MODIFICATION OF PERVIOUS CONCRETE USING STEEL SLAG AS AN AGGREGATE REPLACEMENT: APPLICATION AT PEKAN, PAHANG, MALAYSIA

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Thesis submitted in fulfillment of the requirements
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DEDICATION

Specially dedicated to my beloved parents,

To my beloved siblings,

A.prof. Dr.Wael, Eng. Ghassan and Dr. Bashar,

To my beloved supervisor,

Dr. Nadiatul Adilah Binti Ahmad Abdul Ghani,

To my beloved Co-supervisor,

A.prof Dr. Ramadhansyah Putra Jaya

To my friends and coursemates,

Abdullah Mohammed Yahya, Mohammed Khaled AL-Sayed and Ahmed Saleh Balfaqieh

For all their encouragement, patience, and unconditional support

Thank you so much, only ALLAH can repay all of your kindness

Also dedicated to,

those who have lost their beloved ones during flood session in Pekan , Pahang 2007 and everywhere in this universe.

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ABSTRAK

Banjir adalah bencana alam yang paling besar yang menjejaskan 4.9 juta orang dan menimbulkan kerosakan bernilai beberapa juta setiap tahun di Malaysia. Kira-kira 29,720 Km^2 atau 9% kawasan tanah negara terdedah kepada banjir. Bandar Pekan terletak di tebing Sungai Pahang, sering mengalami kerosakan ekonomi dan pemusnahan fizikal yang disebabkan oleh banjir. Kajian ini adalah cuba mengenalpasti konkrit yang boleh digunakan dengan berkesan di Jalan Kuantan - Pekan yang mempunyai kadar larian air yang tinggi. Matlamat penyelidikan ini adalah untuk mengelakkan atau sekurang-kurangnya meminimumkan larian langsung pada turapan dengan mengekalkan ciri semulajadinya. Kajian ini diproses dalam dua tahap; Tahap pertama adalah mendapatkan rekabentuk campuran yang terbaik daripada hasil awal yang terdiri daripada 48 sampel sampel konkrit padu dengan dimensi ketinggian 100mm berdasarkan ujian kekuatan mampatan 7 hari. Kemudian, nisbah agregat dan nisbah yang berlainan akan diuji untuk memilih kekuatan mampatan yang tinggi untuk digunakan pada peringkat ke-2. Di peringkat ke-2, terdapat 12 sampel konkrit silinder dengan dimensi diameter 200mm * 100mm. Sanga keluli turut digunakan di peringkat ke-2 selain agregat granit. Malah, sanga keluli terlibat dalam tiga peratusan berbeza iaitu 50% Slag Steel dan 50% Granit, 30% Slag Steel dan 70% Granit dan 70% Slag Steel dan 30% Granit. Kadar penyusupan juga akan diuji mengunakan ujian kebolehtelapan. Sebaliknya, aspek utama yang menimbulkan halangan pada laluan pejalan kaki iaitu intensiti hujan akan dikenalpasti. Oleh itu, Kala Kekerapan Pengagihan Intensiti IDF hujan di Stesen Rumah Pam Pahang Tua di tapak 3533102 akan dibangunkan dengan menggunakan MSMA edisi ke-2 untuk dibandingkan dengan kadar penyusupan hasil konkrit.

ABSTRACT

Floods are the most significant natural disasters which affect 4.9 million people and inflict damage worth of several million every year in Malaysia. About 29,720 Km^2 or 9% of the land area of the country is prone to flooding. Pekan town is located on the banks of the Pahang River, regularly suffers both economic damages and physical destructions caused by the floods. This study is a try to determine the suitable pervious concrete that can be used effectively at Jalan Kuantan – Pekan which experienced high direct runoff. The goal of this research is to prevent or at least minimizing hastily the direct runoff on the pavement and preserve their natural characteristics. Indeed, this study is progressed in two stages; 1st stage is obtaining the best mix design out of the preliminary result which consist of 48 samples of cubic concrete samples with dimension of 100mm based on 7 days compressive strength test. Then, different proportion of aggregate and water/cement ratio will be tested in order to select the highest compressive strength to be used in the 2nd stage. In the 2nd stage, there are 12 samples of cylindrical concrete with dimension of 200mm in height *100mm in diameter. Steel slag is used in the 2nd stage besides the granite aggregate. In fact, the steel slag is involved in terms of three different of percentage as 70% Granite and 30% Steel Slag, 50% Steel Slag and 50% Granite and 30% Granite and 70% Steel Slag. Also, Infiltration rate will be tested throughout permeability test. Oppositely, the main aspect that generating the obstacle on the pavement which is the rainfall intensity will be identified. Thus, Intensity Distribution Frequency IDF curve of rainfall of Rumah Pam Pahang Tua Station at site 3533102 will be developed by using MSMA 2nd edition to be compared with infiltration rate results of pervious concrete and to determine the suitability of the pervious concrete to be used.

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σ Sigma represent the compressive strength in Mpa , N/mm^2

P Pressure represent the maximum load on surface area, KN

A Area

i Average rainfall intensity $\left(\frac{\text{mm}}{\text{hr}}\right)$;

T Average Recurrence Interval ARI

d Storm duration (hours)

λ, κ , θ and η fitting constant dependent on the raingauge locationof MSMA (Figure 4.24)

LIST OF ABBREVIATION

WSUD	Water Sensitive Urban Design
DID	Department of Irrigation and Drainage
PCPC	Portland Cement Pervious Concrete
EPA	United States Environmental Protection Agency
BMP	Best Management Practices
NRMCA	National Ready-Mix Concrete Association of Malaysia
CIP	Convergence Indicator Plot
BS	British Standard
ASTM	American Standard Testing Machine
IDF	Intensity Duration Frequency
ARI	Average Recurrence Interval

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

1.1 Background

Historically, Malaysia has not experienced any of natural disasters in terms earthquake or volcanoes or typhoons. However, the most common natural disaster encountered in Malaysia is flood due to variety of reasons; for example, considering even man-made disasters (e.g fall down of a dam) as proper as different grades of precipitation (heavy rain, snow, and hurricane) would probably be an evoke to generate flood. Flood may not be a natural catastrophe that imposes as impressive damages as earthquakes or hurricanes do. However, it has a massive impact on the community that leads to lose property and life.

Pavements are beneficial and allow current human society to move easily. In contrast, impervious surfaces increase the rate and volume of storm water runoff and also prevent rainfall from either infiltrating into or evaporating from the natural soil (Haselbach, 2011). Thus, there is a need for a replacement to impervious pavement that will help in decreasing the stormwater on pavements. Porous concrete additionally recognized as pervious, permeable or no fines concrete is made up of coarse aggregate, components and cement with little to no fine aggregate. Porous concrete, as recommended through its many names and absence of fine aggregate particles, has excessive porosity and excessive permeability in contrast to preferred concrete. This allows water to infiltrate thru the concrete and the permeable sub-base layers and into the floor below. The infiltration ability depends on the plan and depth of the pervious concrete and the permeable sub base layers underneath it (Xu et al., 2018).

Pervious concrete is developing in reputable and increasing number of used products for the development of vehicle parks, foot paths. Indeed, it will drive approaches to take away direct runoff and to help stormwater drainage. However, pervious concrete has never been used in Malaysia, even though it has been used in Europe and china. For example, Beijing, China for the 2008 Summer Olympics and North Gay Avenue - The City of Portland, Oregon in USA.

Due to persevering with urbanization, the magnitude of city stormwater is growing. Urbanization creates additional impenetrable surfaces such as buildings, roads, foot paths and vehicle park all of this has created a wide catchment area for stormwater runoff. The excessive runoff will increase pressure on the existing stormwater technology and receiving waters which leads to flooding. Water sensitive urban design (WSUD) takes environmental, economic, visible science and social elements into account to ensure city water administration is touchy to natural hydrological and ecological processes (Lian, 2010). WSUD is growing in city structure as water resources turn out to be greater and really essential in today's society.

Pervious concrete is commonly used as an initially drainage machine to soak up direct runoff. This relieves the stress on storm water drains and can minimize the need for kerbing and expansive storm water structures which can assist to decrease stormwater infrastructure costs (Öz, 2018). By penetrating water through pervious concrete, it can help filling up nearby floor water sources and water surround root structures for timber and vegetation which would not have obtained any water from an impermeable floor. Minor use of porous concrete is to seize the quantity of city runoff and pollutants flowing into natural waters.

Pervious concrete also filters contamination out of the runoff earlier than it reaches downstream receiving waters. The first water that runs off all through a rainfall event consists of the highest load of pollution. The porous concrete lets this pollutant run off to go with the flow via it and infiltrate the floor below, filtering the water instead of it is flowing straight into a stormwater drain. Porous concrete is viewed to be a green and sustainable alternative material for constructing applications where there are high areas of impermeable surfaces which create high a quantity of stormwater runoff and pollutant runoff. The excessive void ratio and permeability in turn minimizing the strength and durability of the concrete (Chen, 2013).

Majority of the experimental carried out performed on porous concrete has targeted on increasing the strength of the concrete while retaining a suited permeability rate. This has been completed via altering the concrete combination designs to achieve the most appropriate combination with the aid of trailing a number of water-cement ratios, aggregate-cement ratios, aggregate type and dimension and compaction techniques. While these elements are very essential there is only minimal study on the durability of porous concrete. Durability is the potential to withstand time, abrasion, the surroundings or any technique of deterioration. The concrete wants to be capable to filter the required drift of water and be in a position to guide the respective loads of its application.

1.2 Problem Statement

Transportation are taking part in an essential position in any development of a community seeing that the rate motion made by either vehicle or humans represents how energetic and active the community is. To increase effectivity and productiveness of a community transportation in a high secured condition. Thus, an energetic society can be hastily developed and be developed faster.

However, the presence of high depth of direct runoff on highways or roads is performing as boundaries in opposition to vehicle. Moreover, many of the highways are dealing with this trouble in varies aspects such as high intensity of rainfall or direct runoff from high landscape. Indeed, this direct runoff is paralyzing the transportation of vehicle particularly throughout evacuation time. A problem like this should be highlighted in order to be solved smoothly.

Figure 1.1 Jalan Kuantan - Jalan Pekan flood

Figure 1.2 Liputan Banjir in Pekan, Pahang

1.3 Objectives

One essential purpose of this research is to be associated to the issue of interdisciplinary approaches. For example, to assess a monetary effect of a disaster, a researcher has to derive a way to convert the touchable harm from the catastrophe into some different measure displaying a sustainability and liveable environment on society. Owing to this, this study is a try to inspect the likely concrete that can be used effectively in the highways that generally subjected to high direct runoff. The goal of this research is to prevent or at least minimizing hastily the direct runoff on the pavement while preserve the adorable characteristics. Indeed, this study will focus on the potential of pervious to replace the ordinary concrete that has been used extensively in the highway.There are 3 objectives of this research project.

1- To investigate the mechanical properties of pervious concrete
2- To examine the hydrological properties of pervious concrete.
3- Identify rainfall intensity at Rumah Pam Pahang Tua Station at site 3533102.

1.4 Scope of Study

This study will be focused on investigation of the mechanical properties of pervious concrete throughout a compressive strength test besides the hydrological properties by obtaining the infiltration throughout permeability test. Indeed, this study is progressing in two stages; first stage is obtaining provide the preliminary there is 48 samples of cube concrete with dimension of 100mm height which is tested in 7 days for the compressive strength. Indeed, different proportion of aggregate and ratio will be tested in order to select the highest compressive strength to be used in the 2^{nd} stage. Second stage, there is 12 samples of cylindrical concrete with dimension of 200mm height and 100mm in diameter which is tested in 7 days for the compressive strength. However, in the 2^{nd} stage there is a wasted material will present in the mixture which is steel slag. In fact, the steel slag will be involved in terms of three different of percentage 30%,50% and 70% against granite aggregate. This experiment will provide the strength of the concrete due to vertical load.

The hydrological test is implemented by using the falling head test which will be done by my own constructed equipment to avoid any delay in the experimental progress. The samples are taken from the second stage samples of this study. This experiment is targeted provide the amount of the infiltration mm/hr.

The intensity of rainfall of Rumah Pam Pahang Tua Station at site 3533102 in order to identify the amount of precipitation. Moreover, the main aspect that generating the obstacle on the pavement which is the critical direct runoff depth will be measured. This calculation experiment is performed after getting the data from hydrological stations and JPS of Kuantan to provide the necessarily data. The data used are rainfall intensity to develop IDF curve to known the precipitation of rainfall.

Indeed, at the end of this study permeable and strength tests are conducted a number of samples. A comparison between the results of compressive strength (Mpa) and the infiltration rate obtained to make a decision on the material based on the hydrological properties. Moreover, the previous studies of the traditional concrete used and the asphalt concrete that has been widely used in the Malaysian and all over the world for the highway construction will be compared by using the mechanical and the hydrological results obtained from the laboratory test.

1.5 Study Area

Floods are amongst Earth’s frequent and most destructive natural hazards. Around 29,800 Km^2 or 9% of Malaysia land concerned in flood catastrophe and it is affecting nearly 4.82 million human beings which is round 22% of the whole population in this Malaysia (DID, 2007). Owing to this, this research will be targeted on the road Kuantan – Pekan which is the major street that connects Pekan to Kuantan. The research will be a way to overcome the serious trouble that face this street throughout and after a heavy rain or the flood session. From a news reports, Jalan Kuantan-Pekan used to be closed for all traffic users – as shown in Figure 1.1 - in these following dates. On December 2013, 2,100 people evacuated to Flood Relief Centres (FRCs) from 29 villages in that area (Borneo post online, 4th december 2013).

- On December 2014, Jalan Kuantan-Pekan nearby Sekolah Menengah Kebangsaan Ubai is closed to all vehicles following flood waters inundating about 500 metres of the road up to about half a metre of water (FMT news, 3rd January 2015).
- On January 2018, Jalan Kuantan – Pekan - the main road that connect kuantan city to Pekan- was closed to all traffic due to flash flood meanwhile more than 4,600 people in kuatan and pekan are seeking shelter at 24 relief centres.

CHAPTER 2

LITERATURE REVIEW

2.1 Flood

Malaysia is wealthy in that historically it has no longer faced natural catastrophe in the structure of earthquakes, volcanoes and typhoons. Flood is the most considerable catastrophe phenomena that reflect on the social and Economic of the population. Flood is Featured as any flow that surpasses the bank full restriction of a flow or channel and streams out on the floodplain, flatter than bank full release. Flood flooding is introduced on via the incidence of the heavy precipitation and the resultant massive attention of overflow, which surpasses waterway limit. Fundamentally, flooding cases have risen as an aftereffect of place use modifications to make equipped for development. Probably the most essential factors that determine the aspects of flood are precipitation event attributes, term of the precipitation occasion, and the velocity of the stream and flood depth (Choudhari, Panigrahi, & Paul, 2014).

Indeed, the most frequent natural catastrophe regularly encountered in Malaysia is flooding. Two main sorts of floods happen in Malaysia, specifically monsoon floods and flash floods. The Department of Irrigation and Drainage (DID) in Malaysia has estimated that about 29,000 km^2, or 9%, of the whole land region and more than 4.82 million mankind (i.e. 22% of the population) are affected via flooding annually. The harm induced through flooding is estimated to be about US$310 million (Weng, 2005)

2.2 Malaysia Weather

In Malaysia, the rainfall is based on two monsoon seasons which is southwest monsoon and northeast monsoon. Southwest monsoon seasons where originated from deserts of Australia typically commenced from May to August whereas the northeast monsoon seasons which originated from China and north Pacific start between November and February. Besides, there are two transition of duration of inter-monsoon length which commonly begin from March to April and from September to October which brings heavy rainfall. The route of the wind in this inter-monsoon season is variable and commonly more than 10 knots (Kang & Yusof, 2012) . Due to the seasonal rainfall in Malaysia, the chance for incidence of rainfall quantity is various throughout the entire year (Suhaila & Jemain, 2012).

2.3 Hydrological Characteristics

Hydrology is the science that research the water on earth and the atmosphere. The research encompasses its existence, and its distribution cycle, physical and chemical properties, reactions with the surroundings and hydrological studies. This is very wide in scope, in phrases of both quantitative and qualitative. In the career of engineering, hydrology quantitative is majority concerned due to the fact of including infrastructure associated projects.

When find out about hydrology, it is vital to be aware of the hydrological characteristics earlier than go further. Hydrological characteristics consist of rainfall distribution and runoff distribution and particular peak discharge. According to Ministry of Economic Affairs of Malaysia 2004, hydrological characteristics are rainfall, runoff and particular peak discharge.

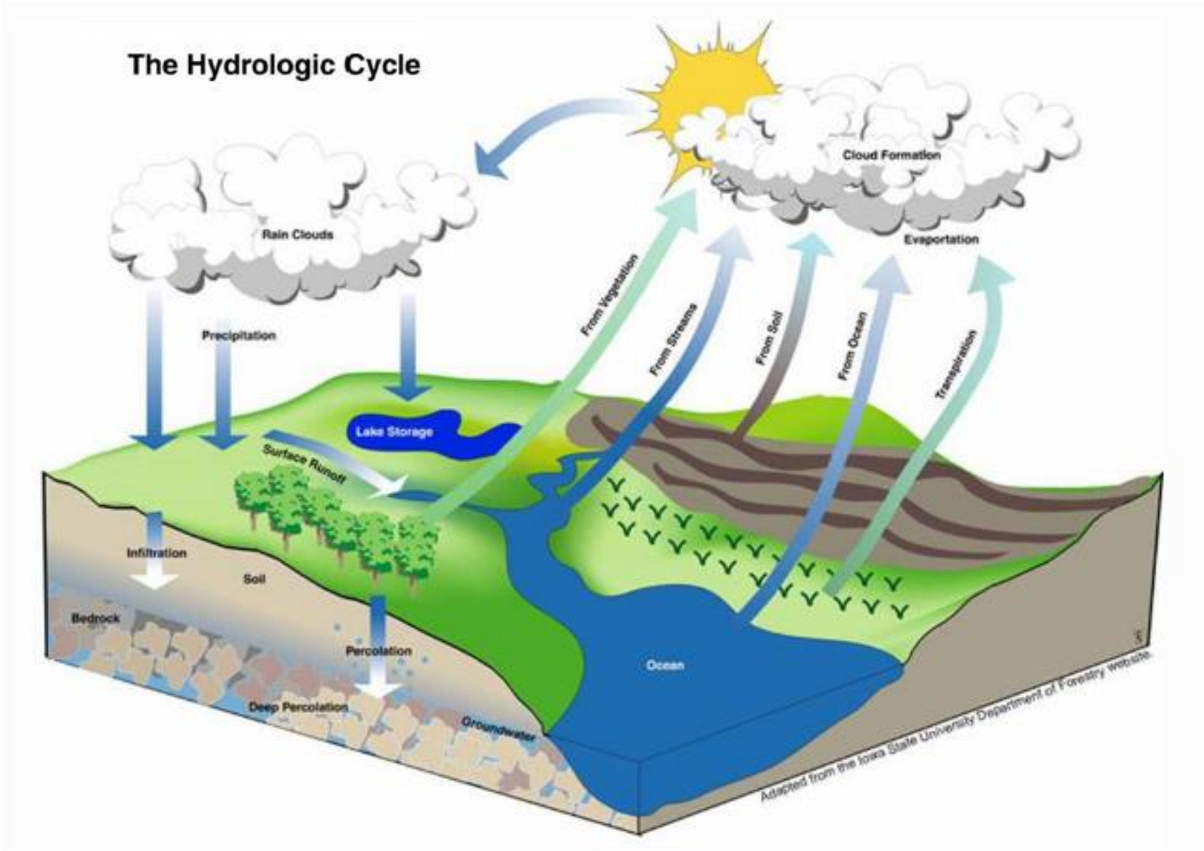


Figure 2. 1 The Hydrological Cycle in Malaysia
Source: (DID,2016)

2.3.1 Rainfall

Rain is shaped from droplets that have condensed from atmospheric water vapour. Eventually, the water droplets develop into larger droplets through colliding and coalescing with each other. Rain develops when gathering cloud droplets turn out to be too heavy and no longer being capable to remain suspended in the cloud and as a result, fall out of the cloud to the ground as rain. Rain can additionally commence as ice crystals that accumulate each other to shape large snowflakes. As the falling snow passes through the freezing stage into hotter air, the flakes dissolved and fall down into rain drops. Precipitation in the shape of water drops of sizes larger than 0.5 mm. The maximum size of the raindrop is about 6 mm (Kang & Yusof, 2012) On the basis of its intensity, rainfall is classified as shown in Table 2.1.

Table 2.1 Rainfall Intensity Analysis

Type	Intensity
Light Rain	< 2.5 mm/h
Moderate rain	2.5 mm/h to 7.5 mm/h
Heavy rain	>7.5 mm/h

Source : (McGraw.Hill,2012.)

The rainfall is an essential consideration in the plan of runoff conveyance and erosion management system. Indeed, the east coast districts, November, December and January are the months with high intensity of rainfall (Wan Zin, Jamaludin, Deni, & Jemain, 2010).

2.3.2 Runoff

Over the land surface, for the generation of runoff, the primary source of water is Rainfall. A part of rainfall that intercepted by the vegetation, buildings and other objects and prevented to reach them on grand surface is called as interception. Part of rainfall stored in the surface depressions which in due course of time gets infiltrate or evaporated is referred as depression storage (Initial detention). When these entire loses are satisfied then excess rainfall moves over land surface is known as overland flow and draining the same into channel or stream is termed as “Runoff”.

Runoff is that portion of the rainfall or irrigation water or any other flow. Applied which leaves a field either as surface or as subsurface flow. When rainfall intensity reaching the soil, surface is less than the infiltration capacity, all the water is absorbed in to the soil. As rain continues soil becomes saturated and infiltration capacity is reduced, shallow depression begins to fill with water, then the over flow starts.

Figure 2.2 Rainfall on Jalan Kuantan - Pekan

Precipitation is the major supply of all waters. When rain begins in falling on a non or much less pervious area, it is known in many approaches that the rainfall is intercepted via buildings, trees, grasses and other objects. Thus, avoiding it from approaching the ground, some section of infiltrates into the ground, some section of it finds its way to innumerable small and giant depression, if rain continues, the soil surface turns into blanketed with a membrane of water and is recognized as floor detention and stream starts towards a set up surface channel. Runoff might also be described as that section of precipitation as properly as of any other flow contribution which show up in surface streams (Wan Zin et al., 2010).

Runoff, every so often referred to as overland flow, is the technique whereby water goes from the ground floor to a waterway or water body. Normally, it applies to go with the flow over a surface. Indeed, Rain falling in a watershed in amounts exceeding the soil absorption limit or vegetation uptake will turns into runoff. Runoff is used to describe the precipitation that is not immediately infiltrated into the groundwater system. Runoff produced by occasions which are generally related to the saturation of the soil or the pavement regardless the material presence(Uju, 2010). Actually, runoff happens when the soil is already saturated or impermeable surface as shown in Figure 2.2. Thus, infiltration is halted or restricted to excess precipitation occurs. This may additionally occur when the intensity rate of the precipitation is higher than the infiltration ability.

2.3.3 Factor Affecting Runoff

There are a few components that have an effect on runoff process. It can be divided into two which are climatic aspect and physiographical factor. Firstly, for climatic factor, runoff is affected via type of precipitation. Precipitation takes place in the shape of rainfall leads to the runoff occasion directly after it reaches the runoff surface. But if the precipitation is in the shape of snow, there is no floor runoff. Second is rainfall intensity factor. If the rainfall depth increased more than infiltration rate of the soil, runoff definitely occurs straight away after a period of time of rainfall occasion. While, runoff begins later if the rainfall depth is low. Thirdly is rainfall period factor. If the period of precipitation takes place in longer time, it effects the quantity of runoff due to soil incapable infiltrate more water into it. Next is distribution of rainfall. Runoff from a watershed relies upon very is basically on the distribution of rainfall. It is additionally expressed as "distribution coefficient" means ratio of the maximum rainfall at a factor with the respect of to the mean rainfall of watershed(Ibrahim, 2014). Therefore, near outlet of watershed runoff will be more. If the direction of prevailing wind is same as drainage system, it results in peak low. A storm moving in the direction of stream slope produce a higher peak in shorter period of time than a storm moving in opposite direction. Another aspects are wind velocity, relative humidity and annual rainfall have an effect on the losses of water from watershed region (Awang, 2015).

Factor of runoff impact also comes from physiographic aspect such as watershed size. A massive watershed takes a longer time for draining the runoff to out stream comparing to the smaller watershed. Next are watershed shapes which are fun form and fern shape. Fun form tends to produce greater runoff very early while fern shape tends to produce much less runoff. Watershed slope additionally cooperate to the runoff effect which is it controls overland stream time and time of concentration of rainfall. For instance, sloppy watershed outcomes in higher runoff reasoned through higher runoff velocity. Other than that, land use which provides the notable impact on the runoff yield such as a region covered through jungles or have thick layer of mulch of leaves and grasses co-operate to the lower runoff due to high water absorption into soil. In addition, soil moisture also turns into one of 12 the factors (Xu et al., 2018). If the rainfall takes place after a period time of dry soil, the quantity of runoff is much less due to higher remark of water into the soil. Soil type, topography characteristics and drainage density.

2.4 Nanotechnology

The American physicist, Richards P. Feynman raised and put forward nanotechnology in his famous lecture at the California Institute of Technology in 1959. Nanotechnology is not a new science or technology, it is rather an augmentation of the sciences and technologies which already exist from many years and it is logical progression of the work that has been done to analyse the nature of our world at an even smaller scale (Das & Shah, 2017).

Nanotechnology has the potential to make construction faster, safer, cheaper and more varied, resulting in smart construction. Automation of nanotechnology construction can allow for the creation of structures from advanced homes to gigantic skyscrapers much more quickly and at much lower cost and higher efficiency. In the near future, Nanotechnology can be used to sense cracks in foundations of structures and can send Nano bots to repair them. It can also provide self-powered failure prediction and previsuing mechanisms for high capital structures (Das & Shah, 2017).

Nowadays, Nanotechnology has been applied in various fields especially in smart construction. Indeed, Nanotechnology has a great achievement in terms of quality, functionality and durability of on three main components of construction. One of them is related direct used on the highway construction.

2.5 Thirsty Concrete

Portland Cement Pervious Concrete (PCPC) is a unique construction fabric with several environmental, economic, and structural advantages. Although pervious concrete has been in use for more than 50 years in various applications, the current United States Environmental Protection Agency EPA guidelines in issued to support the federal clean water regulation are renewing the interest of many entities for revisiting applications of this special material and furthermore the use of PCPC has been emergent in the latest years. However, due to the fact of pervious concrete has its own unique homes that substantially differs from that of traditional concrete, the procedure of combination design, placing, and curing need to be well organized and appropriate performed to obtain the required results. As any other material, PCPC has it is own hazard which might also be bypassed if utilized in a suitable manner and appropriate application.

Indeed, pervious concrete pavement is a special and practical that is required to meet sophisticating environmental demands. By taking pictures of rainwater and permitting it to seep into the ground, pervious concrete is instrumental in recharging groundwater, decreasing stormwater runoff, and meeting U.S. Environmental Protection Agency (EPA) stormwater regulations. In fact, the use of pervious concrete is amongst the Best Management Practices (BMP) recommended via the EPA— and by other parties and geotechnical engineers throughout the country—for the administration of stormwater runoff on a regional and local basis (Huang, 2010). This pavement technology creates more environment friendly land use with the aid of removing the need for retention ponds, swales, and other stormwater administration devices. In doing so, pervious concrete has the capability to decrease general project expenses on a first-cost groundwork.

In pervious concrete, cautiously managed quantities of water and cementitious substances are used to create a paste that shapes a thick coating round mixture particle. A pervious concrete combination consists of little or no sand, developing a substantial void content. Using enough paste to coat and bind the aggregate particles together creates a machine of extraordinarily permeable, interconnected voids that drains quickly. Typically, between 15% and 25% voids are accomplished in the hardened concrete, and stream rates for water throughout pervious concrete generally are round 480 in./hr (0.34 cm/s, which is 200 L /m2/min), even though they can be higher. Both the low mortar percentage and high porosity also minimize strength in contrast to traditional concrete mixtures, however enough electricity for many purposes is easily achieved (Abdel & Mohamed, 2013). While pervious concrete can be used for a wide range of applications, its major use is in pavement. This study will care on the pavement purposes of the material, which additionally has been referred to as porous concrete, permeable concrete, no-fines concrete, gap-graded concrete, and enhanced-porosity concrete.

2.6 Techniques for Thirsty Concrete Design

When water strikes the Topmix Permeable concrete, it doesn't stream in all directions, slicking up the surface. It flows only in downward course and it disappears nearly instantly. Traditional concrete has to be permeable sufficient to let at least 300 millimetres of water per hour through the floor level. Topmix Permeable, in contrast, incorporates 36,000 millimetres of water an hour, or about 880 gallons every minute. This disappeared water provides up in the water beneath earth's surface. Tarmac, a UK building materials and solutions agency generated Topmix Permeable to divert rainwater throughout storms (Das & Shah, 2017).

2.7 Advantages of Portland Cement Pervious Concrete

2.7.1 Direct Runoff

The essential environmental benefits of PCPC consist of reducing down the quantity of storm water runoff released into storm sewers and maintaining natural ecosystems through preserving aquifer ranges due to immediately recharging groundwater (Geoffroy, Carlson, & Engelbrecht, 2006) . Since pervious concrete as defined through Iowa State University Report (2006) is lighter in colour than traditional asphalt surfaces and because it has an open-cell for it does not soak up and save warmness and then radiate it in returned into the surroundings consequently lowering the urban heat-island impact particularly in massive cities where most areas are paved with impermeable construction materials; the warmness island leads to the massive power consumption up to 12% and higher city temperatures ("A publication of the national ready mixed concrete association," 2006) .

2.7.2 Noise

One of the most urgent issues dealing with highway owners is perceived noise via travellers and abutters. Undesirable and potentially hazardous noise is handled as a kind of environmental contamination and can lead to a hazard to public health (Rutkevičius et al., 2013). While the noise produced from tire pavement interaction is simply one of quite a few noise sources for nearly all roads, it turns into the essential source of users noise for vehicular speeds over 55 km/h (35 mph) (Van Dam, 2016). In the United States, nearly 70% of the noise on high-speed gadgets dominated through vehicles is generated at the tire-pavement interface (as track site visitors volumes increase, truck noise becomes more predominant) (Wiegand, 2006) .

Improving the noise absorption, especially at low frequencies, is recognized very essential in the transport enterprise and the construction of buildings. Typical sound absorbing substances come in forms of a number of foams, fibres, boards, mats, perforated metals, aerogels, and others, as a high sound absorption coefficient is typically determined only in porous materials (Rutkevičius et al., 2013).

To mitigate the noise, at least for the motorway abutters, engineers generally specify noise barriers. However, noise obstacles are expensive, and it has been shown that they are ineffective as a noise-dampening answer (Concrete Pavement Technology Center, 2006).

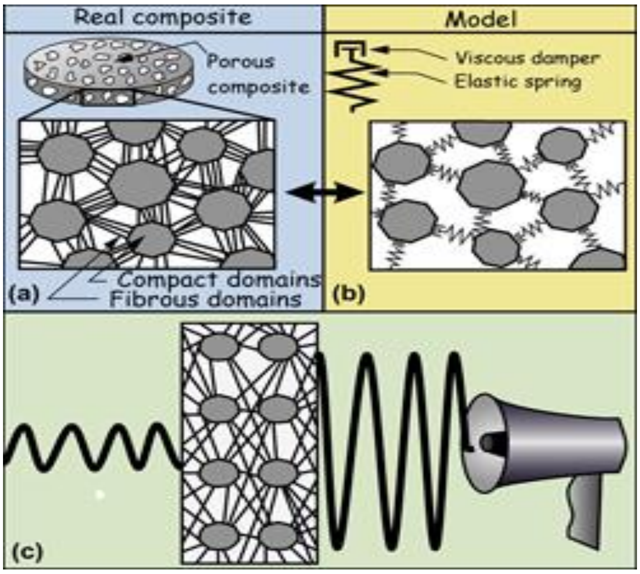


Figure 2.3 less noise pollution generated by PC
Source: (Concrete Pavement Technology Center, 2006).

2.7.3 Pollution

Another main environmental benefit of pervious concrete is its workable in improving the quality of storm water runoff as it naturally filters storm water and can limit pollutant loads getting into streams, ponds, and rivers hence can "treat" the air pollution prior to launch (Tennis, Leming, & Akers, 2004). As quoted by (Tong & Tong, 2011) , up to 75% of the total urban contaminant masses can be decreased with the aid of the usage of PCPC pavement. PCPC presents "first-flush pollution manages and storm water management" and has furthermore been identified as a Best Management Practice through the U.S. Environmental Protection Agency.

As stormwater flows throughout streets, sidewalks, lawns and golf courses, it can select up dangerous pollutants and push them into storm drains, rivers and streams. This pollution can include lawn and garden fertilizers, pet waste, sand and sediment, chemical contaminants and litter.

Actually, Stormwater runoff can reason a quantity of environmental troubles as chesapeakebay jornal has noted: -

- Fast-moving stormwater runoff can erode flow banks, destructing lots of miles of aquatic habitat.
- Stormwater runoff can push excess vitamins from fertilizers, pet waste and different sources into rivers and streams. Nutrients can gasoline the development of algae blooms that create low-oxygen lifeless zones that suffocate marine life.
- Stormwater runoff can push excess sediment into rivers and streams. Sediment can block daylight from attaining underwater grasses and suffocate shellfish.
- Stormwater runoff can push pesticides, leaking gas or motor oil and some chemical contaminants into rivers and streams. Chemical contaminants can damage the fitness of people and wildlife.

2.8 Portland Cement Pervious Concrete Constituents

The permeability of PCPC is created through the exclusion of fine combination from the traditional concrete mixture, where moderate quantities or no fine aggregate is covered in the mixture. Portland cement pervious concrete is furthermore comprised of coarse aggregate, cementitious materials, water, admixtures, and, in some cases, fibres. In this section, the above-mentioned constituents of pervious concrete are discussed.

2.8.1 Cementitious Materials

Similar to traditional concrete, pervious concrete employs Portland cements in accordance with ASTM C 150 and C 1157 and blended cements conforming to ASTM C 595 and C 1157). Additionally, supplementary cementitious substances (SCMs) such as fly ash, pozzolans (ASTM C 618), and ground-granulated blast furnace slag (ASTM C 989) might also be used to alter concrete performance, setting time, charge of strength development, porosity, permeability, etc. Typical levels of cementitious substances in pervious concrete combinations 270 to 415 kg/m^3 (450 to 700 lb/yd^3) according to NRMCA (2004).

2.8.2 Aggregates

The main factor of PCPC is the coarse aggregate. Typical coarse aggregate quantities in a pervious concrete combinations vary from 1400 to 1550 kg/m^3 (Lian & Zhuge, 2010). Generally, the strength of concrete does not depend on the aggregate strength as failure of concrete specimens in a compression test typically happens at the aggregate-paste interface where the bond strength is weaker than both the strength of the paste and the strength of the aggregate. Yet, in pervious concrete the cement paste is restricted and the aggregate depend on the contact surfaces between one any other for strength (Lian & Zhuge, 2010).

The coarse aggregates employed in pervious concrete combinations are typically either rounded aggregates (gravel) or angular aggregates (crushed stone) researches have proven that higher strengths are carried out through potential of utilizing gravel (Huang et al., 2010). According to Tennis et. al. (2004), frequently used gradations of coarse aggregate consist of gap-graded or narrowly-graded coarse aggregates in accordance with ASTM C 33 "Standard Specification for Concrete Aggregates" No. 67 (19.0 to 4.75 mm), No. 8 (9.5 to 2.36 mm), or No. 89 (9.5 to 1.18 mm) sieves and ASTM D 448 "Specification for Crushed Stone, Crushed Slag and Gravel for Water bound Base and Surface Courses of Pavements". Moreover, single-sized aggregate up to 20 mm is preferably to be used due to larger aggregates supply a rougher floor owing to this growing will increase skid resistance. For purposes like low-traffic pavements and parking lots, smaller sized aggregates are preferable as their appears are more appealing. In Figure 2.4, the smaller size of Granite Aggregate, the higher the compressive and flexural strengths however in this case electricity is traded off with permeability as permeability decreases with the boundary in aggregate size.

Table 2.2 Table of properties for crushed Granite Aggregate

Property	Type	Fresh crushed granite aggregate Maximum size of aggregate		
		10 mm	20 mm	40 mm
Physical properties Specific Gravity		2.8	2.8	2.8
Water absorption		0.3	0.3	0.3
Bulk density kg/m^3	Loose	1408	1462	1406
	Rodded	1561	1625	1590
Percentage	Loose	50	48	49
	Rodded	44	42	43
Mechanical properties Crushing value (%)		25	22	-
Impact value (%)		18	17	-
Abrasion value (%)		29	26	26

Source: (Abdel & Mohamed, 2013)

Figure 2.4 Granite Aggregate Size

2.8.3 Steel Slag

Steel Slag is produced as a by-product during the oxidation of steel pellets in an electric arc furnace. This by-product that mainly consists of calcium carbonate is broken down to smaller sizes to be used as aggregates in asphalt and concrete. They are particularly useful in areas where good-quality aggregate is scarce. Aggregate is the main component of Portland cement concrete (Ahmedzade & Sengoz, 2009). The coarse aggregates (with particle size more than 4.75 mm) that are obtained either from natural sources or by crushing large size rocks are bound with cement paste to form Portland cement concrete. The fine aggregates (with particle size less than 4.75 mm) are utilized to fill the gaps between the coarse aggregate particles.

The process of crushing large-size rocks and producing artificial stone through the use of Portland cement as a gluing material has facilitated the production of structural components of various shapes and sizes. Due to their inert nature, it is presumed that aggregates do not contribute to the durability of concrete. However, deterioration of concrete is noted when the aggregates are not chemically inert, for example reaction between certain minerals in the aggregates and the alkaline compounds in cement leads to map cracking of concrete (Maslehuddin, 2003). The durability of concrete is also influenced by the quality of aggregates in situations where the aggregates are weak and absorptive.

The use of industrial by-products of the steel industry such as blast furnace slag and steel slag has been established in a number of applications in the civil engineering sector. Steel production requires the removal of excess silicon and carbon from iron by oxidation. In steel production, the furnace is loaded with iron or scrap minerals, fluxing agents, usually limestone and dolomite, and coke as a fuel and reducing agent. Carbon and silicon are removed as carbon dioxide and the remaining oxidizing elements are combined with lime addition to form steel slag. Steel slag is a hard and dense material, resistant to abrasion and dark color. It contains significant quantities of free iron, which gives the material a high density and hardness, and finds large quantities as shown in Figure 2.5. These properties make steel slag a particularly suitable aggregate for road construction (Wang, 2010).

Figure 2.5 Enormous amount of steel slag at Lion Titco Sdn.Bhd

The application of slag in road construction is based on the angularity and high shear strength of the constituent particles, which makes them suitable for different layers of pavement. It must be said that the superior properties of friction resistance of steel slag and its resistance to permanent deformation (formation of grooves) often hide the potential of this material for cracking (Ahmedzade & Sengoz, 2009).

Table 2.3 Properties of steel slag

Properties	**Standard**	**Steel slag Aggregate coarse**
Abrasion loss (%) (Los Angeles)	ASTM DC-131	20
Frost action (%) (with Na_2SO_4)	ASTM C-88	8.56
Specific gravity (g/cm^3)	ASTM C-127	3.017
Specific gravity (g/cm^3)	ASTM C-128	
Specific gravity (g/cm^3)	ASTM D-854	

Source: (Ahmedzade & Sengoz, 2009)

2.8.4 Water

All organisms, including humans, require water for their survival. Therefore, ensuring adequate water supply is essential for human well-being. Although our planet is often called the Blue Plant, [there are common warnings about the increasing scarcity of water in the world. However, unlike oil, water circulates, forming closed hydrological cycles. The amount of water will not decrease in time scales shorter than the geological ones (Lim, 2006).

Water is the most vital constituent for all concrete. Water hydrates the cement to shape the bond between the aggregate which sequentially offers concrete its strength and additionally creates a potential substance. Because Portland cement pervious concrete is sensitive to modifications in water content, the specific quantity of water is necessary and as a consequence area fine-tuning is commonly critical (CIP 38).

According to NRMCA (2004) the typical w/c ratio for pervious concrete combinations is in the range of 0.27 to 0.34 whereas other literature has indicated that this vary goes up to 0.45 (CIP 38). Lower w/c ratios considerably reduce workability of PCPC and reasons insufficient consistency due to decreasing the bonds between the particles as can be viewed in Figure 2.6.

Moreover, a water amount that is too low will also obstruct appropriate curing of the concrete and lead to a precocious ravelling floor failure (CIP 38). On the other hand, higher w/c ratios can also lead to over-workable combination encouraging segregation and consecutively decrease permeability due to blockage of the voids.

Figure 2.6 PCPC water content (a) too little water, (b) proper amount of water, and (c) too much water (NRMCA, 2011)

2.8.5 Chemical Admixtures

As in traditional concrete, chemical admixtures might also be used in pervious concrete to achieve more desirable or distinctive properties. Retarders or hydration-stabilizing admixtures are commonly used to overcome troubles related with the fast setting time of Portland cement pervious concrete whereas a high range water reducer is usually used to help in the placement of the pervious concrete combination with the aid of performing like a lubricant between interlocking aggregates due to its low workability. Air-entraining admixtures have been used in countries where freeze-thaw is a challenge to reduce harm in pervious concrete. Viscosity editing admixtures are beneficial in avoiding drain-down of the paste (Savun, Phillips, & Phillips, 2013). Chemical admixtures used need to conform to ASTM C 494 whereas ASTM C 260 governs air-entraining admixtures.

2.9 Pervious Concrete Mixture Proportioning

Although Portland cement pervious concrete is comprised of the identical ingredients as traditional concrete, its characteristics have mandated the mixture proportioning to enhance as an “art form” instead of a constant practice. A successful combination for pervious concrete constantly meets the need of strength for loadings, permeability for ideal hydrological function, freeze-thaw resistance, and clogging resistance with minimal preservation value (Ibrahim et al., 2014). Water-to-cement ratio (w/c) and aggregate-cement ratio (a/c) are the key measures affecting the 24 mechanical and hydrological properties of Portland cement pervious concrete and upon which the mix design is based. Table 2.4 summarizes the impact of w/c and a/c ratios on specifications and overall performance of PCPC meanwhile Table 2.5 illustrates material proportions for ordinary PCPC.

Table 2.4 Effects of w/c and c/a ratio on PCPC Properties.

Ratio	**Proper Values**	**Low**	**High**
W/C C/A*	0.27 – 0.30 (by weight) 0.18 – 0.22 (by volume)	• Low workability • Low strength • Low flexural strength • Low elastic modulus • Low freeze -thaw-durability	• Low permeability • Low void ratios • Eliminate the anticipated hydraulic function • Eliminate the effective service life

* The Aggregate – Cement Ratio (A/C) Is Inverted for Illustration Purposes

Table 2.5 Typical materials proportions in pervious concrete

Materials	Proportions, kg/m^3
Cementitious materials	270 to 415 (450 to 700)
Aggregate	1190 to 1480 (2000 to 2500)
w/c (by mass)	0.27 to 0.34
a/c (by mass)	4 to 4.5:1
Fine: coarse aggregate ratio (by mass)	0 to 1:1

2.10 Different Previous Studies on PCPC

This section aims to provide a brief sight on various previous researches held attempting to investigate, improve, or optimize on one or more of Portland cement pervious concrete properties.

2.10.1 Mix Design

Bay area pervious concrete company has provided a practical tool to allow estimation of the porosity of the pervious concrete based on its aggregate bulk density during design of PCPC when using pea gravel.

2.10.2 Specifications and Test Methods

Mahboub et. al. (2009) examined the compaction and consolidation of pervious concrete where the research introduced cylindrical specimen guidance techniques that will produce laboratory specimens that are comparable to the area pervious concrete slab. The study concluded that the conventional approach of rodding cylinders does not precisely signify a roller-compacted pervious concrete slabs where pneumatically pressing the pervious concrete cylinders at 10 psi (0.07 MPa) correlated properly to specimens cored from roller-compacted pervious concrete.

2.10.3 Structural Design and Properties

Ghafoori et. al. (1995) investigated the physical and engineering characteristics of a range of PCPC combinations where combinations subjected to have an effect on compaction were studied under unconfined compression, indirect tension, and static modulus of elasticity. The effect of impact-compaction energies, consolidation techniques, mixture proportions, curing types, and testing prerequisites on physical and engineering properties were also studied. The research concluded that the strength of no-fines concrete is strongly associated to its combination percentage and compaction energy. A sealed compressive strength of 20.7 MPa (3,000 psi) can simply be executed with an aggregate cement ratio of 4.5:1 or less and a minimum compaction power of 165 J/m (4,303 ft-lb/cu ft).

Andrew et. al. (2010) tried to define the outcomes of aggregate size and gradation on the unit weight, strength, porosity, and permeability of pervious concrete mixtures. The water-cement ratio (w/c) and cement-aggregate ratio (c/a) were stored steady at 0.29 and 0.22, respectively, with a design unit weight of 2002 kg/m3 (125 lb./ft3). Fifteen one-of-a-kind mixture gradations were examined and classified in accordance to nominal maximum aggregate sizes of 9.5, 12.5, and 19.0 mm. The results indicated that as the porosity increased, strength lowered and permeability increased. As the gradation grew to become much less uniform or single-sized and more well-graded the strength also increased, whereas the porosity and permeability decreased.

2.11 Permeability

The permeability of Portland cement pervious concrete varies with the void content, aggregate size, and density of the combination permitting 81-730 Litres of water per minute to pass via each rectangular meter, Figure 1.1 and Figure 1.2 illustrates the texture/open-cell shape of Portland cement pervious concrete and a sample draining water respectively. Due to the excessive void content of pervious concrete, it is regarded to be a lightweight concrete with unit weight typically ranging from 1600 to 1900 kg/m3 in contrast to the unit weight of traditional concrete which is normally round 2300 kg/m^3 (Abdel & Mohamed, 2013).

The flow rate through pervious concrete depends on the materials and placing operations. Typical flow rates for water through pervious concrete are 3gal/ft^2/min (288 in./hr, 120 L /m^2/min, or 0.2 cm/s) to 8 gal/ft^2/min (770 in./hr, 320 L /m^2/min, or 0.54 cm/s), with rates up to 17 gal/ft^2/min (1650 in./hr, 700 L /m^2/min, 1.2 cm/s) and higher having been measured in the laboratory (Crouch, 2004).

CHAPTER 3

INTRODUCTION

3.1 Background

The experimental program herein is designed to study mechanical and hydrological properties of Portland cement pervious concrete, attempting to reach a point where balance is made between the mechanical properties and the permeability of the pervious concrete to achieve pervious concrete mixtures which are of good mechanical properties. Moreover, the Annual Average rainfall intensity at Rumah Pam Pahang Tua Station at site 3533102 is to be determined.

60 samples of pervious concrete (PC) were prepared to be involved in two stages. The preliminary result 16 mixtures, as the first stage, were prepared with coarse aggregate to withstand and to attain a high compressive strength. In the first stage, there are two categories divided under the basis of aggregate variety which are Single-Sized Aggregate and Multi-Sized Aggregate by preparing 5 mixtures and 11 mixtures respectively. This stage consist of 48 samples of PC were prepared by using Granite aggregate of the size of (4.5, 9.5, 12, 14, 20) mm. The cement content is to be constant with a 440 kg/m^3. In the second stage, 12 samples were prepared by using one of the wasted materials which is steel slag. In the second stage, there are three categories of PC which are prepared by replacing a percentage of granite aggregate by steel slag aggregate in three stages. Firstly, 70% of granite and 30% of steel slag. Secondly, 50% of granite and 50% of steel slag. Thirdly, 30% of granite and 70% of steel slag. A rang of water/cement (w/c) ratios (0.30 and 0.40) is used. Figure 7 illustrates the mixing of cement with granite aggregate.

Figure 3.1 Cement and Granite

3.2 Materials

Materials consumed within this experimental program (cement, granite aggregates and steel slag) were of local origin and have been acquired from the Malaysian market. These elements can be summarized as follows:

Figure 3. 2 Portland Cement

Figure 3. 3 Steel Slag (dark colour) and Granite Aggregate

3.2.1 Portland Cement Properties

Ordinary Portland Cement Type I was used in the preparation of the concrete mixtures for this study. The cement was procured from "Malaysian market", CEM I 42.5 R, manufactured according to the standards ASTM CI50. The physical, mechanical, and chemical properties of Portland cement used are illustrated in Table 3.1.

Table 3.1 Chemical Properties of Portland Cement

Chemical Properties	OPC
SiO_2	17.00
Al_2O_3	3.90
Fe_2O_3	3.20
CaO	70.00
MgO	1.5
Na_2O	0.02
K_2O	0.53
SO_3	3.60
LOI: %	0.25

Source :(Ramadhansyah, 2011)

3.2.2 Coarse Aggregate

Coarse Aggregates used in preparing the PC for the first stage of this research was collected from the Civil Engineering laboratory at UMP- Gambang campus. Granite Aggregate was chosen to be the coarse aggregate for this research due to the abundance and low cost in Malaysia. Additionally, granite aggregate is widely used in the asphalt concrete for highway construction. However, there is no much studies on the mechanical behaviour of the granite aggregate in the pervious concrete.

Secondly, For the second stage of this research the crushed steel slag aggregate collected from "Lion Titco Company, located at Kuala-Lumpur nearby Kula Lumpur International Airport KLIA, is used during the experimental work of this second stage of this study. Granite Aggregate used had a bulk specific gravity of 2.54. Sieve Analysis for the granite aggregates was conducted according to ASTM C 33; the results realized are tabulated in Table 3.2.

Nonetheless, the natural gradation of coarse aggregates is considered of minor value for this research as it is one of the aspects investigated. Three gradations were used to inspect the effect of the particle size distribution on the properties and durability of Pervious Portland Cement Concrete. In the 1st stage, starting from 1st to 5th mixture gradation schemes utilized were single-sized coarse aggregates retained on either 20 mm or 14mm sieve. There is also Multi-sized aggregate is used which consist of 4.75mm, 9.5 mm 12.5mm and 19mm. The overall scheme utilized coarse aggregate. Accordingly, upon the procurement of the aggregate materials from their sources, they have been sieved to separate the mixture according to particle sizes 12.5 mm and 9.5mm.

Table 3.2 Sieve Analysis for Coarse Aggregates

Sieve No./ Size	% Pass accumulative Tested Coarse Aggregate 1
¾ in 19 mm	100
½ in 12.5 mm	94
3/8 in 9.5mm	57
#4 4.75mm	11

3.3 Experimental Program

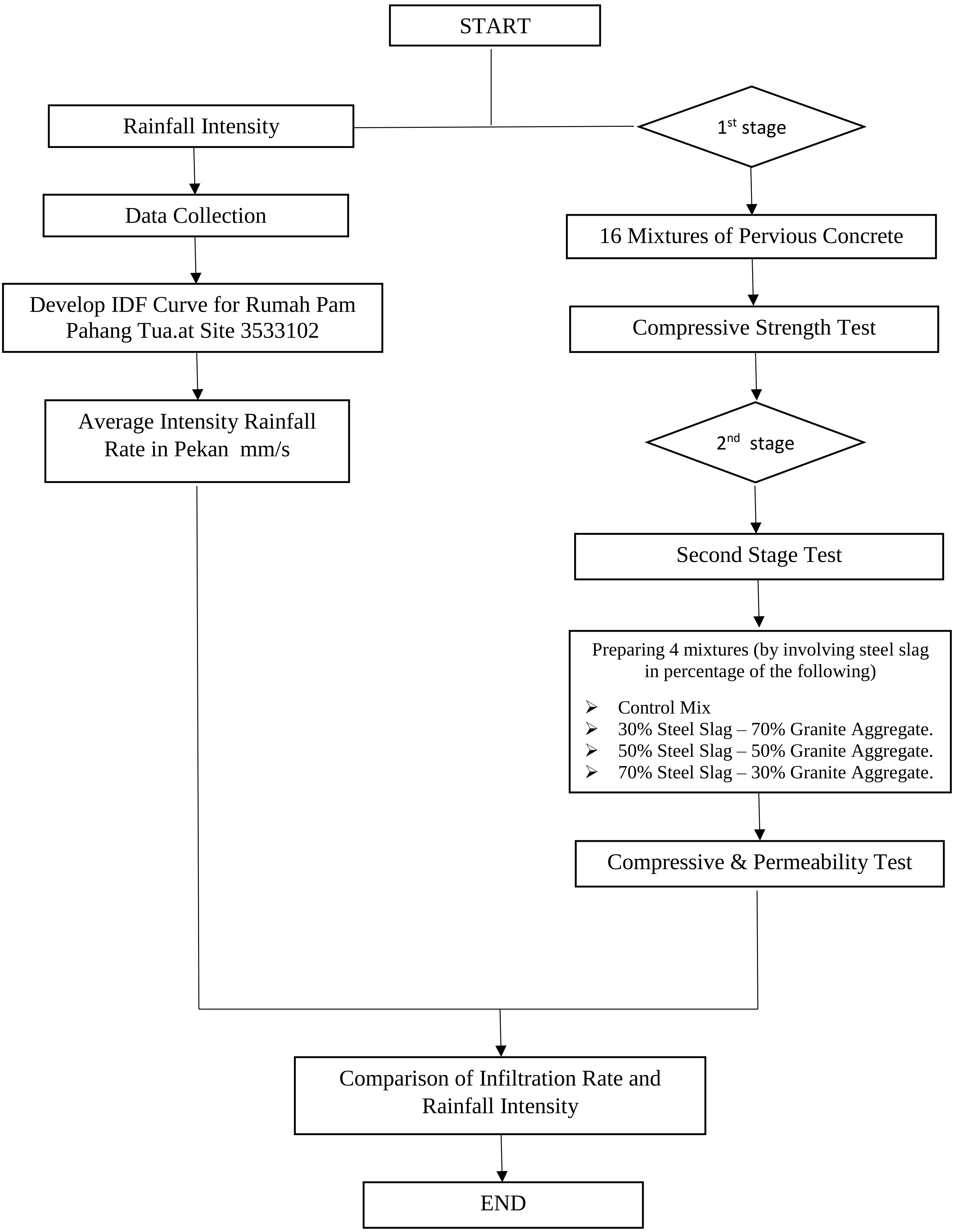
The experimental program can be grouped into five main categories as follows:

(1) Compressive strength test

(2) Permeability test

(3) Rainfall Analysis.

Indeed, this study is progressing in two stages; first stage is obtaining provide the preliminary there is 48 samples of cube concrete with dimension of 100mm height which is tested in 7 days for the compressive strength. Indeed, different proportion of aggregate and ratio will be tested in order to select the highest compressive strength to be used in the 2^{nd} stage. Second stage, there is 12 samples of cylindrical concrete with dimension of 200mm height and 100mm in diameter which is tested in 7 days for the compressive strength. However, in the 2^{nd} stage there is a wasted material will present in the mixture which is steel slag. In fact, the steel slag will be involved in terms of three different of percentage 30%,50% and 70% against granite aggregate. The hydrological test is implemented by using the falling head test which will be done to obtain the Infiltration Rate. Then, the intensity of rainfall of Rumah Pam Pahang Tua Station at site 3533102 in order to identify the amount of precipitation.



Flowchart 3.1 Experimental programme

3.4 Compressive Strength

The mechanical properties are the chief standards for the structural design of pavements. Due to the high void ratio of pervious concrete, the mechanical properties along with compressive is constantly inferior to that of conventional concrete. The approach and quantity of compaction and the porosity are the two primary aspects that influences the mechanical properties of PCPC.

Table 3.3 Sample Distribution.

Sample Type	Type of Mould	No. of sample	Dimension
Cube	Plastic	48	100*100
Cylindrical	Steel	16	100*200

3.4.1 First Stage (Preliminary Result)

In this stage, there is an importance to have a clear statistical result for pervious concrete in order to attain a reliable comparison between the pervious concrete with granite aggregate and steel slag. Furthermore, there is no abundance of experiments for pervious concrete compressive results especially when granite and steel slag are involved. Indeed, there are 16 mixtures for PC were prepared in total of 48 samples. There are two categorizes of the first stage which are Single-sized aggregate mixture and multi-sized aggregate mixture. Single-sized aggregate mixture having either the size of 14mm or 20 mm. Multi-sized aggregate mixture sized as a mingle sizes of any of the 5 sizes which are 4.75mm, 9.5mm, 12.5mm, 14mm and 19mm as shown in figure below

Figure 3.4 The 5 sizes of granite aggregate used

Cubic samples of pervious concrete were prepared based on quantity of size aggregate used while maintaining cement and water content constant. Compressive strength is the targeted test for the abovementioned samples. This samples were having different quantity of aggregate and sizes as well. This step has been implemented to investigate many aspects such as how would the mechanical behaviour being effect by different percentage.

However, the hydrological performance effected negatively with the increase of strength of pervious concrete. Pervious concrete mixtures can develop compressive strengths in the range of 3.5 MPa to 28 MPa (500 to 4000 psi), which is appropriate for a widespread variety of applications ("A publication of the national ready mixed concrete association," 2006). Pervious concretes with enhanced static strengths (at the range of 30 – 50 MPa) were produced by modifying the compositional properties as well as the method of compaction (El-maaty, 2016) also high strength pervious concrete (32 to 46 MPa) can be achieved through both SCM-modification, using silica fume (SF) and superplasticizer (SP) and polymer-modification(Jiang, Zhou, Huang, & Chen, 2016) .As with any concrete, the properties and combinations of specific materials, as well as placement techniques and environmental conditions, will dictate the actual in-place strength. Table 2. Illustrated the plan of the 1st stage of this research.

Table 3.4 Details of the Compressive Strength Mix Design.

Aggregate Type	Granite Aggregate
No. Mixtures	16
Type of samples	Cubic
Dimension	100*100*100
Experimental duration	7 days
Water / Cement ratio	35%
Aggregate / Cement ratio	4/1
Name of the Machine	Compressive strength
Lab	Concrete Lab
Purpose	To get pressure capacity in unit of Mpa

3.4.1.1 Single-Sized Mix Design

Table 3.5 Single- Sized Mix design for PC.

Materials		Weight of materials per mix	Density per m^3	Ratio	
				C / A	**W / C**
Mix 1	Cement	1.041	347.44	1:4.2	0.292
	Aggregate 20mm	4.361	1453.7		
	Water	0.305	101.37		
Mix 2	Cement	1.078	359.33	1:4.6	0.28
	Aggregate 14mm	4.982	1661		
	Water	0.306	102		
Mix 3	Cement	1.064	354.67	1:3.1	0.31
	Aggregate 14mm	3.252	1084		
	Water	0.339	113		
Mix 4	Cement	1.057	270	1:3.7	0.31
	Aggregate 20mm	4.012	1003		
	Water	0.336	84		
Mix 5	Cement	1.066	355	1:2.95	0.32
	Aggregate 20mm	3.139	1046		
	Water	0.324	115		

The samples which have been stated clearly in Table 3.5 is placed on the machine in vertical condition on the machine of the compressive strength. Then, start the machine to measure the amount of resistance that can be sustained by the samples. The data which been collected from the machine is in unit of N/mm.

3.4.1.2 Multi-Sized Mix Design

Table 3.6 Multi- Sized mix design for PC

Mix	Materials		Materials Weight per mix	Density per m^3	Ratio C / A	Ratio W/C
Mix 6	Cement		1.244	311	1:4	0.41
	Aggregate	20mm	2..480	1245		
		14mm	1.249			
		12.5mm	1.249			
	Water		0.378	126		
Mix 7	Cement		1.249	312.3	1:4	0.27
	Aggregate	20mm	1.249	1245		
		14mm	2.483			
		12.5mm	1.247			
	Water		0.334	84		
Mix 8	Cement		1.244	311	1:4	0.33
	Aggregate	20mm	0.622	1244		
		14mm	1.859			
		12.5mm	2.488			
	Water		0.408	102		
Mix 9	Cement		0.310	310	1:4	0.31
	Aggregate	14mm	2.476	1238		
		12.5mm	1.237			
		9.5mm	1.238			
	Water		0.388	97		

Mix	Materials		Materials Weight per mix	Density per m^3	Ratio	
					C: A	W/C
Mix 10	Cement		1.76	440	1:3.6	0.30
	Aggregate	14mm	1.407	1600		
		12.5mm	2.371			
		9.5mm	2.813			
	Water		0.558	133		
Mix 11	Cement		1.76	440	1:4	0.3
	Aggregate	14mm	3.52	1760		
		12.5mm	1.76			
		9.5mm	3.52			
	Water		0.334	132		
Mix 12	Cement		1.218	360	1:4.5	0.3
	Aggregate	14mm	0.729	1620		
		9.5mm	2.88			
		4.75mm	2.883			
	Water		0.410	108		
Mix 13	Cement		1.002	334	1:4	0.35
	Aggregate	14 mm	1.007	1338		
		4.75mm	1.237			
	Water		0.353	118		

	Materials		Weight per mix	Density per m^3	Ratio	
					C: A	W/C
Mix 14	Cement		1.003	334	1:4	0.31
	Aggregate	20 mm	1.001	1335		
		14 mm	3.004			
	Water		0.315	105		
Mix 15	Cement		1.004	334	1:4	0.31
	Aggregate	20mm	3.002	1333		
		14 mm	1.000			
	Water		0.314	105		
Mix 16	Cement		1.002	334	1:4	0.31
	Aggregate	20 mm	2.002	1333		
		14 mm	2.002			
	Water		0.315	105		

3.4.2 Second Stage

After the 1st stage, a new term of this study has begun which involving a wasted material. In this stage, Steel slag aggregate is involved in the mix design for the pervious concrete besides the granite aggregate there are 12 pervious concrete samples were prepared. These samples were designed by referring to the preliminary data that has been collected in the 1st stage. As the 10th mix has reached the maximum compressive strength among other mixtures, so it has been selected to be the mix design for the second stage. In this stage, the 12 samples are in prepared in cylindrical shape as shown in the Figure 3.6. Indeed, this stage all samples are designed to be tested in terms of mechanical and hydrological properties to investigate the behaviour of pervious concrete among compressive strength and permeability. As shown in the Figure 3.5, the preparation for mix design is isolated in terms of the kinds of aggregate and 3 sizes of aggregate in different bowls and small amount of water in two bottles.

Figure 3.5 Preparation of steel slag (second stage)

In this stage, there are 3 categories of experiment that have been conducted as stated in the Table 3.7

Table 3.7 Distribution of involving steel slag in PC in percentage

Mixture No.	Aggregate	
	Granite	Steel Slag
Mix 1	50 %	50%
Mix 2	70%	30%
Mix 3	30%	70%

Figure 3.6 Cylindrical Sample of PC

3.4.2.1 The 1st Mix Design.

Table 3.8 Cylindrical Samples of PC 1st Mix Design

Mould size	Materials	Weight of materials per mix (Kg)			Density per m^3
200*100	Cement	2.5			391
	Granite	14 mm	1.3	2.44	971
		12.5mm	2.2		
		10 mm	2.6		
	Steel slag	14 mm	1.3	2.44	971
		12.5mm	2.2		
		10 mm	2.6		
	Water	0.312		0.312	78

3.4.2.2 The 2nd Mix Design.

Table 3.9 Cylindrical Samples of PC the 2nd Mix Design

Mould size	Materials	Weight of materials per mix (Kg)			Density per m^3
200*100	Cement	2.5			391
	Granite	14 mm	1.8	3.42	1359
		12.5mm	3.1		
		10 mm	3.64		
	Steel slag	14 mm	0.78	1.46	583
		12.5mm	1.32		
		10 mm	1.56		
	Water	0.312		0.312	78

3.4.2.3 The 3RD Mix Design.

Table 3.10 Cylindrical Samples of PC 3rd Mix Design.

Mould size	Materials	Weight of materials per mix (Kg)			Density per m^3
200*100	Cement	2.5			391
	Granite	14 mm	1.8	3.42	1359
		12.5mm	3.1		
		10 mm	3.64		
	Steel slag	14 mm	0.78	1.46	583
		12.5mm	1.32		
		10 mm	1.56		
	Water	0.312			78

Figure 3.7 cylindrical samples of PC with steel slag.

It is known that any increase in the compressive strength will lead to decrease in the infiltration rate. Owing to this, the aim of this stage is to attaining a balance between permeability and compressive of the PC to fulfil an adequate specification.

3.5 Manual Method for vibration

Initially, preliminarily result was a space to examine a manual way of vibration which has been implemented for the 2nd mix design only. After preparing the mix design and place it inside the steel mould in three dosages. The upper opened part of the mould was covered by plastic bag and bind it by rubber band. Finally, keep overturning the mould in interval time on every side ass shown in Figures below.

Figure 3.8 Sample of Mix 2

Figure 3.9 Rubber Band and Plastic

Figure 3.10 Sample covered by plastic bag

Figure 3.11 Rubber band binds the plastic bag

Figure 3.12 Overturn it to each side in an interval time

Figure 3.13 Samples of Mix 2

3.6 Compressive Strength

In this study, the Compressive strength of the pervious concrete was determined on cube and cylinder specimens that were cured in water curing and tested for 7 days as per ASTM C39M-18 as shown in Figure 3.15. All the specimens for compressive strength test have been stored in the curing tank until the testing day. Three specimens have been tested for each curing age to obtain the average compressive strength. The compression test was performed by using 2000KN UTM machine. The compressive strength test has been conducted according to the following steps. Removed specimens from water tank and ensure the specimens was dried before beginning the test. Weight the entire specimens to determine the sample weight. Checked the compression testing machine to make sure the upper and lower bearing blocks are clean and dry. Gently wipe and clean the bearing faces to ensure it is clean and in dry condition. Place the sample on the lower bearing block. Setup the Universal Testing Machine (UTM) by select correct sample size and run the machine**.** Figure 18 show the testing set up below. The value of Compressive strength was calculated from the maximum loading acting on cross sectional area of cubes and cylinder by using this Equation 3.1.

Figure 3.14 Compressive Strength Test

Figure 3.15 Curing for pervious concrete

$$\text{Compressive Strength } \sigma = \frac{P}{A} \qquad \text{Equation 3.1}$$

As the cylindrical samples of pervious concrete has no smooth top and bottom. Thus, to avoid any inaccuracy result in the compressive strength test which needs the samples to be placed on as in Figure 3.14, the samples have been smoothened by using the cutter machine to have a smooth surface in both sides as shown in the Figure 3.16, 3.17 and 3.18.

Figure 3.16 Take-off piece of the cylindrical sample

Figure 3.17 Cutter machine to smoothen the surface of PC

Figure 3.18 Wasted parts of PC

3.7 Permeability Test

One of the important hydrological properties for the pervious concrete is the infiltration rate which is the speed of water passing through the porous concrete. The interconnected void structure of PCPC allows the motion of water into the hardened concrete. The relationship between strength and porosity is inversely proportional where enormously porous combinations commonly yields decrease strength and vice versa. According to (Tennis et al., 2004), PCPC with void ratios between 15% and 25% produce strength values greater than 13.8 MPa (2000 psi) with a permeability of about 200 L/m²/min (480 in./hr.). Permeability values up to 600 L/m²/min (1440 in./hr.) were reported for PCPC mixtures with a void ratio exceeding 20% (Geoffroy et al., 2006).

In terms of the permeability test, the falling head test based on the standard BS 1377-5:1990 and ASTM D2435 – 04. The falling head equipment test will be construct in the University Malaysia Pahang laboratory for the pervious concrete. As shown in the Figure 3.22.

Figure 3.19 Permeability test (Falling Head Test)

The cylindrical sample is placed inside the pipe to be tested in terms of permeability. Physically, the falling head test will be pipes U- shape that have two exits with a stopcock in the middle as shown in the Figure 3.19 ,3.20 and 3.21. The sample will be placed on the left exit. After placing the sample, the silicon will rubbed surround the sample to avoid any leakage and then the other pipe will put on top of it as shown in Figure 3.22 and 3.23.

Figure 3.20 Sample is placed and were rubbed by silicon

After that, the tube will be interface from outside to double confirm that there is no leakage to outside medium as shown in the Figure 3.22. Then, the water will be poured into it till the water comes from the second exit. Then the stopcock will be closed, so the water will be accumulating on the sample and reach a known point above the sample. On that time, the stopcock will be opened and time will be measured from that time until all the water on sample penetrate into the sample water and moves out from the second exist. Noted that, there is no any water leakage during or after the process of the mobility of the water from the first pipe where the sample is placed to the second pipe where act as an exist for the water. The unit that will be taken from the falling head is mm per sec. This instrument has been constructed exclusive for this research and all tools needed were bought from Malaysian market equipment. Dimensions of the pipes were selected to fit the pervious concrete cylindrical sample.

Figure 3.21 Falling Head test used for infiltration rate investigation

Figure 3.22 Outside view for where the PC is placed

Figure 3.23 Inside view for PC

3.8 Data Analyse

The data that obtained will be analysed with several method and calculation. The rainfall pattern Intensity Duration Frequency (IDF) curve will be developed.

3.9 New Intensity Duration Frequency (IDF) Curve

Intensity Duration Frequency (IDF) curve is graphical representation gives the expected rainfall intensity of a given duration. Rainfall Intensity (mm/hr), Rainfall Duration (how many hours it rained at that intensity) and Rainfall Frequency (how often that rain storm repeats itself) are the parameters that make up the axes of the graph of IDF curve. An IDF curve is created with long term rainfall records collected at a rainfall monitoring station. And the more data have, the more accurate IDF curve will be. All calculation guideline by MSMA 2nd Edition and use Average Recurrence Interval (ARI) of 5ARI, 10ARI, 20ARI, 50ARI, and 100ARI.

3.10 Result of Analysis

From the result of calculation to get the intensity value, these results will be represented in form of graph. After that, Rumah Pam Pahang Tua station at site 3533102 will be selected for comparison in develop of IDF curve guideline by MSMA2. This study selects Rumah Pam Pahang Tua Station since it is located nearby Pahang river in Pekan which has experienced flood event during the past years. Furthermore, Rumah Pam Pahang Tua station was selected because this station is considered as critical and surrounded by residential area. The comparison will be discussed on the maximum intensity value for selected intervals and the infiltration rate of the pervious concrete cylindrical samples.

CHAPTER 4

RESULT & ANALYSIS

4.1 Introduction

In this chapter, the results of the laboratory work which have been carried out at Civil Engineering laboratory, UMP are discussed. Relationships between the compressive strength, permeability are presented. In addition, a statistical analysis of the rainfall intensity parameters is provided. The conducted experimental work includes two major sections that compromise hardened concrete testing and permeability test. The results of compressive strength and the permeability of each sample of the pervious pavement section are tabulated. The samples have been prepared based on the standard of BS:1881 PART116:1983 & ASTM C39-03.

4.2 Compressive Strength.

In order to justify the strength of pervious concrete samples, this destructive test has been carried out on 64 samples of pervious concrete which categorised as 16 cylindrical samples and 48 cube samples.

4.2.1 Preliminary Result

There is no specific study has been carried out on the behaviour of various granite aggregate size on the pervious concrete the preliminary results were collected by using plastic cubic mould size of 100*100*100. Furthermore, the ratio between the cement **(C)**, Aggregate **(A)** size (20 mm, 14mm, 12.5 mm, 9.75mm, 4.75mm) and water **(W)** were the factors that played an important role in this preliminary study. The average cube compressive strengths result at the age of 7 days for all of the concrete mixtures by using either single-sized of Aggregate (20mm, 14mm) with various sizes are tabulated and mentioned in table 2.2. Noted that the samples above have been prepared with no existence of the steel slag only granite aggregate in single- sized and multi-sized aggregate.

4.2.1.1 Single-Sized Aggregate

4.2.1.1.1 20 mm Granite Aggregate

Table 4.1 Compressive strength results for PC of monolingual 20mm aggregate

	Materials	Weight of materials per mix	Density per m^3	Ratio		Average weight of sample	Average 7 days strength Mpa
				C : A	W/C		
Mix 1	Cement	1.041	347.44	1:3.2	0.292	1.908	6.701
	Aggregate 20mm	4.361	1437.7				
	Water	0.305	101.37				
Mix 2	Cement	1.057	270	1:3.7	0.31	1.304	0.602
	Aggregate 20mm	4.012	1003				
	Water	0.336	84				
Mix 3	Cement	1.066	355	1:2.95	0.32	1.290	1.275
	Aggregate 20mm	3.139	1046				
	Water	0.324	115				

The samples above have been prepared by using monolingual aggregate size which is 20 mm granite aggregate that is available at highway and traffic laboratory - UMP. The shape of the samples where such like zigzag and sinuous as seen in the Figures 4.1 and 4.2 mixtures where prepared with some differences in the mix design which reflected on the compressive result. These changes are the cement / Aggregate ratio and water/ cement ratio which is directly affecting the weight of the sample. The results were illustrated in Figure 4.3.

Figure 4.1 Zigzag Pervious Concrete Monolingual Aggregate Sample

Figure 4.2 pervious concrete with Improper Vibration

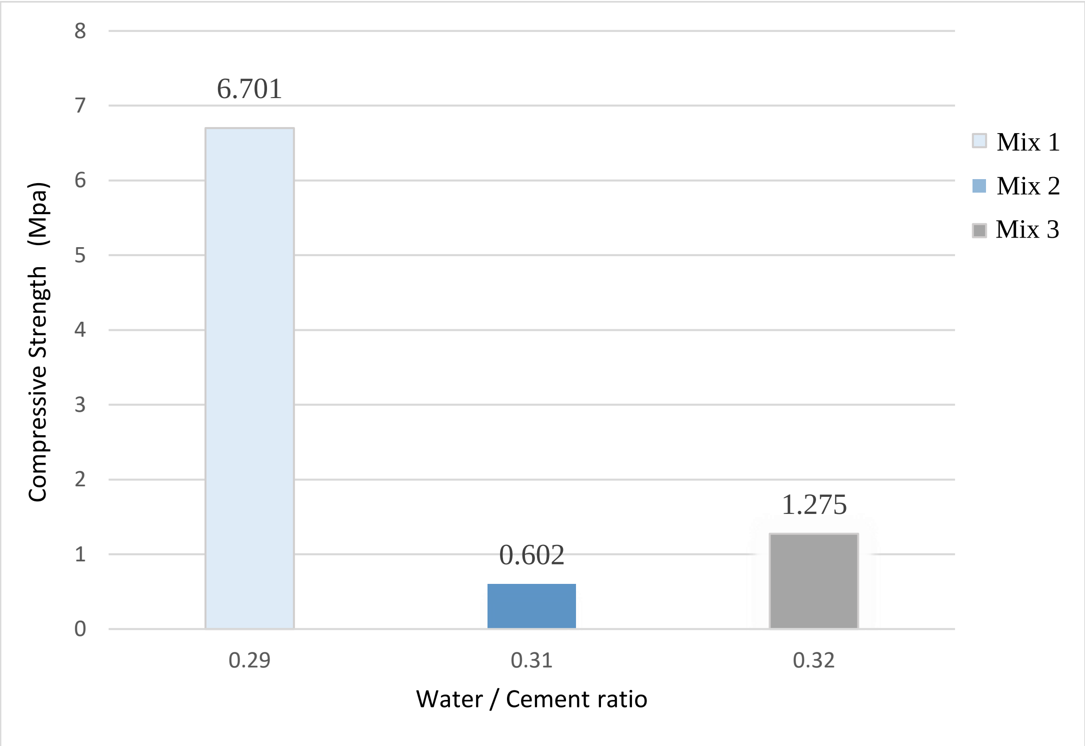


Figure 4.3 Compressive strength for monolingual aggregate sample of 20mm

Obviously, mix 1 has reached the maximum strength among others since it was clearly observed that higher amount of cement has penetrate the sample and gathered at the bottom of the pervious concrete which leads to high weight. Thus, it is probably playing an important role in the compressive strength of the pervious concrete. It seems that Mix 2 has the lowest value of the compressive strength compared to other two mixes, that might be because of the manual procedure that has been implemented as shown in the Figures 3. 9-13. Indeed, this procedure has been carried out in order to obtain higher void ratio between aggregate particles which obviously negatively effect on the infiltration rate later on. This procedure has replaced the vibration process to observe the difference between the two approaches.

4.2.1.1.2 14 mm Granite Aggregate

Table 4.2 Compressive strength results for PC of monolingual Aggregate 14mm

	Materials	Materials weight per mix	Density per m^3	Ratio C/A	Ratio W/C	Average sample weight	Av. 7 days strength Mpa
Mix 4	Cement	1.078	359.33	1:4.6	0.28	1.562	3
	Aggregate 14mm	4.982	1661				
	Water	0.306	102				
Mix 5	Cement	1.064	354.67	1:3.1	0.31	1.320	1.4
	Aggregate 14mm	3.252	1084				
	Water	0.339	113				

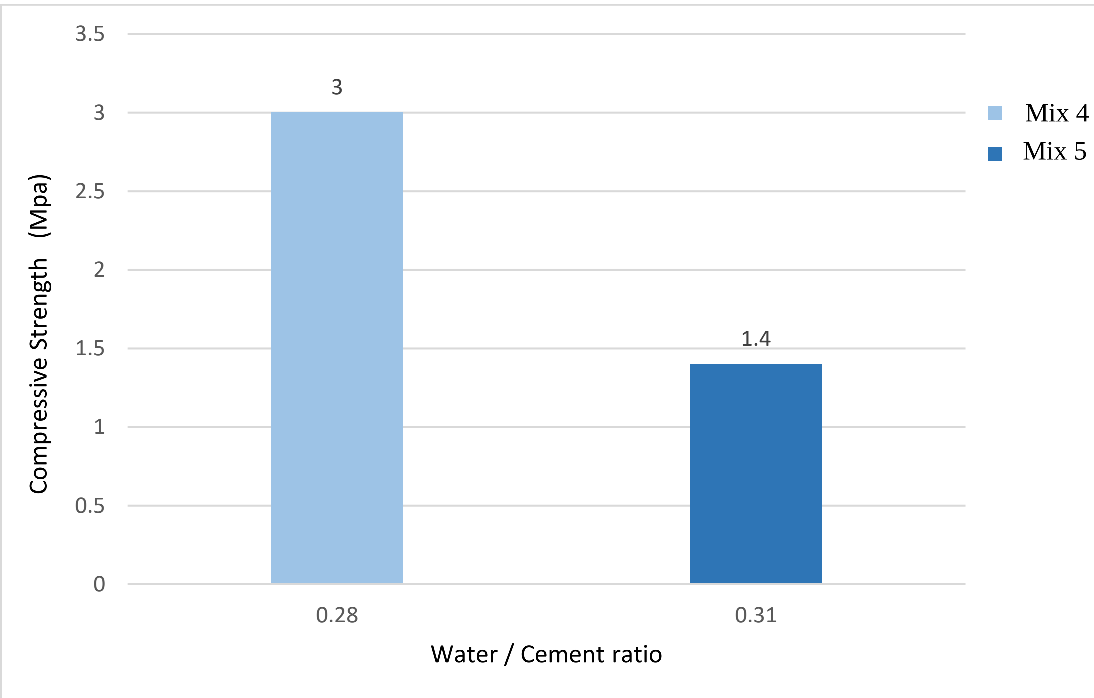


Figure 4.4 Compressive Strength for Monolingual 14mm

Based on the above results, mix 4 and 5 which were prepared by monolingual aggregate size has recorded different values as their mix design is. Indeed, the ratio of the cement / aggregate in the mix 4 is much higher compared to mix 5 which reflects on higher the average weight of mix 4 samples. Besides, it is clearly observed the lower amount of water (with respect to cement) used has empower the strength of the pervious concrete samples. These sample where having a shape that still look like zigzag and sinuous where the texture was to gruff.

4.2.1.2 Multi-Sized Aggregate

Table 4.3 Compressive Strength of the multi-sized Aggregate

	Materials		Materials weight per mix	Density per m^3	Ratio		Av. Weight	Av. 7 days strength Mpa
					C:A	**W/C**		
Mix 6	Cement		1.244	311	1:4	0.41	1.235	3.7
	Aggregate	20mm	2..480	1245				
		14mm	1.249					
		12.5mm	1.249					
	Water		0.378	126				
Mix 7	Cement		1.249	312.3	1:4	0.27	1.331	3.2
	Aggregate	20mm	1.249	1245				
		14mm	2.483					
		12.5mm	1.247					
	Water		0.334	84				
Mix 8	Cement		1.244	311	1:4	0.33	1.646	3.257
	Aggregate	20mm	0.622	1244				
		14mm	1.859					
		12.5mm	2.488					
	Water		0.408	102				

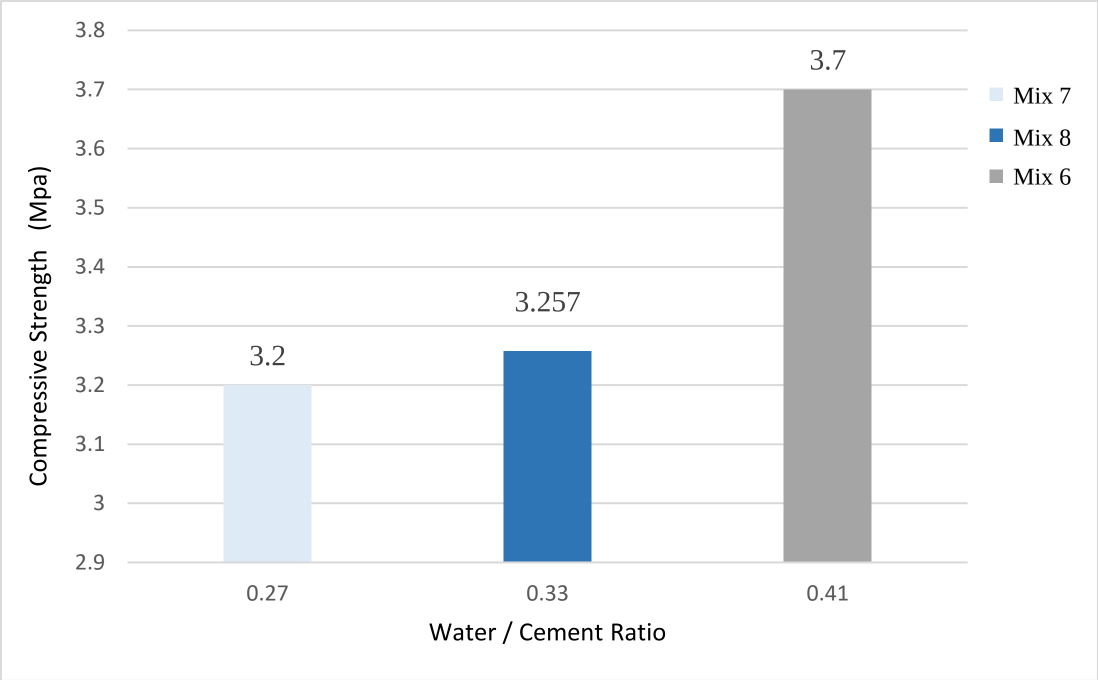


Figure 4.5 Compressive Strength for Multi-size Aggregate

These 3 mixtures based on trilingual aggregate size which are 20mm, 14mm and 12.5mm. Indeed, the procedure in preparing the pervious concrete cubic samples was same to all the mixtures in the stage and later on in this study as well. Moreover, the ratio C/A is similar in for all above mentioned mixtures; Nevertheless, the results of the compressive strength was not perfectly equal due to different amount and sizes of aggregate used.

Indeed, the trilingual sizes of granite aggregate were not utilized by same amount in each mix which has been done intentionally. The purpose of using different amount in each mix design is to investigate their effect on the compressive strength which is so conspicuously stated in the Table 4.3. Additionally, one more factor was not the identical in the mix design of these mixtures which is the ratio of W/C. Overall, the compressive strength is so close between each other since it differs by less than 0.5 Mpa.

Figure 4.6 Mix 8 sample

Table 4.4 Compressive Strength Result for triple sized Aggregate (14, 12.5, 9.5)mm

Materials			Weight per mix	Density per m³	Ratio C: A	Ratio W/C	Av. Sample weight	7 days strength Mpa
Mix 9	Cement		1.24	310	1:4	0.31	1.621	3.766
	Aggregate	14mm	2.476	1238				
		12.5mm	1.237					
		9.5mm	1.238					
	Water		0.388	97				
Mix 10	Cement		1.76	440	1:3.6	0.30	1.751	10.891
	Aggregate	14mm	1.407	1600				
		12.5mm	2.371					
		9.5mm	2.813					
	Water		0.558	133				
Mix 11	Cement		1.76	440	1:4	0.3	1.814	3.102
	Aggregate	14mm	3.52	1760				
		12.5mm	1.76					
		9.5mm	3.52					
	Water		0.334	132				

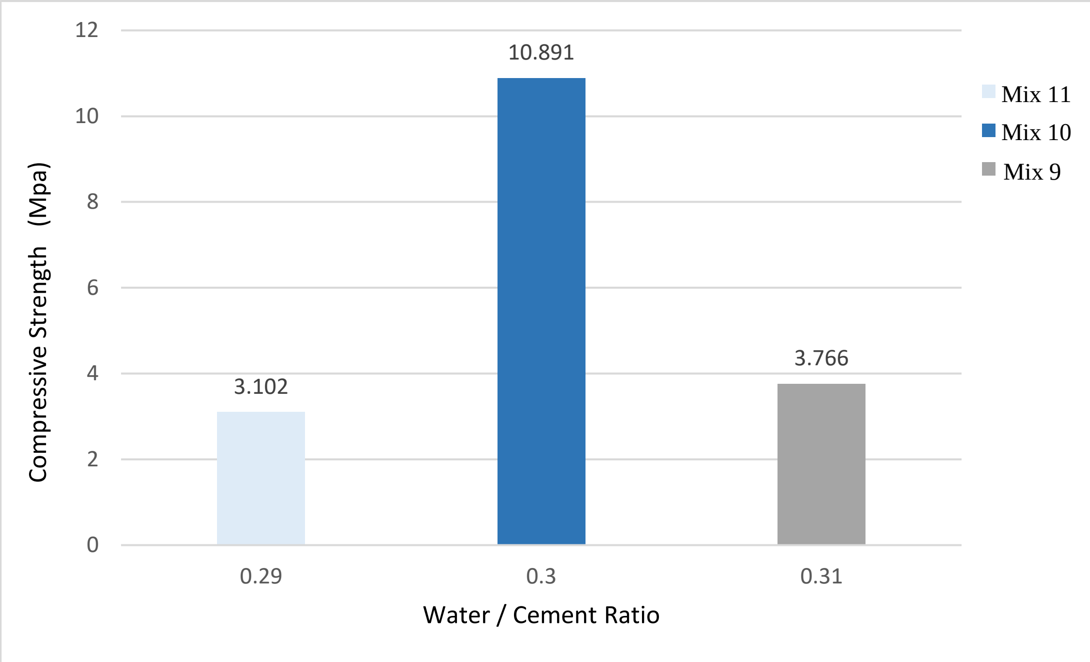


Figure 4.7 Compressive Strength for Aggregate samples

These 3 mixtures based on Multi – Sized aggregate size which are 14mm, 12.5mm and 9.5mm. It is stated clearly that the highest compressive strength result has been recorded in mixture number 10 which has reach 10.891 Mpa which captured in Figure 4.8. It is illustrated in the above graph that compressive strength result of mix 9 and mix 11 are too close. Even though the aggregate sizes are same for all three mixtures, the mix design and the proportion of each aggregate size is quite different. Overall, mix 10 has a great mix design among other mixtures since it involves a ratio of C/A as 1:3.6, W/C as 0.3 and an average weight of 1.751 kilogram.

Figure 4.8 Mix 10 sample

Table 4.5 Compressive Strength for Aggregate samples

	Materials		Material weight per mix	Density per m^3	Ratio		Av. Sample weight	Av. 7 days strength Mpa
					C: A	**W/C**		
Mix 12	Cement		1.218	360	1:4.5	0.21	1.565	2.322
	Aggregate	14mm	0.729	1620				
		9.5mm	2.88					
		4.75mm	2.883					
	Water		0.410	108				

Unique mix has been carried out to start involving 4.75 mm of granite aggregate as hint to indicate the influence of involving lowest number in the coarse aggregate size. Indeed, it shows the lowest compressive strength compared to all other mixtures who have not involving this aggregate size in the mix design. Indeed, it is known that the smaller sizes of the granite aggregate used in the PC is to increase the compressive however, in this case the compressive strength has decreased it. Probably the reason of this up normal phenomena is because the insufficient water content as shown in the Figure 4.9.

Figure 4.9 Low water content in the Mix 12

Table 4.6 Compressive Strength Result for Dual-Sized of Aggregate

	Material		Material weight per mix	Density per m^3	Ratio C: A	Ratio W/C	Av. Sample weight	Av. 7 days strength Mpa
Mix 13	Cement		1.002	334	1:4	0.35	1.767	6.48
	Aggregate	14 mm	1.007	1338				
		4.75mm	1.237					
	Water		0.353	118				
Mix 14	Cement		1.003	334	1:4	0.31	1.777	4.691
	Aggregate	20 mm	1.001	1335				
		14 mm	3.004					
	Water		0.315	105				
Mix 15	Cement		1.004	334	1:4	0.31	1.74	6.659
	Aggregate	20mm	3.002	1333				
		14 mm	1.000					
	Water		0.314	105				
Mix 16	Cement		1.002	334	1:4	0.31	1.829	9.588
	Aggregate	20 mm	2.002	1333				
		14 mm	2.002					
	Water		0.315	105				

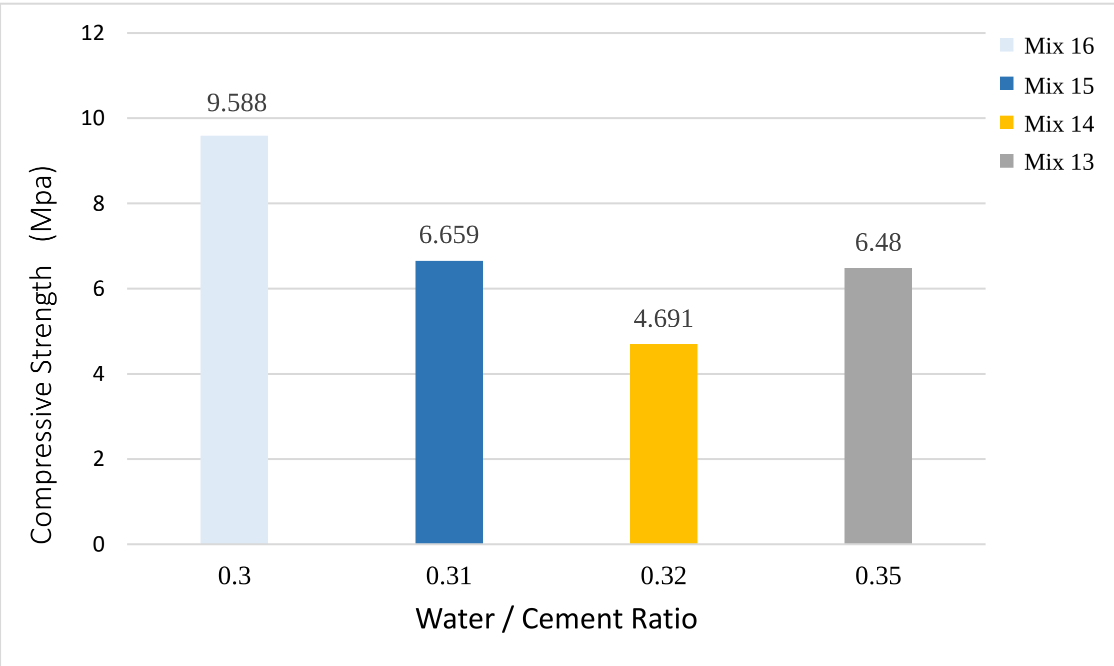


Figure 4.10 Compressive Strength Result for Mix 13 to Mix16

As observed in the Table 4.6, the mix design of the PC is two size the C/A is constant for all 4 mixtures and the ratio of W/C as well. Furthermore, all mixtures 13,14, 15 and 16 has an overall density of granite aggregate of 1333 kg/m^3 with 20mm and 14mm granite aggregate size. Additionally, the average weight of PC sample is too close which around 1.7 Kg per sample. Although all previously mentioned identical features, the compressive strength result is different among the mixtures. Thus, the proportional granite aggregate size dosage has played an important role in the mechanical properties.

Beside Tables f 4.1 - 6, Figure 4.11 has illustrated the compressive strength result values of the preliminary result of this study which consist of 16 mixtures of PC. The 7 days compressive strength results that have been recorded are various as shown in Figure 4.11.

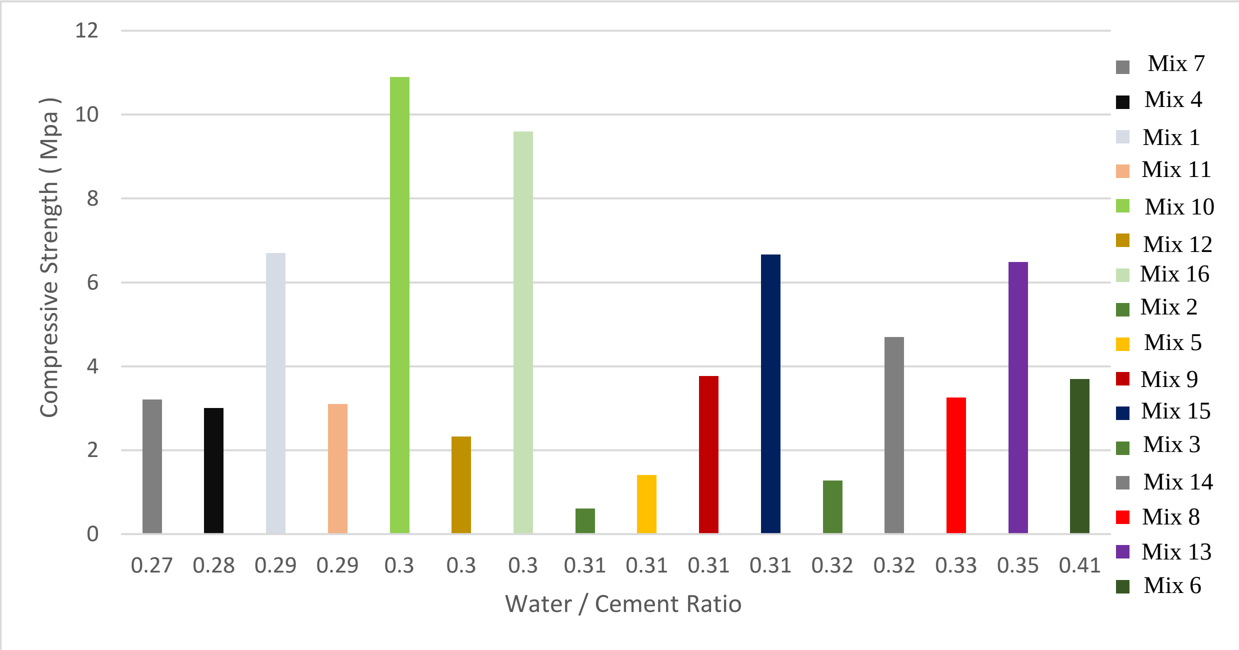


Figure 4.11 Compressive Strength 7 Days

However, upon a closer inspection of the results, it is noticed that 16 mixtures of pervious concrete have different value of compressive strength due to various sizes and volume of aggregate 7 days compressive strength for Portland cement pervious concrete mixtures ranged from 0.602 MPa to 10.9 MPa. Indeed, 10th mix has achieved the highest strength compression after 7 days curing in water at room temperature compared to the 16 mixtures. As known, 10.9 Mpa is 2 thirds of the ultimate compressive strength which is indicated to be almost 17 Mpa . Meanwhile, the previous studies of the control mix has reached the maximum 7 days compressive strength of 6.45 Mpa (Ibrahim et al., 2014).

4.2.2 Steel Slag in Pervious Concrete

In this stage, the pervious concrete for pavement purposes is usually made by using Cement, Granite Aggregate, Water; however, in this stage the steel slag takes a place in the ingredients of the mixture of pervious concrete. So, the steel aggregates particles have been used in various sizes. There are three categories of cylindrical pervious concrete samples were made in the basis of percentage of involving the steel slag which are mentioned below: -

- 50% Steel Slag and 50% Granite.
- 30% Steel Slag and 70% Granite.
- 70% Steel Slag and 30% Granite.

This differences of percentage of steel slag will represent the presence of steel slag in three different values low as 30%, equivalent percentage as (50% - 50%) and high as 70% of the mixture.

Figure 4.12 Steel Slag Mixed with Granite

Table 4.7 Compressive Strength Result for Mix10 (70% Granite - 30% Steel Slag)

Mould size	No. of sample	Materials	Weight of materials per mix (Kg)			Density per m^3	Sample Weight kg	7 days strength Mpa
200*100	3	Cement		2.5		391	2.208	11.8
		Granite	14 mm	1.3	2.44	971		
			12.5mm	2.2				
			10 mm	2.6				
		Steel slag	14 mm	1.3	2.44	971		
			12.5mm	2.2				
			10 mm	2.6				
		Water		0.312		78		

The cylindrical samples are prepared by using the mix design illustrated in Table 4.7. Indeed, as mentioned earlier this mixture is based on the 50% Granite and 50% Steel Slag Aggregate with three sizes of aggregate which are 14mm,12.5mm and 10mm. Noted that, the basis of steel slag replace is based on the weight of the steel slag and granite aggregate. As shown in the figure This mixture has achieved higher compressive strength compared to the control mix since it reached 11.8 Mpa meanwhile control mix recorded 10.891 Mpa. This indicated that the steel slag has influenced positively the mechanical behaviour of PC when it is involved with equal dosage of granite aggregate.

Figure 4.13 50% Granite - 50% steel slag

Table 4.8 Compressive Strength Result Mix10 - 50%S – 50% G

Mould size	No. of sample	Materials	Weight of materials per mix (Kg)			Density per m^3	Sample Weight kg	7 days strength Mpa
200*100	3	Cement	2.5			391	2.3	11.7
		Granite	14 mm	1.8	3.42	1359		
			12.5mm	3.1				
			10 mm	3.64				
		Steel slag	14 mm	0.78	2.44	583		
			12.5mm	1.32				
			10 mm	1.56				
		Water	0.312			78		

30% Granite and 70% Steel Slag of the weight of PC is the principle that followed in preparing the mix design. This mixture has shown a slight increase in the strength since it reached 11.07 Mpa compared to control mix of 10.891 Mpa; however, it is a bit lower in compressive strength than the previous mixture Mix10-S 50%- G50%. In terms of the weight of pervious concrete samples are still too close to the Mix10-S 50%- G50% which is in the range of 2.2 - 2.3 Kg. The cylindrical sample was looking smooth and well organized. As shown in the Figure 4.14, one of the sample's compressive strength result.

Figure 4.14 Compressive Strength for Cylindrical sample

Table 4.9 Compressive Strength Result Mix10 - 70%S – 30% G

Mould size	No. of sample	Materials	Weight of materials per mix (Kg)			Density per m³	Sample Weight kg	7 days strength Mpa
200*100	3	Cement		2.5		391	2.3	8.9
		Granite	14 mm	0.78	1.46	583		
			12.5mm	1.32				
			10 mm	1.56				
		Steel Slag	14 mm	1.8	2.44	1359		
			12.5mm	3.1				
			10 mm	3.64				
		Water		0.312		78		

The result of the compressive strength of Mix10 - 70%S – 30% G is recorded in Table 4.9. This mix is based on 30% Granite and 70% Steel Slag where this high weight of the steel slag used in cylindrical sample has negatively effected the strength. Indeed, the compressive strength of PC in Mix10 - 70%S – 30% G has lowered by 2 Mpa compared to the control mix which considered as the lowest compressive strength achieved. This low result has occurred due to the high percentage of steel slag that has high angularity that leads to low contact point between the aggregate particles. Thus, low contact points lead to high void ratio that reflected on low compressive strength as seen in the result in the Figure 4.15.

Figure 4.15 Compressive Strength result for Mix10 (70%S – 30% G)

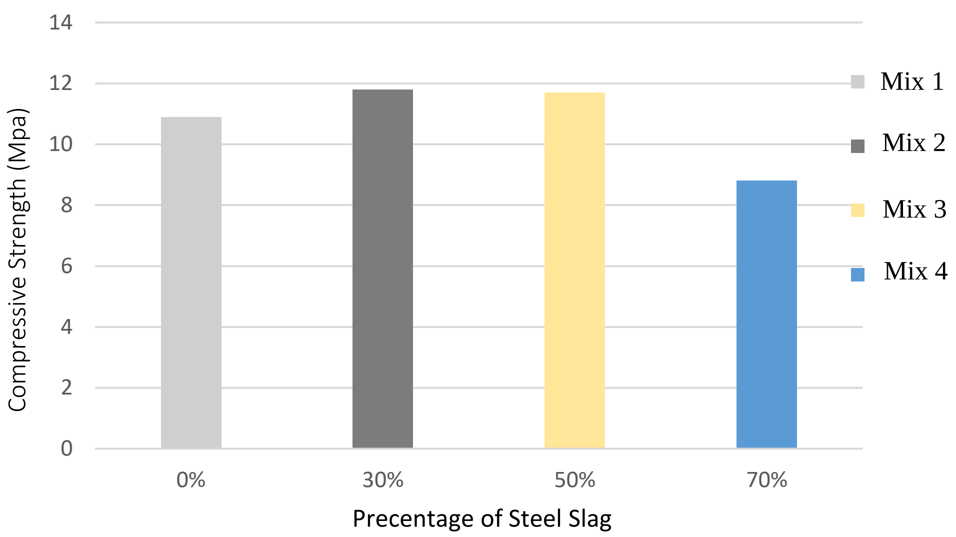


Figure 4.16 7 days Compressive Strength

The 7 days compressive strength results were different due to different ingredients involved. Indeed, the values are mentioned in Table 4.7, 4.8 and 4.9 which elaborated in the Figure 4.16. It is also worth mentioning that even compressive strength results, the mix control has reached 10.9 Mpa; meanwhile, with the first existing steel slag in the pervious the strength has increased to 11.8 Mpa due to the high resistance that steel slag possesses. However, the more up to 50% of steel slag aggregate involved in the mixture much more strength obtained since 30% and 50% of steel slag have increased the strength of pervious concrete compared to mix control.

4.3 PERMEABILITY TEST

Pervious concrete is a special type of concrete with a high porosity and accordingly typical permeability tests performed on conventional concrete such as RCPT was deemed unreliable(Abdel & Mohamed, 2013). A simple experiment was designed to investigate the hydrological properties for different pervious concrete mixtures studied. There are forth categories of pervious concrete cylindrical samples were tested for one of the hydrological parameters which is permeability. In this stage, the time taken for the water to pass through the specimen was recorded via a stopwatch. Indeed, the 1st category is the control mix (A) - which has no steel aggregates- 2nd category 70% granite and 30% steel, 3rd category. Indeed, the samples are dimensioned as 150 mm height * 50 mm diameter at civil engineering laboratory in Universti Malaysia Pahang. The results of the permeability test by using simple instrument below to record the infiltration rate throughout permeability.

Table 4.10 Infiltration rate for A Category

	Sample	Infiltration mm/s	Av. Infiltration rate
Category A (control mix)	A1	4.7	4.5 mm/s
	A2	4.3	
	A3	4.6	

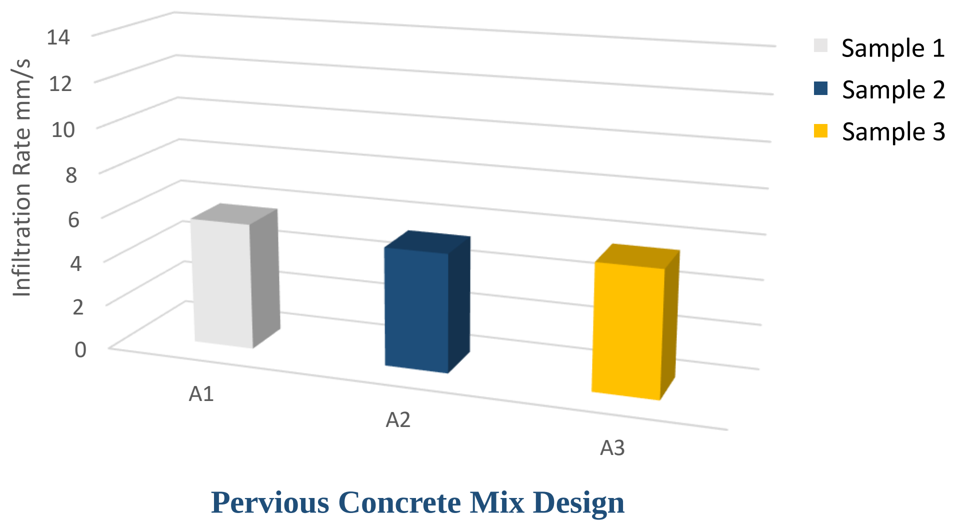


Figure 4.17 Infiltration Rate for A Category

In Table 4.10, the infiltration of category A of the pervious concrete samples has achieved an average of infiltration rate of 4.5 mm/s which considered as quite pretty. It is noticeable from Figure 4.17; the ability of the pervious concrete has recorded a harmonious value which provide a reliable data. It is stated that this category has no existence of steel slag aggregates.

Table 4.11 Infiltration rate for B Category

	Sample	Infiltration mm/s	Av. Infiltration rate
Category B (70 G – 30 S)	B1	6.5	7.0 mm/s
	B2	7.3	
	B3	7.1	

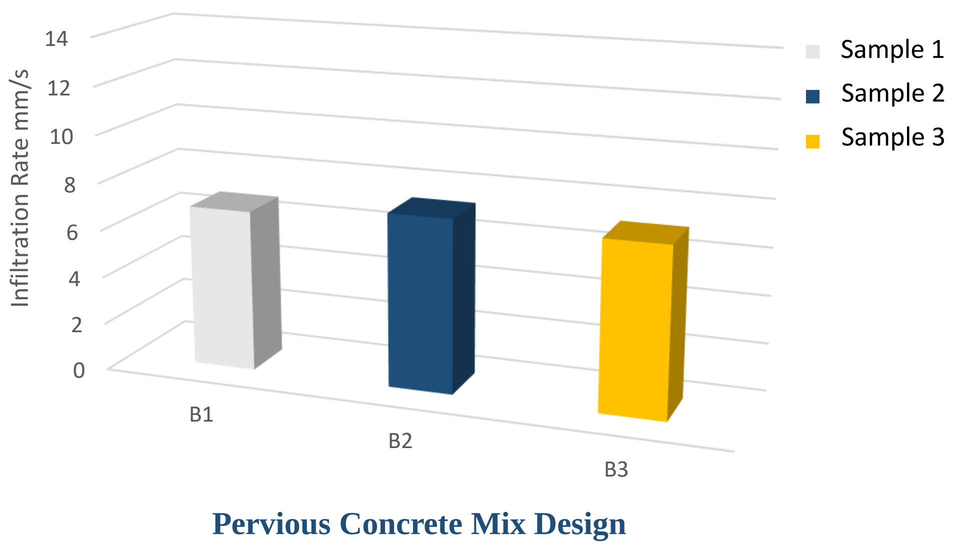


Figure 4.18 Infiltration rate for B Category

Figure 4.18, Illustrates the effect of using 30% of steel slag in the pervious concrete cylindrical sample which has achieved higher infiltration value as the author expected. In fact, the steel slag has performed well by 30% percent involvement in the PC in terms of hydrological properties through permeability test as noticed from Table 4.11. Although there is a disparity in the bar graph data, the water permeability generally increases.

Table 4.12 Infiltration rate for C Category

	Sample	Infiltration mm/s	Av. Infiltration rate
Category C (50 G – 50 S)	C1	8.4	8.6 mm/s
	C2	8.8	
	C3	8.5	

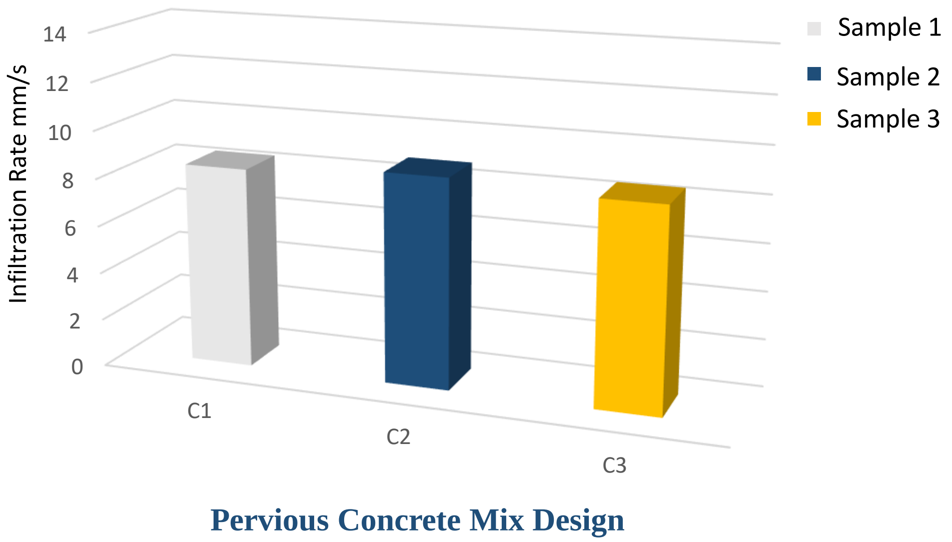


Figure 4.19 Infiltration rate for C Category

Figure 4.19 has shown an incredible increase in the permeability test while the amount of steel slag aggregate has increased to 50%. The appearance of these samples where dark from approximately all sides as showed in Figure 4.20.

Figure 4.20 Appearance of Equal Amount of Steel Slag and Granite Aggregate in PC

Table 4.13 Infiltration rate for D Category

	Sample	Infiltration mm/s	Av. Infiltration rate
Category 4 (30 G – 70 S)	D1	13.7	13.9
	D2	14.2	
	D3	13,9	

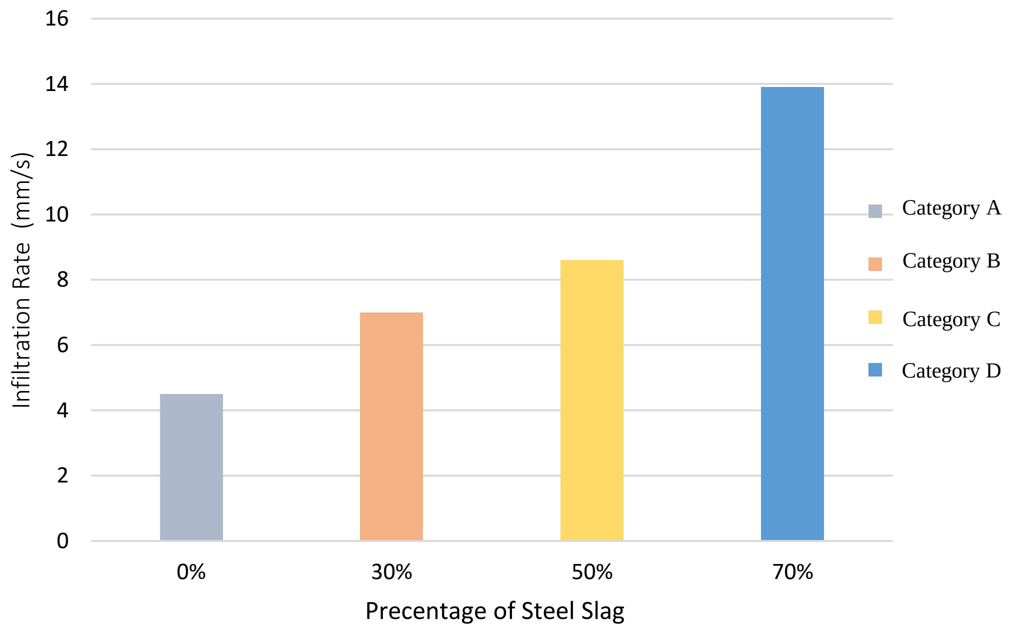


Figure 4.21 Infiltration Rate Results

In the Figure 4.21, the permeability results are various in the value of the infiltration rate since the range from 5 mm/s to 14 mm/s. Indeed, the first bar is representing the control mix for permeability which has achieved the lowest infiltration rate as 5 mm/s which because of using granite aggregate with no presence of steel slag; meanwhile, the highest permeability infiltration has reached the maximum of infiltration rate of 14 mm/s while the percentage of steel has reached 70 percentage of the mixture as mentioned in Table 4.13. Indeed, the moderated permeable concrete has achieved in terms of the speed of water pass through the sample has occurred while the mixture consists of equivalent values of steel slag and granite on the basis of weight.

In this respect, it is worth to illustrate the mechanical and hydrological properties which are compressive strength and infiltration rate throughout a graph as shown in Figure 4.22.

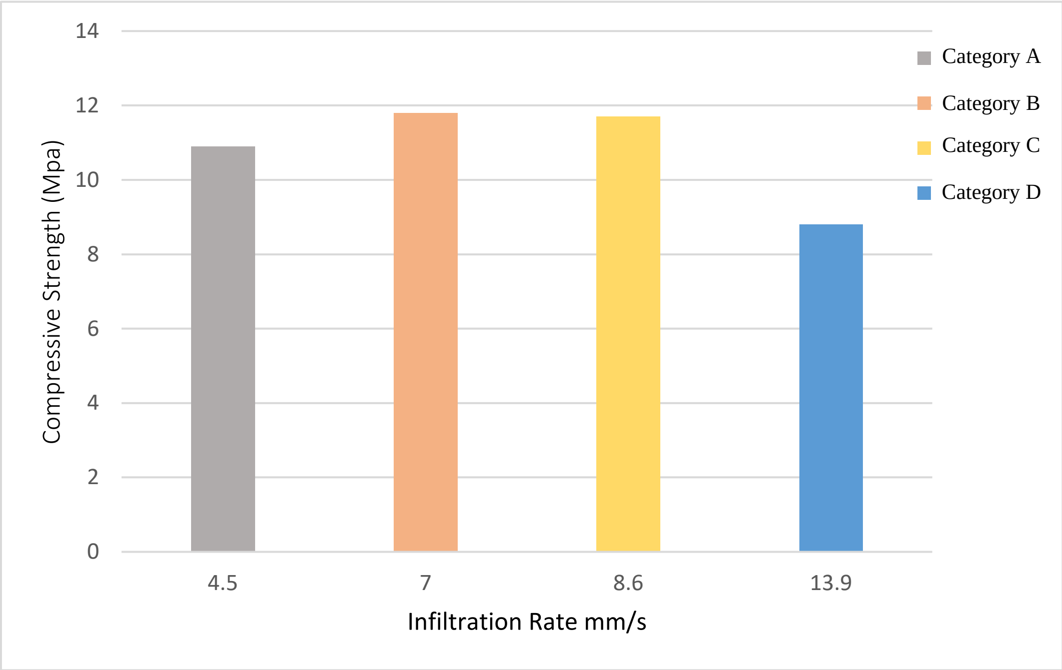


Figure 4.22 Compressive Strength vs Infiltration Rate Results

It is clearly illustrated that the both aspects have influenced by each other: it is meant that compressive has increased slightly with percentage of 30% of steel slag. However, by increasing the percentage of steel slag in pervious concrete sample, the compressive strength decreased dramatically to reach 8.8 Mpa which considered the lowest compared to all dosages of steel slag. In contrast, the infiltration rate has increased by the increase of the steel slag percentage dosage which indicate a positive correlation relationship.

4.4 Development of IDF Curve for Station Rumah Pam Pahang Tua By Using Msma 2nd Edition

4.4.1 Introduction

The development of IDF curve is based from MSMA 2nd edition. The IDF curve calculation is based on 5ARI, 10ARI, 20ARI, 50ARI, and 100ARI for Rumah Pam Pahang Tua Station (3533102). The parameter that provide in MSMA 2nd edition use for calculation to get intensity value. This study selects Rumah Pam Pahang Tua Station since it is located nearby Pahang river in Pekan which has experienced flood event during the past years. The location of station is shown in Figure 4.23.

Figure 4.23 Location of Rainfall and Evaporation Station at site 3533102

Development of IDF curve for Rumah Pam Pahang Tua Station was calculated by using empirical formula.

4.4.2 IDF Curve Development for Rumah Pam Pahang Tua Station by using MSMA 2nd Edition.

In the respect of Empirical IDF Curve, Empirical equations should be utilized to minimise error in estimating the rainfall intensity values from the IDF curves (MSMA 2nd Edition, 2012). It is expressed as

$$i = \frac{\lambda T^{\kappa}}{(d + \theta)} \qquad Equation\ 4.1$$

where,

i = Average rainfall intensity $\left(\frac{\text{mm}}{\text{hr}}\right)$;

T = Average recurrence interval − ARI ($0.5 \leq T \leq 12$ month and $2 \leq T \leq 100$ year);

d = Storm duration (hours), $0.0833 \leq d \leq 72$; and

λ, κ, θ and η = fitting constant dependent on the raingauge location (Figure 4.24).

From, the empirical equation used different parameter for different station. Hence, the parameter that use for Rumah Pam Pahang Tua Station was verified in Figure 4.24.

Table 2.B1: Fitting Constants for the IDF Empirical Equation for the Different Locations in Malaysia for High ARIs between 2 and 100 Year and Storm Durations from 5 Minutes to 72 Hours

State	No.	Station ID	Station Name	Constants			
				λ	κ	θ	η
Malacca	1	2222001	Bukit Sebukor	95.823	0.169	0.660	0.947
	2	2224038	Chin Chin Tepi Jalan	54.241	0.161	0.114	0.846
	3	2321006	Ladang Lendu	72.163	0.184	0.376	0.900
Negeri Sembilan	1	2719001	Setor JPS Sikamat	52.823	0.167	0.159	0.811
	2	2722202	Kg Sawah Lebar K Pilah	44.811	0.181	0.137	0.811
	3	2723002	Sungai Kepis	54.400	0.176	0.134	0.842
	4	2725083	Ladang New Rompin	57.616	0.191	0.224	0.817
	5	2920012	Petaling K Kelawang	50.749	0.173	0.235	0.854
Pahang	1	2630001	Sungai Pukim	46.577	0.232	0.169	0.687
	2	2634193	Sungai Anak Endau	66.179	0.182	0.081	0.589
	3	2828173	Kg Gambir	47.701	0.182	0.096	0.715
	4	3026156	Pos Iskandar	47.452	0.184	0.071	0.780
	5	3121143	Simpang Pelangai	57.109	0.165	0.190	0.867
	6	3134165	Dispensari Nenasi	61.697	0.152	0.120	0.593
	7	3231163	Kg Unchang	55.568	0.179	0.096	0.649
	8	3424081	JPS Temerloh	73.141	[illegible]	0.577	0.896
	9	3533102	Rumah Pam Pahang Tua	58.483	0.212	0.197	0.586
	10	3628001	Pintu Kaw. Pulau Kertam	50.924	0.211	[illegible]	0.716
	11	3818054	Setor JPS Raub	53.115	0.168	0.191	0.833
	12	3924072	Rmh Pam Paya Kangsar	62.301	0.167	0.363	0.868
	13	3930012	Sungai Lembing PCC Mill	45.999	0.210	0.074	0.590
	14	4023001	Kg Sungai Yap	65.914	0.195	0.252	0.817
	15	4127001	Hulu Tekai Kwsn."B"	59.861	0.226	0.213	0.762
	16	4219001	Bukit Bentong	73.676	0.165	0.384	0.879
	17	4223115	Kg Merting	52.731	0.184	0.096	0.805
	18	4513033	Gunung Brinchang	42.004	0.164	0.046	0.802

Figure 4.24 Constant Parameters for the Hydrological Stations

Source: (MSMA 2nd Edition, 2012.)

The results for intensity value obtained from the frequency analysis for durations of 5 minutes to 4320 minutes for Rumah Pam Pahang Tua Station (3533102) are presented in Table 4.14. The method used to derive IDF Curve is based on MSMA second edition and has been develop in Figure 4.25.

Table 4.14 Intensity Value for Rumah Pam Pahang Tua Station by MSMA 2012

Duration	**Average Recurrence Interval ARI (mm/hr)**				
(minutes)	**5 ARI**	**10 ARI**	**20 ARI**	**50 ARI**	**100 ARI**
5	173.33	200.77	232.55	282.41	327.11
10	148.81	172.37	199.65	242.46	280.84
15	131.87	152.74	176.92	214.85	248.86
30	101.64	117.73	136.37	165.61	191.82
45	84.93	98.38	113.95	138.38	160.28
60	74.04	85.76	99.33	120.63	139.72
120	51.87	60.08	69.59	84.51	97.89
180	41.63	48.22	55.86	67.83	78.57
360	28.25	32.72	37.90	46.02	53.31
540	22.41	25.96	30.07	36.52	42.30
720	19.00	22.00	25.49	30.95	35.85
1440	12.72	14.73	17.06	20.72	24.00
2880	8.49	9.84	11.39	13.83	16.02
4320	6.70	7.76	8.99	10.92	12.65

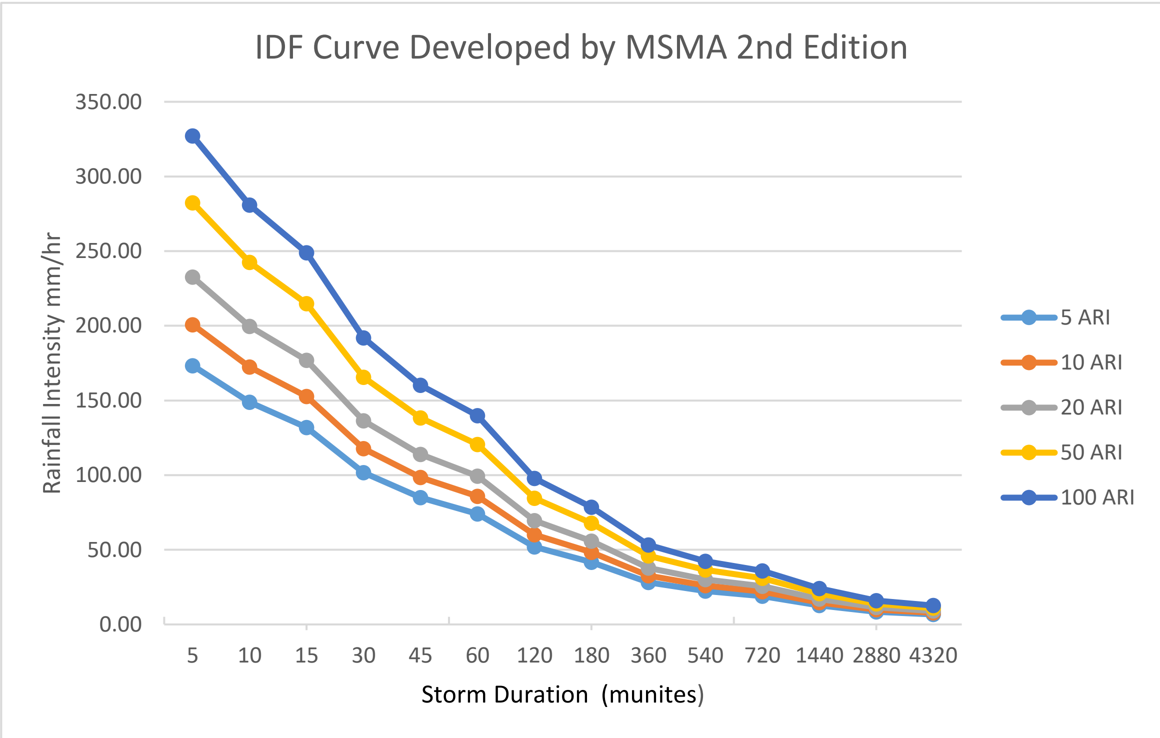


Figure 4.25 IDF Curve for Rumah Pam Pahang Tua Station by MSMA 2012

4.5 Comparison Intensity Value for Rumah Pam Pahang Tua Station by MSMA 2nd Edition and Infiltration Rate of Pervious Concrete

It is noticeable that the data collected from Rumah Pam Pahang Tua Station site 3533102 and the maximum value of rainfall intensity of 100 ARI gained from the developed IDF Curve by MSMA 2nd edition which is 327.11 mm/hr. By inspecting the standard on Table 1 (*McGraw.Hill,2005*), 327.11mm/hr is considered as heavy rain.

It is worth to be said that the critical value of the rainfall intensity for 100 ARI obtained from the IDF curve is almost 1.1 mm/sec. Meanwhile, the lowest infiltration rate obtained in this study is 4.5 mm/s which is adequate to full fill the requirement of the rainfall intensity obtained from MSMA 2nd edition regarding at site 3533102 critical zone during flood session in Pekan, Pahang.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

All results and discussion are identifying to provide a conclusion that answering the objective. To sum up this study, there are three outcomes which are stated clearly below regarding the compressive strength and permeability of the pervious concrete. Result of the IDF curve developed as well as the necessary comparison between intensity of the rainfall and the infiltration rate. Following are the summary of all issues discussed.

- Based on the preliminary result, the mix control has reached 10.9 Mpa; meanwhile, with the first existing steel slag in the pervious the strength has increased to 11.8 Mpa due to the high resistance that steel slag possesses. However, the more up to 50% of steel slag aggregate involved in the mixture much more strength obtained since 30% and 50% of steel slag have increased the strength of pervious concrete compared to mix control.
- The permeability results are various in the value of the infiltration rate since the range from 5 mm/s to 14 mm/s. The highest permeability infiltration has reached the maximum of infiltration rate of 14 mm/s while the percentage of steel has reached 70 percentage of the mixture.
- It is worth to be said that the critical value of the rainfall intensity for 100 ARI obtained from the IDF curve is almost 1.1 mm/sec. Meanwhile, the lowest infiltration rate obtained in this study is 4.5 mm/s which is adequate to full fill the requirement of the rainfall intensity obtained from MSMA 2nd edition regarding at site 3533102 critical zone during flood session in Pekan, Pahang as the author expected.

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Appendix A

1^{st} Mixture

Materials		Weight of Materials per mix	Density per m^3	Weight of sample Kg	7 days strength Mpa
Cement		1.041	308.44		
Aggregate	20mm	3.361	995.73	3.9	6.701
Water		0.305	90.37		

2^{nd} Mixture

Materials		Weight of Materials per mix	Density per m^3	Weight of Sample	7 days strength Mpa
Cement		1.078	1078	1.551	1.758
Aggregate	14mm	4.982	1423	1.592	4.344
Water		0.306	0.306	1.543	2.897

3rd Mixture

Materials		Weight of Materials per mix	Weight of materials per sample	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1.064	0.355	355	1.330	0.98
Aggregate	14mm	3.252	1.084	1048	1.348	1.382
Water		0.339	0.113	113	1.282	1.460

4th Mixture

Materials		Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1.057	264	1.288	0.682
				1.172	0.321
Aggregate	20mm	4.012	1000		
				1.322	0.597
Water		0.336	84	1.433	0.809

5th Mixture

Materials		Weight of materials per mix Kg	Weight of materials per sample Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1.066	0.355	355	1.244	1.072
Aggregate	14mm	3.139	1.046	1046	1.377	1.972
Water		0.324	0.115	115	1.251	0.78

6th Mixture

Materials		Ratio of materials per mix Kg	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength
Cement		1	1.244	311	1.183	3.814
Aggregate	20mm	2	2..480			
	14mm	1	1.249	1245	1.287	3.567
	12.5mm	1	1.249			
Water		0.304	0.378	94.5	1.216	3.790

7th Mixture

Materials		Ratio of materials per mix	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength MPa
Cement		1	1.249	312.3	1.357	2.662
	20mm	1	1.249		1.322	
Aggregate	14mm	2	2.483	1245	1.304	3.35
	12.5mm	1	1.247		1.341	
Water		0.267	0.334	84	0.983	3.593

8th Mixture

Materials		Ratio of materials per mix	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.244	311	1.628	3.558
	20mm	0.5	0.622		1.569	2.423
Aggregate	14mm	1.5	1.859	1244	1.722	3.763
	12.5mm	2	2.488		1.664	3.283
Water		0.328	0.408	102		

9^{th} Mixture

Materials		Ratio of materials per mix	Weight of Materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.238	310	1.650	4.002
	14mm	2	2.476		1.564	4.51
Aggregate	12.5mm	1	1.237	1238	1.728	3.744
	9.5mm	1	1.238		1.560	
Water		0.313	0.388	97		2.806

10^{th} Mixture

Materials		Ratio of materials per mix K	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.76	391	1.958	7.463
	14mm	0.8	1.407		1.876	8.912
Aggregate	12.5mm	1.35	2.371	1465	1.940	7.902
	9.5mm	1.6	2.813		1.931	7.77
Water		0.317	0.558	124	1.048	10.96

11th Mixture

Materials		Ratio of materials per mix	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.76	294	1.870	5.976
Aggregate	20mm	1	1.761		1.892	3.723
	14mm	2	3.519	1467	1.772	0.99
	9.5mm	2	3.519		1.792	3.591
Water		0.3	0.547	91.2	1.766	1.725

12th Mixture

Materials		Ratio of materials per mix K	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.218	244	1.575	1.762
Aggregate	14mm	0.598	0.729		1.508	0.985
	9.5mm	2.239	2.731	1269	1.546	2.549
	4.75mm	2.367	2.883		1.558	2.849
Water		0.336	0.410	82	1.563	3.435

13th Mixture

Materials		Ratio of materials per mix	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.002	334	1.733	6.78
Aggregate	14mm	1	1.007	1338	1.736	52.2
	4.75mm	3	3.006			
Water		0.353	0.353	118	1.834	7.439

14th Mixture

Materials		Ratio of materials per mix K	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.003	334	1.717	3.982
Aggregate	20mm	1	1.001	1335	1.793	4.963
	14mm	3	3.004			
Water		0.314	0.315	105	1.821	5.128`

15th Mixture

Materials		Ratio of materials per mix	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength
Cement		1	1.004	334	1.774	5.889
Aggregate	20mm	3	3.002	1333	1.734	6.839
	14 mm	1	1.000		1.714	7.228
Water		0.314	0.314	105		

16th Mixture

Materials		Ratio of materials per mix K	Weight of materials per mix Kg	Density per m^3	Weight of sample	7 days strength Mpa
Cement		1	1.002	334	1.830	9.122
Aggregate	20mm	2	.2002	1333	1.861	9.88
	14 mm	2	2.002		1.796	9.762
Water		0.315	0.315	105		

Appendix B

$$i = \frac{\lambda\, T^{\kappa}}{(d + \theta)^{\eta}}$$

when , $\mathbf{T = 5}$ ARI

d = 5 minutes = 0.083 hour

$$i = \frac{58.483 * 5^{0.212}}{(0.083 + 0.197)^{0.586}} = 173.33 \quad mm/hr$$

d = 10 minutes = 0.167 hour

$$i = \frac{58.483 * 5^{0.212}}{(0.167 + 0.197)^{0.586}} = 148.81 \quad mm/hr$$

d = 15 minutes = 0.25 hour

$$i = \frac{58.483 * 5^{0.212}}{(0.250 + 0.197)^{0.586}} = 131.87 \quad mm/hr$$

d = 30 minutes = 0.5 hour

$$i = \frac{58.483 * 5^{0.212}}{(0.500 + 0.197)^{0.586}} = 101.64 \quad mm/hr$$

d = 45 minutes = 0.750 hour

$$i = \frac{58.483 * 5^{0.212}}{(0.750 + 0.197)^{0.586}} = 84.93 \quad mm/hr$$

d = 60 minutes = 1 hour

$$i = \frac{58.483 * 5^{0.212}}{(1 + 0.197)^{0.586}} = 74.04 \quad mm/hr$$

d = 120 minutes = 2 hours

$$i = \frac{58.483 * 5^{0.212}}{(2 + 0.197)^{0.586}} = 51.87 \quad mm/hr$$

d = 180 minutes = 3 hours

$$i = \frac{58.483 * 5^{0.212}}{(3 + 0.197)^{0.586}} = 41.63 \quad mm/hr$$

d = 360 minutes = 6 hours

$$i = \frac{58.483 * 5^{0.212}}{(6 + 0.197)^{0.586}} \quad = \quad 28.25 \quad mm/hr$$

d = 540 minutes = 9 hours

$$i = \frac{58.483 * 5^{0.212}}{(9 + 0.197)^{0.586}} \quad = \quad 22.41 \quad mm/hr$$

d = 720 minutes = 12 hours

$$i = \frac{58.483 * 5^{0.212}}{(12 + 0.197)^{0.586}} \quad = \quad 19.00 \quad mm/hr$$

d = 1440 minutes = 24 hours

$$i = \frac{58.483 * 5^{0.212}}{(24 + 0.197)^{0.586}} \quad = \quad 12.71 \quad mm/hr$$

d = 2880 minutes = 48 hours

$$i = \frac{58.483 * 5^{0.212}}{(48 + 0.197)^{0.586}} \quad = \quad 8.49 \quad mm/hr$$

d = 4320 minutes = 72 hours

$$i = \frac{58.483 * 5^{0.212}}{(72 + 0.197)^{0.586}} \quad = \quad 6.70 \quad mm/hr$$

when , T = 10 ARI

d = 5 minutes = 0.083 hour

$$i = \frac{58.483 * 10^{0.212}}{(0.083 + 0.197)^{0.586}} = 200.77 \quad mm/hr$$

d = 10 minutes = 0.167 hour

$$i = \frac{58.483 * 10^{0.212}}{(0.167 + 0.197)^{0.586}} = 172.37 \quad mm/hr$$

d = 15 minutes = 0.25 hour

$$i = \frac{58.483 * 10^{0.212}}{(0.250 + 0.197)^{0.586}} = 152.74 \quad mm/hr$$

d = 30 minutes = 0.5 hour

$$i = \frac{58.483 * 10^{0.212}}{(0.500 + 0.197)^{0.586}} = 117.73 \quad mm/hr$$

d = 45 minutes = 0.750 hour

$$i = \frac{58.483 * 10^{0.212}}{(0.750 + 0.197)^{0.586}} = 98.38 \quad mm/hr$$

d = 60 minutes = 1 hour

$$i = \frac{58.483 * 10^{0.212}}{(1 + 0.197)^{0.586}} = 85.76 \quad mm/hr$$

d = 120 minutes = 2 hours

$$i = \frac{58.483 * 10^{0.212}}{(2+ 0.197)^{0.586}} = 60.08 \quad mm/hr$$

d = 180 minutes = 3 hours

$$i = \frac{58.483 * 10^{0.212}}{(3 + 0.197)^{0.586}} = 48.22 \quad mm/hr$$

d = 360 minutes = 6 hours

$$i = \frac{58.483 * 10^{0.212}}{(6 + 0.197)^{0.586}} = 32.72 \quad mm/hr$$

d = 540 minutes = 9 hours

$$i = \frac{58.483 * 10^{0.212}}{(9 + 0.197)^{0.586}} = 25.96 \quad mm/hr$$

d = 720 minutes = 12 hours

$$i = \frac{58.483 * 10^{0.212}}{(12 + 0.197)^{0.586}} = 22.00 \quad mm/hr$$

d = 1440 minutes = 24 hours

$$i = \frac{58.483 * 10^{0.212}}{(24 + 0.197)^{0.586}} = 14.73 \quad mm/hr$$

d = 2880 minutes = 48 hours

$$i = \frac{58.483 * 10^{0.212}}{(48 + 0.197)^{0.586}} = 9.84 \quad mm/hr$$

d = 4320 minutes = 72 hours

$$i = \frac{58.483 * 10^{0.212}}{(72 + 0.197)^{0.586}} = 7.76 \quad mm/hr$$

when , $\mathbf{T = 20ARI}$

d = 5 minutes = 0.083 hour

$$i = \frac{58.483 * 20^{0.212}}{(0.083 + 0.197)^{0.586}} = 232.55 \quad mm/hr$$

d = 10 minutes = 0.167 hour

$$i = \frac{58.483 * 20^{0.212}}{(0.167 + 0.197)^{0.586}} = 199.65 \quad mm/hr$$

d = 15 minutes = 0.25 hour

$$i = \frac{58.483 * 20^{0.212}}{(0.250 + 0.197)^{0.586}} = 176.92 \quad mm/hr$$

d = 30 minutes = 0.5 hour

$$i = \frac{58.483 * 20^{0.212}}{(0.500 + 0.197)^{0.586}} = 136.37 \quad mm/hr$$

d = 45 minutes = 0.750 hour

$$i = \frac{58.483 * 20^{0.212}}{(0.750 + 0.197)^{0.586}} = 113.95 \quad mm/hr$$

d = 60 minutes = 1 hour

$$i = \frac{58.483 * 20^{0.212}}{(1 + 0.197)^{0.586}} = 99.33 \quad mm/hr$$

d = 120 minutes = 2 hours

$$i = \frac{58.483 * 20^{0.212}}{(2+ 0.197)^{0.586}} = 69.59 \quad mm/hr$$

d = 180 minutes = 3 hours

$$i = \frac{58.483 * 20^{0.212}}{(3 + 0.197)^{0.586}} = 55.86 \quad mm/hr$$

d = 360 minutes = 6 hours

$$i = \frac{58.483 * 20^{0.212}}{(6 + 0.197)^{0.586}} = 37.90 \quad mm/hr$$

d = 540 minutes = 9 hours

$$i = \frac{58.483 * 20^{0.212}}{(9 + 0.197)^{0.586}} = 30.07 \quad mm/hr$$

d = 720 minutes = 12 hours

$$i = \frac{58.483 * 20^{0.212}}{(12 + 0.197)^{0.586}} = 25.49 \quad mm/hr$$

d = 1440 minutes = 24 hours

$$i = \frac{58.483 * 20^{0.212}}{(24 + 0.197)^{0.586}} = 17.06 \quad mm/hr$$

d = 2880 minutes = 48 hours

$$i = \frac{58.483 * 20^{0.212}}{(48 + 0.197)^{0.586}} = 11.39 \quad mm/hr$$

d = 4320 minutes = 72 hours

$$i = \frac{58.483 * 20^{0.212}}{(72 + 0.197)^{0.586}} = 8.99 \quad mm/hr$$

when , $T = 50$ARI

d = 5 minutes = 0.083 hour

$$i = \frac{58.483 * 50^{0.212}}{(0.083 + 0.197)^{0.586}} = 282.41 \quad mm/hr$$

d = 10 minutes = 0.167 hour

$$i = \frac{58.483 * 50^{0.212}}{(0.167 + 0.197)^{0.586}} = 242.46 \quad mm/hr$$

d = 15 minutes = 0.25 hour

$$i = \frac{58.483 * 50^{0.212}}{(0.250 + 0.197)^{0.586}} = 214.85 \quad mm/hr$$

d = 30 minutes = 0.5 hour

$$i = \frac{58.483 * 50^{0.212}}{(0.500 + 0.197)^{0.586}} = 165.61 \quad mm/hr$$

d = 45 minutes = 0.750 hour

$$i = \frac{58.483 * 50^{0.212}}{(0.750 + 0.197)^{0.586}} = 113.95 \quad mm/hr$$

d = 60 minutes = 1 hour

$$i = \frac{58.483 * 50^{0.212}}{(1 + 0.197)^{0.586}} = 99.33 \quad mm/hr$$

d = 120 minutes = 2 hours

$$i = \frac{58.483 * 50^{0.212}}{(2 + 0.197)^{0.586}} = 69.59 \quad mm/hr$$

d = 180 minutes = 3 hours

$$i = \frac{58.483 * 50^{0.212}}{(3 + 0.197)^{0.586}} = 55.86 \quad mm/hr$$

d = 360 minutes = 6 hours

$$i = \frac{58.483 * 50^{0.212}}{(6 + 0.197)^{0.586}} = 37.90 \quad mm/hr$$

d = 540 minutes = 9 hours

$$i = \frac{58.483 * 50^{0.212}}{(9 + 0.197)^{0.586}} = 30.07 \quad mm/hr$$

d = 720 minutes = 12 hours

$$i = \frac{58.483 * 50^{0.212}}{(12 + 0.197)^{0.586}} = 25.49 \quad mm/hr$$

d = 1440 minutes = 24 hours

$$i = \frac{58.483 * 50^{0.212}}{(24 + 0.197)^{0.586}} = 17.06 \quad mm/hr$$

d = 2880 minutes = 48 hours

$$i = \frac{58.483 * 50^{0.212}}{(48 + 0.197)^{0.586}} = 11.39 \quad mm/hr$$

d = 4320 minutes = 72 hours

$$i = \frac{58.483 * 50^{0.212}}{(72 + 0.197)^{0.586}} = 8.99 \quad mm/hr$$

when , $T = 100$ARI

d = 5 minutes = 0.083 hour

$$i = \frac{58.483 * 100^{0.212}}{(0.083 + 0.197)^{0.586}} = 327.11 \quad mm/hr$$

d = 10 minutes = 0.167 hour

$$i = \frac{58.483 * 100^{0.212}}{(0.167 + 0.197)^{0.586}} = 280.84 \quad mm/hr$$

d = 15 minutes = 0.25 hour

$$i = \frac{58.483 * 100^{0.212}}{(0.250 + 0.197)^{0.586}} = 248.86 \quad mm/hr$$

d = 30 minutes = 0.5 hour

$$i = \frac{58.483 * 100^{0.212}}{(0.500 + 0.197)^{0.586}} = 191.82 \quad mm/hr$$

d = 45 minutes = 0.750 hour

$$i = \frac{58.483 * 100^{0.212}}{(0.750 + 0.197)^{0.586}} = 160.28 \quad mm/hr$$

d = 60 minutes = 1 hour

$$i = \frac{58.483 * 100^{0.212}}{(1 + 0.197)^{0.586}} = 139.72 \quad mm/hr$$

d = 120 minutes = 2 hours

$$i = \frac{58.483 * 100^{0.212}}{(2 + 0.197)^{0.586}} = 97.89 \quad mm/hr$$

d = 180 minutes = 3 hours

$$i = \frac{58.483 * 100^{0.212}}{(3 + 0.197)^{0.586}} = 78.57 \quad mm/hr$$

d = 360 minutes = 6 hours

$$i = \frac{58.483 * 100^{0.212}}{(6 + 0.197)^{0.586}} = 53.31 \quad mm/hr$$

d = 540 minutes = 9 hours

$$i = \frac{58.483 * 100^{0.212}}{(9 + 0.197)^{0.586}} = 42.30 \quad mm/hr$$

d = 720 minutes = 12 hours

$$i = \frac{58.483 * 100^{0.212}}{(12 + 0.197)^{0.586}} = 35.85 \quad mm/hr$$

d = 1440 minutes = 24 hours

$$i = \frac{58.483 * 100^{0.212}}{(24 + 0.197)^{0.586}} = 24.00 \quad mm/hr$$

d = 2880 minutes = 48 hours

$$i = \frac{58.483 * 100^{0.212}}{(48 + 0.197)^{0.586}} = 16.02 \quad mm/hr$$

d = 4320 minutes = 72 hours

$$i = \frac{58.483 * 100^{0.212}}{(72 + 0.197)^{0.586}} = 12.65 \quad mm/hr$$