline the significance of the collected results. Theories and conclusions were made on multiple observations through repeated protocols. Results are presented using a series of pictures, graphs and tables. The results calculated are permeability coefficients and the flow rate. Using the initial permeability, this allows for comparison of each contaminant used for testing.

The experiments were an attempt to stimulate the occurrence of clogging. This simulation is important to determine the trends of permeability changing with time and the effects of various sedimentation types, such as sand and clay. Permeability (mm/s) was calculated using Darcy's Law.

4.2 Results

The effects of clogging were determined using the Falling-head test apparatus, as described in section 3.7. The specimens were divided into G1, G3, G4 and G5, which contained the porosity 31.07%, 19.81%, 26.37% and 19.38% respectively (Refer to Table 3). The samples were exposed to clogging first with 0.5m of turbid water. Test on contaminated samples were repeated five times all using tap water to calculate the change with respect to time from attempted clogging, therefore, the mean and standard deviation were calculated for each set of results.

The changes in permeability of specimens were determined using sedimentation from various materials. Initial permeability was determined using non-contaminated tap water and calculated using Darcy's Law, mentioned in Chapter 2. These results were used for comparison with experiments involving sand and clay as sedimentation types. The initial permeability was calculated as 14.8, 3.9, 10.6 and 4.0 mm/s, respectively (Refer to Table 5). G1 and G4 groups measured greater permeability. In contrast, the low std. deviation, 0.58 and 0.48 respectively, showed consistency for flow rate. Much lower values of permeability were measured in G3 and G5 at less than 20% porosity.

4.2.1 Properties of Pervious Concrete

Batch Name	Aggregate ratio %	Aggregate to Cement ratio A/C	Water to Cement ratio W/C	Height x Diameter (mm)	Volume (mm^3)	Dry Mass (g)	Buoyant Mass (g)	Porosity %	Density (t/m^3)
G1	100% - 9.5mm	0.5	0.33	200 x 100	1570.8	2944.9	1862.1	31.07	1.87
G3	50% - 9.5mm 50% - 4.5mm	0.5	0.33	200 x 100	1570.8	3404.9	2145.2	19.81	2.17
G4	25% - 9.5mm 75% - 4.75mm	0.5	0.33	200 x 100	1570.8	3182.1	2023.9	26.27	2.03
G5	100% - 4.75mm	0.5	0.33	200 x 100	1570.8	3350.3	2083.9	19.38	2.13

Table 3: Table of Results PC Properties: Depicting initial test results, constants aggregate to cement ratio and water to cement ratio. Dry mass was calculated after drying in oven for 24hrs at 110^{o}C. Porosity was calculated using formulas mentioned in chapter 2. Buoyant mass calculated as shown in figure 10, Porosity results of fresh sample using tap water. The results were calculated as mean ± Std. deviation.

Batch Name	Aggregate ratio %	Tap Water Time (s)	Initial Head (mm)	Finish Head (mm)	Area of pipe (mm^2)	Area of Sample (mm^2)	length of Sample (mm)	Permeability (mm/s)
G1	100% - 9.5mm	16.908 ±0.58	200	50	7088.2184	7853.9816	200	14.7993
G3	50% - 9.5mm 50% - 4.75mm	63.85 ±1.07	200	50	7088.2184	7853.9816	200	3.9190
G4	25% - 9.5mm 75% - 4.75mm	23.562 ±0.48	200	50	7088.2184	7853.9816	200	10.6199
G5	100% - 4.75mm	62.178 ± 1.06	200	50	7088.2184	7853.9816	200	4.0244

Table 4: Table of Results Tap Water; depicts permeability measurements using tap water. The flow rate of non-contaminated water can be used as a control for comparison with following experiments. Permeability was calculated using Darcy's Law, mentioned in Chapter 2. This set of results can be used as a control for comparison with clogging experiments. The results were calculated as mean ± Std. deviation. N=5.

The collected results ultimately reveal which sedimentation types had serious implications on the life cycle of permeable concrete. At first, water was poured rather quickly and was allowed to build up to a higher head. This is not reflective off real world conditions, as the build-up of head would not normally happen in a rain event as the higher head would help push contaminants through the specimen. This method was carried out only with the stormwater (Refer to Figure 12), however, with clay and sand tests the head of water was not allowed to build up past 50mm. This would simulate real world conditions more closely, following a down pour from a storm event. This way, the higher pressure head was not assisting the dirty water through.

A. **B.**

Figure 12: A. Contaminating the sample with 0.5m of stormwater water was poured in quickly to allow head to build up. B: contaminating the samples by pouring the equivalent of 0.5m of dirty water, but at a slower rate to keep the head of water below 50mm. These photos were taken in the USQ laboratory during testing.

Testing showed slower times at the start of the test and with each test a gradual increase in speed was noticed as the specimen was slowly being unclogged.

4.2.2 Storm Water

Storm water collected from Lake Annand was used to simulate the effects of stormwater runoff on PC. In terms of permeability, storm water tests revealed no significant difference in contrast to tap water. The duration of water flow for specimens G3 and G5 was slightly longer, measuring at 70.5 and 75.7 seconds (Refer to Table 5). The calculated permeability was also slightly comparative, measuring at 3.6 and 3.3 mm/s. Furthermore, there were no significant differences between G1 and G4 samples when comparing with non-contaminated water. This time, there was slight variation for results, G3 and G5 obtained std. deviation of 4.8 and 2.9 respectively. The most significant of these values is for sample G3.

Batch Name	Aggregate ratio %	Storm Water Time (s)	Initial Head (mm)	Finish Head (mm)	Permeability (mm/s)
G1	100% - 9.5mm	16.51 ± 0.36	200	50	15.1560
G3	50% - 9.5mm 50% - 4.75mm	70.48 ± 4.84	200	50	3.5503
G4	25% - 9.5mm 75% - 4.75mm	25.3 ± 0.86	200	50	9.8904
G5	100% - 4.75mm	75.72 ± 2.93	200	50	3.3046

Table 5: Table of Results Storm Water; Permeability test results after 0.5m of storm water percolates through sample then re-tested using tap water average of five tests. The results were calculated as mean ± Std. deviation.

4.2.3 Using Clay from Fresh Earth Works

Fresh earth works and water from erosion were tested on samples G1 and G3 (Refer to Figure 13 & 14). The permeability was reduced as expected due to much higher turbidity levels when compared to the previous results. The duration of time for the water to run through the contamination outlined below was slightly longer, measuring at 17.42 and 80.03 seconds, respectively (Refer to Table 6). The same volume of water was used, but poured over the sample slower so that the head of water did not surpass 50mm.

In conclusion, results showed that fine particles, such as clay alone, hardly had an effect on permeability. Therefore, did not influence significant clogging. However, clay content in water was not calculated. Therefore, it is hard to determine a correlation between clay content and its influence on clogging. The contaminated water collected was used to simulate potential consequences from erosion occurring worst case scenario from construction runoff.

Batch Name	Aggregate ratio %	Tap Water Time (s)	Initial Head (mm)	Finish Head (mm)	Permeability (mm/s)	Contaminant
G1	100% - 9.5mm	17.416±0.21	200	50	14.3676	Clay
G3	50% - 9.5mm 50% - 4.75mm	80.036±3.65	200	50	3.1264	Clay

Table 6: Table of Results Clay; The results were calculated as mean ± Std. deviation.

Figure 13: Pictures depicting the contamination of water used for FHT. Clay content was as a consequence of erosion resulting in high turbidity levels.

A  B

Figure 14: Depicts pictures taken on the 26/08/15. The water used was significantly turbid. **A:** Depicts the flow of water during the FHT. Note the turbidity of the water used. **B:** Depicts pictures following FHT showing contamination of specimens.

4.2.4 Using Sand

To simulate PC subject to 20 years life cycle, 80 grams of sand per litre of water was added (Refer to Figure 15). This amount was determined following literature review of similar experiments (Pezzaniti, et al., 2009). The combination of sand and water also influenced turbidity levels, however, not as extensive as clay. Sand contaminated water was tested on specimens G4 and G5.

Figure 15: Using sand as a sedimentation type. The picture above represents the effect sand has on water turbidity.

The permeability for samples G4 and G5 are 2.55 and 1.98 mm/s respectively. In contrast to flow rate, 97.76 and 125.94 respectively, sand was found to have significant consequences on permeability (Refer to Table 7). However, for both samples, there appeared to be significant variability between results. Std. deviation of 118.3 and 24.68, respectively, were calculated. Note, that for G4 a greater value of 309.4s was obtained, suggesting, the effects of clogging. Ideally, specimens would have been cleaned via maintenance techniques on a regular basis before being clogged with the equivalent of simulated 20 year build-up of sand such as sweeping, vacuuming and pressure washing every 12 months. This would have provided more consistency in results.

Batch Name	Aggregate ratio %	Tap Water Time (s)	Initial Head (mm)	Finish Head (mm)	Permeability (mm/s)	Turbid Water 80g/l
G4	25% - 9.5mm 75% - 4.75mm	97.766±118.3	200	50	2.5594	Sand
G5	100% - 4.75mm	125.94±24.68	200	50	1.9869	Sand

Table 7: Table of Results Sand; The results were calculated as mean ± std. deviation.

In contrast to the initial permeability, results obtain from sand as a sedimentation type significantly influenced the occurrence of clogging. In comparison to clay contamination, the permeability was significantly lower (Refer to Figure 16). Therefore, sand appears to be the most detrimental on PC. G5 obtained the lowest permeability measurement in comparison to G4. It is possible sand adhered to the surface within the specimens. Thus, emphasising the need for a regular maintenance procedure.

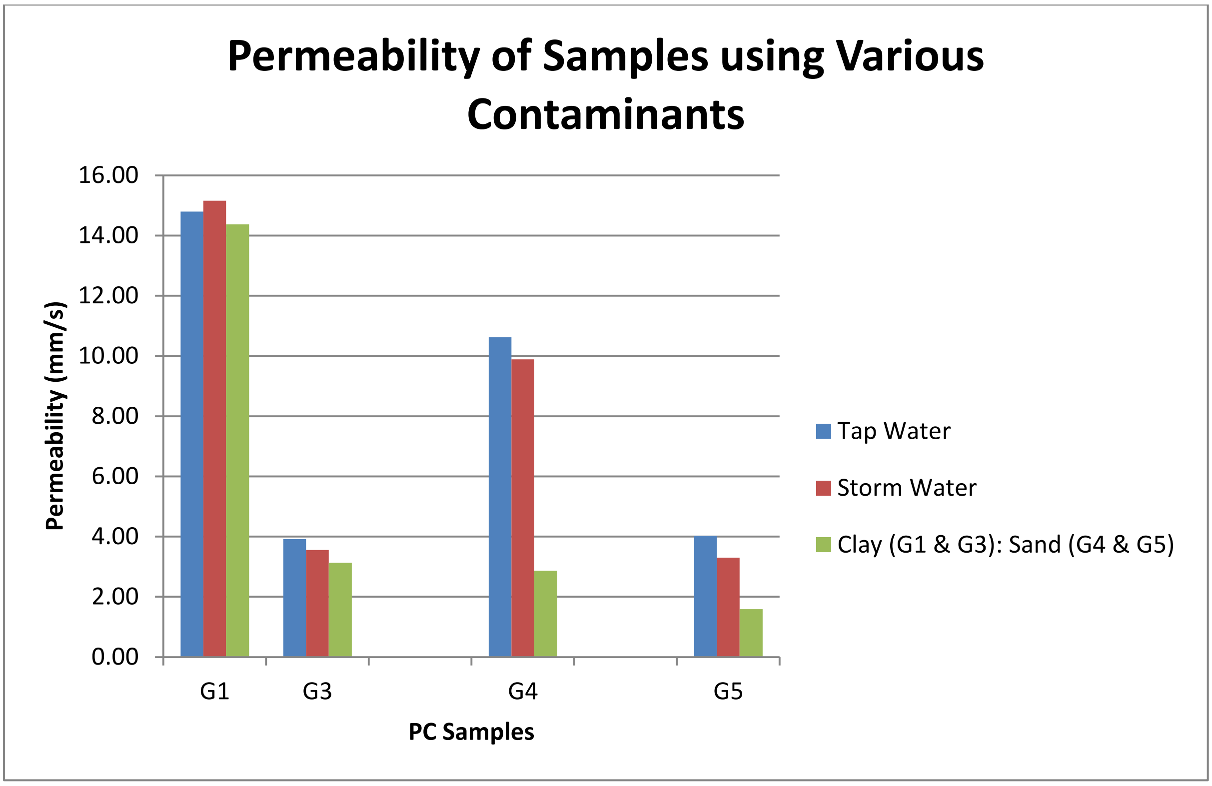


Figure 16: Graph of Results: Permeability of samples after exposure to contaminants

4.2.5 Effects of PC Maintenance on Clogging

The efficiency of maintenance was determined following sand testing. PC samples G4 and G5 were vacuumed using a conventional household vacuum cleaner then tested and also re- tested after being high pressure cleaned (Refer to Figure 14). However, the desired results were not obtained as permeability was further reduced following vacuuming, suggesting the suction caused a build-up of contaminants within a section of the PC cylinder.

Batch Name	Aggregate ratio %	Tap Water Time Seconds (vacuuming)	Tap Water Time Seconds (pressure blasting)	Initial Head (mm)	Finish Head (mm)	Permeability After Vacuuming (mm/s)	Permeability After Pressure Blasting (mm/s)
G4	25% - 9.5mm 75% - 4.75mm	583.6±203.8	87.27±94.26	200	50	0.4288	2.8673
G5	100% - 4.75mm	128.6±19.4	157.02±63.49	200	50	1.9458	1.5936

Table 8: Table of Results Maintenance; flow through the samples after vacuuming samples G4 & G5 and next column water blasting samples G4 & G5 only tested with sand

In contrast to previous trials, vacuuming appeared to worsen the effects of clogging on G4 and G5 samples. Obtaining flow rates as 583.6 and 128.6s respectively. The permeability calculated was significantly low as 0.42 and 1.94 mm/s respectively (Refer to Table 8). Following pressure blasting, the G4 sample improved slightly, with an average flow rate of 87.3s. Therefore, suggesting pressure blasting is beneficial. However, G5 on average appeared to worsen clogging again through the obtained flow rate of 157.02s. Variations between results were significant as the standard deviation calculated suggests a wider range of results.

Looking at the samples configuration G4 is higher in porosity at 26.3%, lighter in mass and has a lower density then G5. Vacuuming was very detrimental and just helped clog the sample even more until its permeability was greatly reduced (Refer to Figure 17). A more industrial purposely designed sweeper truck and vacuum may have given different results as sweeping the top first and then a higher suction may have helped unblock the sand from the voids. Pressure cleaning improved the results by pushing the sand through the specimen but neither method from the tests showed the desired outcomes from vacuuming or pressure blasting and maintenance showed that PC properties behave very differently due to porosity, density and mass.

Statistical analysis of sand samples revealed significant variation between repetitive results. This can suggest that more trials were needed and more maintenance was required between trials. The variation between results can suggest the accumulation of contaminants between results.

Figure 17: Vacuuming sample after clogging with sand

Figure 18: Pressure blasting sample after clogging with sand

Overall, sand appeared to have the most significant implications on permeable concrete. Clay and storm water had virtually no effect on PC, however, literature review suggests that over time, the accumulation of these contaminants would be detrimental for the function of PC. Fine particles would cause negligible permeability reduction. However, the problem would be the build-up of clay in the underlying bedding referred to as the aggregate base or sub-base and not in the PC, see below figures (Refer to Figure 19 & 20).

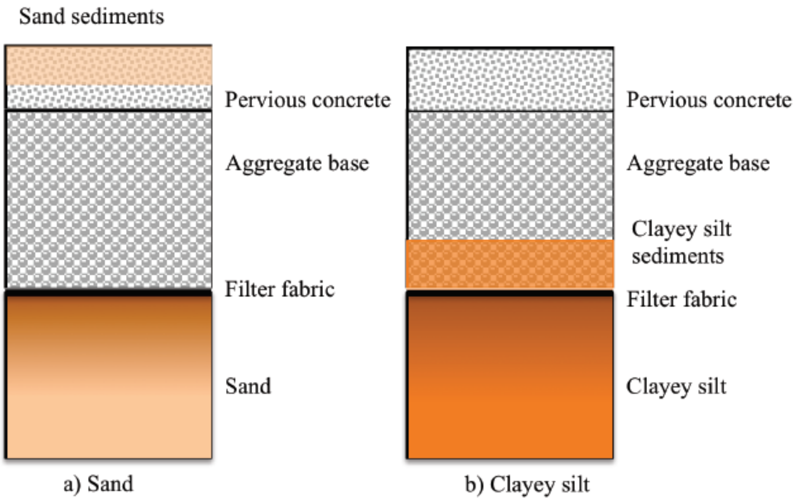


Figure 19: Cross section showing sand sitting on top of the PC and where clay builds up in the base, once passing through the PC. (Tong, 2011)

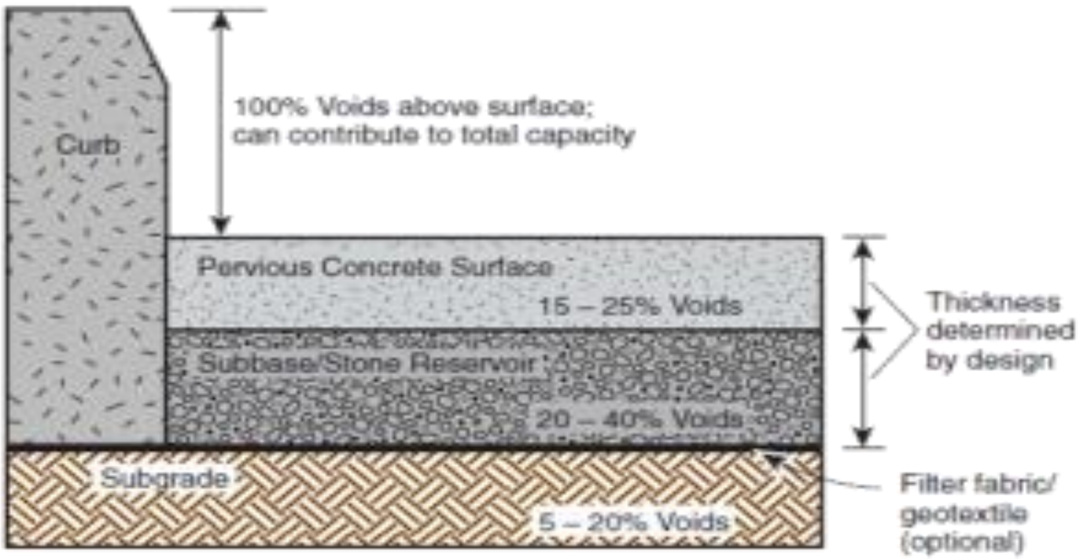


Figure 20: Cross section of typical PC layout used for pavement applications (ACPA, Last Modified 2015).

Description	G1	G3	G4	G5
Aggregate Ratio (%)	100% - 9.5mm	50% - 9.5mm 50% - 4.75mm	25% - 9.5mm 75% - 4.75mm	100% - 4.75mm
Dry Mass (g)	2944.9	3404.9	3182.1	3350.3
Buoyant Mass (g)	1862.1	2145.2	2023.9	2083.9
Porosity (%)	31.7	19.81	26.27	19.38
Dry Density (t/m^3)	1.87	2.17	2.03	2.13
Initial Head (mm)	200	200	200	200
Finish Head (mm)	50	50	50	50
Tap Water				
Initial results flow rate (s)	16.9	63.9	23.6	62.2
Permeability (mm/s)	14.8 ± 0.58	3.9 ± 1.07	10.6 ± 0.48	4 ± 1.06
Storm Water				
*Flow Rate (s)	16.5	70.5	25.3	75.7
*Permeability (mm/s)	15.2 ± 0.36	3.6 ± 4.84	9.9 ± 0.86	3.3 ± 2.93
Clay				
*Flow rate (s)	17.4	80	Not tested	Not tested
*Permeability (mm/s)	14.4 ± 0.21	3.1 ± 3.65	Not tested	Not tested
Sand				
*Flow rate (s)	Not tested	Not tested	97.8	126
*Permeability (mm/s)	Not tested	Not tested	2.6 ± 118.3	2 ± 24.68
Sand after vacuuming/pressure blasting				
*Flow rate (s) after vacuuming	Not tested	Not tested	583.6 ± 203.8	128.6 ± 19.4
*Flow rate (s) after pressure blasting	Not tested	Not tested	87.3 ± 94.26	157 ± 63.49
*Permeability after vacuuming (mm/s)	Not tested	Not tested	0.43	1.95
*Permeability after pressure blasting (mm/s)	Not tested	Not tested	2.9	1.6

Table 9: Summary of results table *Flow rate and permeability re-tested using tap water.

4.3 Discussion

For PC to mitigate stormwater runoff there is the risk of clogging, defined as a reduction in hydraulic conductivity that reduces infiltration into the pavement or exfiltration into the subgrade. Studies have shown that hydraulic conductivity is an appropriate tool to evaluate permeable concrete clogging, as a function of time (Sansalone, et al., 2012). Sansalone found that matter retained and the resulting decrease of total porosity in pavement was also due to the sub-base the underlying bedding not being able to stay clean and trapping matter.

However, this study pointed out that the clogged depth is limited to the first several centimetres of PC. Sansalone compared four types of cleaning methods: (Mallen, 2006) moistening followed by sweeping, (Tennis, et al., 2004) sweeping followed by vacuuming, (Haselbach & Freeman, 2006) vacuuming alone, and (Yukari, 2009) high pressure water jetting and vacuuming. Results indicate that vacuuming and high pressure water jetting could recover 100% of the initial infiltration rate.

However, in contrast other laboratories measured the effects of sand and clay in a saturated pervious concrete pavement system, and the subsequence effect of surface cleaning by pressure washing and/or vacuuming (Coughlin, J; Campbell, C; Mays, D;, 2012). It appeared; both sand and clay caused clogging that was irreversible by pressure washing. Experiments conducted at USQ, suggest that traditional cleaning methods, such as vacuuming, may not work effectively for sand. Furthermore, in contrast, pressure cleaning represented only slight beneficial maintenance. Vacuum cleaners with larger concealed pressure may be beneficial or used as a combination with pressure cleaning. However, the results obtained in this study were achieved by using a standard house hold vacuum cleaner. Therefore, not representing the effects of large scale industrial vacuum cleaners that would normally be used.

Sand appeared most detrimental to the PC specimens, as seen through significantly low permeability measurements. It is possible, that saturated sand had the ability to adhere to the inner surface of the cylindrical sample. Other findings suggest, the higher the initial permeability achieves higher residual permeability compared to other specimens with the same sand sedimentation load (Haselback, et al., 2006). Suggesting, the clogging effect and permeability reduction of PC can be influenced by the initial void ratio of pervious concrete as well as high permeability (Haselback, et al., 2006). However, this presents with an issue. By increasing permeability of concrete, this in turn would decrease the overall density and strength, therefore, limiting applications of use. Therefore, it is not recommended PC be used for development in the vicinity of sandy coastal areas.

When using laboratory procedures that mimic a series of clogging cycles, previous studies have suggested that under extreme and substantial deposition of clay will significantly reduce its service capability (Haselback, 2010). Visual inspections of PC samples suggest that clogging with sediments, such as clay, appears to occur near the surface of PC systems. Suggesting that over time, a build-up of fine deposition layer could cause permeability to decrease gradually (Haselback, 2010). Fortunately, Haselback (2010) revealed that permeability and flow rate can be returned to normal with conventional maintenance techniques. From this, experiment can be used to determine specific drying times to model weather variability and different clay properties. In contrast to USQ results, it appeared clay sediments are fairly negligible in the effects of clogging.

4.4 Limitations

This experimental protocol present with many limitations. Firstly, proper cleaning of the specimens between each test is required to limit contamination from previous trials. As seen throughout the five repeats, variability was significant between results. This is vital as the accumulation of contaminants can impact the properties of permeable concrete.

Furthermore, porosity and permeability of concrete is affected by moisture. Oven-dried condition has been reported to increase permeability. Incomplete drying of a conditioning specimen results in residual water being present in the pore system. Residual water can block passage and reduce flow through the specimen (Kearsley & Wainwright, 2001).

4.5 Future Direction

To get PC into the main stream of subdivision development would be an issue for local government. Until developers are conditioned on their development application that it is a requirement that they must have so much percentage of permeable pavement then PC will be intergrated into devlopments and new land buyers conditioned to use it on their driveways as well (unless being made to change nothing will change). All these issues/changes are not dramatic in anyway as it has become main stream for policy change in construction over the last 20 years, for instance it is now imperitive that building projects take into account evironmental concerns, WHS and native title and such policies are now part and parcel of the construction process. A considerable amount of budget goes into preliminary studies on environmental concerns, accommodating wildlife and native title. PC could be just another requirement in the environmental section.

CHAPTER 5

CONCLUSION

5.1 Conclusion

At first glance it seems like not an option that developers would be interested in using PC but higher upfront cost are off-set by possible elimination/reduction of stormwater drain network and the land required for retention basins. Retensions basins are popping up in many highly developed areas in Toowoomba which require a large portion of land to be devoted for this purpose. Permeable concrete is actually a retention basin in itself, with 150mm layer of PC plus the bedding layer of 200 to 300mm gives PC in theory capable of handling 300mm of rain in a very short duration before contributing to stormwater runoff.

PC will play a larger part in future urban design projects and provide more work for engineers with each site require engineering input. Clean groundwater will be an essential component in future years as urban regions grow and blocking off infiltration areas to aquifers is not a good option. It was less than 10 years ago that Toowoomba held a referendum to drink recylced water as dams and underground supplies are finite in there supply and require replenishing through the hydrological cycle.

Clogging is the only drawback to PC but with proper staging and planning in new subdivision projects that access of vehicles and muddy areas are controlled and PC applied later in the devlopment stage after houses are built and freshly turfed. PC is another important addition to a sustainable green subdivision. Even a special type of grid entrance that shakes the dirt of cars before they come into contact with PC. However the most important parameter in PC in a city like Toowoomba would be from the underlying bedding material clogging and not the PC.

As mentioned, permeable concrete has various environmental benefits, such as stormwater filtration, to reduce overflow reaching receiving waters and thereby reduce peak flow of rivers and streams. Therefore, to potentially address issues associated with flooding in high risk areas. Stormwater retention is also beneficial for aggriculture applications by feeding groundwater recharge. Futhermore, PC can be used to facilitate the biodegradation of oils from vehicles in urbanised areas. The diffusion of vapours and gases has been seen to limit concentration of pollution.

Although, there are various benefical applications for permeable concetre. The reason it’s not commonly used may lie within the overall density, life cycle and costs. As PC is 25% more expensive than conventional concrete, this cost may be too great to address the problems of clogging and high maintenance. As many investigators suggest that PC has a lifecycle between 3 and 20 years, dependent on conditions and sediment contamination.

Stormwater runoff increases with urbanisation of cities, time of concentration diminishes and there is a lot more runoff. Toowoomba experienced in 2011 a storm event that was enhanced by impervious development. From this event council spent a large portion of money on flood mitigation works repairing damage to infrastructure and improving retention basins. Flood retention basins were not a noticeble site in Toowoomba 30 years ago like they are today.

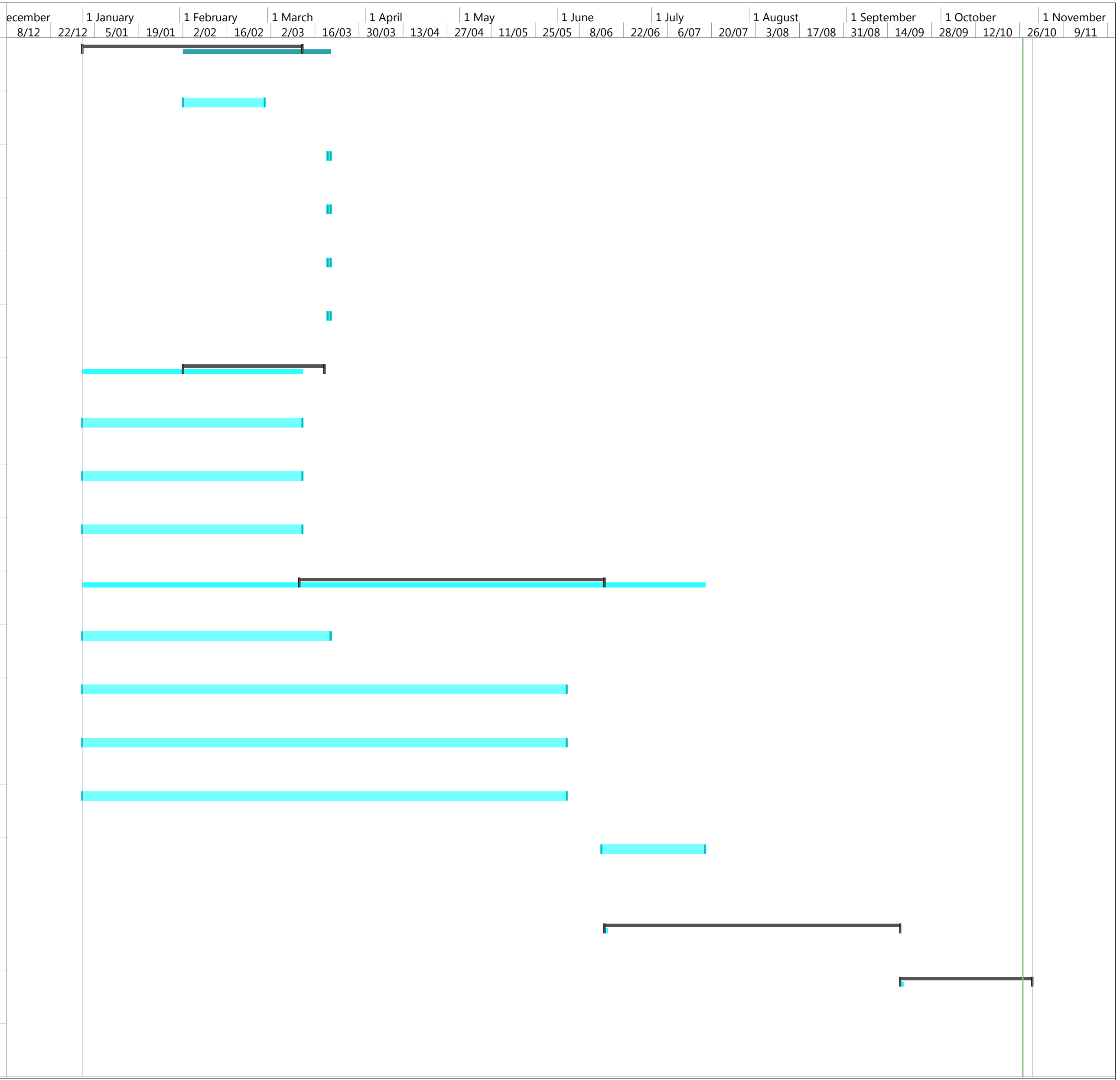
Toowoomba a town that was on the verge of drinking recycled water as dams and underground aquifers due to drought, were low in supply. So therefore making permeable areas un-permeable and blocking the recharge of underground aquifers you would think that a city like Toowoomba would know a lot on the topic.

CHAPTER 6

Time Frame

6.1 Gannt Chart Next Page

ID		Task Mode	Task Name	Duration	Start	Finish
1			**Choose Topic for Dissertation**	**50 days**	**Thu 1/01/15**	**Wed 11/03/15**
2			Finalise with supervisor by email and verbal	20 days	Mon 2/02/15	Fri 27/02/15
3			Arrange group meeting	1 day	Fri 20/03/15	Fri 20/03/15
4			Discuss scope of the project	1 day	Fri 20/03/15	Fri 20/03/15
5			Project deliverables	1 day	Fri 20/03/15	Fri 20/03/15
6			Meeting conclusion	1 day	Fri 20/03/15	Fri 20/03/15
7			**Project Specification**	**33 days**	**Mon 2/02/15**	**Wed 18/03/15**
8			Project aim	50 days	Thu 1/01/15	Wed 11/03/15
9			Project break up into key dot points	50 days	Thu 1/01/15	Wed 11/03/15
10			Submit to supervisor for approval	50 days	Thu 1/01/15	Wed 11/03/15
11			**Preliminary Report**	**69 days**	**Wed 11/03/15**	**Mon 15/06/15**
12			Set up template for project	57 days	Thu 1/01/15	Fri 20/03/15
13			Refer to reference book for methodology	110 days	Thu 1/01/15	Wed 3/06/15
14			Setup project requirements from specification	110 days	Thu 1/01/15	Wed 3/06/15
15			Finish preliminary report for assessment	110 days	Thu 1/01/15	Wed 3/06/15
16			If preliminary report is not on track remedy by the given time	25 days	Mon 15/06/15	Fri 17/07/15
17			**Partial Draft Dissertation**	**68 days**	**Tue 16/06/15**	**Thu 17/09/15**
19			**Dissertation Submission**	**30 days**	**Fri 18/09/15**	**Thu 29/10/15**
20			<New Task>			



Project: Project Timeline.mpp
Date: Tue 27/10/15

Task
Split
Milestone
Summary
Project Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress
Manual Progress

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Appendix A: Project Specification

ENG 4111/2 Research Project

Project Specification

For: **John Eaton**

Topic: Investigation into the effect of contaminants on permeable concrete effectiveness during its life cycle.

Supervisor: Yan Zhuge, Vasantha & Krishna

Sponsorship: Faculty of Health, Engineering & Sciences

Project Aim: Permeable concrete used for roads and carparks loses its ability to absorb surface runoff, due to clogging of the pores in the concrete. This project focuses on the causes of clogging with laboratory testing and analysis using storm water runoff. From the analysis this will help identify what type of maintenance is required to keep the surface pervious and what contaminants are detrimental in reducing the life cycle of permeable concrete.

Program: **Draft**

1. Research on how permeable concrete is made to be a porous material, from this make up test samples of permeable concrete if samples are not available.
2. Conduct research using as the bench mark concrete exposed only to clean water.
3. Analysis dirty water to see what contaminants are contained in rain water surface runoff that would cause clogging of the pores in the concrete.
4. Apply dirty water to the test specimens and divide the test specimens into three segments top, middle & bottom to investigate clogging locations.
5. From the research investigate the possibility of a preventative measure to increase overall effectiveness of permeable concrete.
6. From the research come up with a quality cost effective product to warrant industry use with minimal maintenance required.
7. Evaluate the test results and determine best permeability of the various mix designs. Compare the outcomes between concrete samples
8. Submit final dissertation on research, testing, results and conclusion.

Agreed:

Student Name: John Eaton Date: 23 March 2015

Supervisor Name: Yan Zhuge Date: 23 March 2015