A STUDY ON THE EXTENT OF POND ACCUMULATION INFLUENCE ON ROADS'S HYDROPLANING PHENOMENON

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By

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ABSTRAK

Konsep “jalan yang memaafkan” ialah satu reka bentuk dan pembinaan jalan yang menghalang sebab-sebab terjadinya kesilapan ketika memandu serta mengurangkan keseriusan akibat daripada kesilapan ketika memandu. Salah satu masalah timbul berkaitan dengan konsep maafkan jalan ialah pembentukan kolam air mempengaruhi hidrosatah ketika permukaan jalan dalam keadaan basah. Oleh itu, kajian tentang sejauh mana kolam air terbentuk di Nibong Tebal telah dikaji. Dua lokasi kajian di Nibong Tebal telah dipilih. Kajian tentang sejauh mana akuasatah terjadi di Nibong Tebal boleh dilaksanakan melalui ujian kerja ukur lopak air. Kualiti permukaan jalan di Nibong Tebal pula boleh diselesaikan melalui ujian Sand Patch dan rintangan kelincir. Kesemua hasil data telah dianalis menggunakan perisian statistik SPSS untuk mencari hubungan dan korelasi di antara parameter. Selain itu, kedua-dua lokasi kajian yang terpilih menunjukkan risiko tinggi terhadap akuasatah kerana panjang lopak air ialah lebih daripada 10m. Purata kedalaman tekstur di kedua-dua lokasi kajian ialah 0.07m. Hasil data purata rintangan kelincir di lokasi kajian 1 ialah 41 dan lokasi kajian 2 ialah 50. Daripada analis pekali korelasi di lokasi kajian 1, hanya rintangan kelincir berkorelasi dengan panjang lopak air. Dengan kata lain, apabila panjang lopak air meningkat, nilai rintangan kelincir akan menurun. Lokasi kajian 2 pula menunjukkan tiada korelasi di antara parameter yang terlibat. Kajian ini boleh dilakukan menggunakan cara mengenalpasti kualiti dan keadaan jalan serta mengenalpasti hubungan di antara parameter.

ABSTRACT

"Forgiving Road" is a designed and built road that prevents the causes of driving errors and reduces the consequences of driving errors. One problem encountered related to unforgiving road is the extent of pond accumulation influence hydroplaning which usually occurs on wet pavement. Hence, study about the extent of pond accumulation in Nibong Tebal, Pulau Pinang has been done. Two study locations in Nibong Tebal were selected. The extent of pond accumulation can be accessed through pond measurement test. Otherwise, the pavement quality in Nibong Tebal can be determined through the sand patch test and skid resistance test. All the results were analysed using SPSS Statistics Software in order to establish the relationship and correlation between the parameters. Moreover, it shows that both study locations had high risk of hydroplaning because the length of pond was more than 10m. The average texture depth for both sites was 0.07mm. The result of average skid resistance in study location 1 and 2 were 41 and 50 respectively. From the correlation analysis in study location 1, it shows only skid resistance correlate with length of pond. When length of pond increased, the skid resistance value decreased. Study location 2 shows no correlation between the related parameters. The extent of pond accumulation can be identified by determining the pavement quality and relationship of the parameter.

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CHAPTER 1

INTRODUCTION

1.1 Background

In the context of this study, the meaning of forgiving road is a designed and built road that prevents the causes of driving errors and reduces the consequences of driving errors. It also allows the road user to regain control while driving and return to the travel lane without serious injuries and damages (Bald et al., 2011). A roadside is considered unforgiving when hazardous objects such as trees are placed at an inappropriate distance from the road, thus increasing the so the risk of severe accidents. The purpose of the 'forgiving roadside' concept is to avoid crashes of errant vehicles with potential hazards or to minimise crash consequences (La Torre, 2012).

The first priority of forgiving roadsides is to reduce the consequences of an accident caused by driving errors, vehicle malfunctions, or poor roadway conditions. It must focus on treatments that bring errant vehicles back into the lane to reduce injury or fatal run-off-road accidents. If the vehicle still hits a road element, the second priority is to reduce the severity of the crash. In other words, the roadside should “forgive” the driver for his/her error by reducing the severity of run-off-road accidents (La Torre, 2012).

Hydroplaning is a physical phenomenon, which appears on wet road and can cause serious accidents. Safety data reveals that a wide part of accidents occurs on wet pavement (Cerezo et al., 2010). The risk of hydroplaning exists when the speed of the vehicle is high enough to develop upward hydrodynamic pressure which is equal to or higher than the tire inflation pressure. Hydroplaning of vehicles is a very important safety concern particularly during wet-weather highway operations for highway authorities and road user (Kumar et al., 2012).

Hydroplaning phenomenon also called as aquaplaning. A report called Pavement and Geometric Design Criteria for Minimizing Hydroplaning was prepared for the Federal Highway Administration in Washington D.C. in December 1979. According to the report, variables that influence aquaplaning are surface texture, cross fall, drainage path length, rainfall, tread design depth, tyre pressure and vehicle speed. The first three factors are within the engineer's control, whereas the remaining ones are less controllable. It also stated that, "Loss of contact can occur between 64 and 72 km/h in 'puddles' of about 25 mm maximum depth and about 9 m in length." (Nygardhs, 2003).

Research from Linkoping University, Sweden stated that aquaplaning accidents are relatively rare, but could have fatal effects. For instance, in the years of 1992-1998 less than one percent of the total amount of traffic accidents was classified by the police as related to aquaplaning. Considering the low rate of accidents that can be said to be associated with the phenomenon, aquaplaning seems to be a small problem. Although small, it is a problem that could theoretically be eliminated if it was possible to predict the risks (Nygardhs, 2003).

Accidents are more likely on just wet roads than on flooded ones. Sabey says that ''…. about 60% of the wet road skidding accidents occur… when the roads are wet but it is not raining''(Sabey, Williams and Lupton, 1970). Walter J. Tappeiner (formerly President of Advanced Asphalt Technologies, Virginia, USA) stated that the probability of accidents to occur increases significantly when the texture depth of road surface is less than 0.6mm (Harun and Sarif, 2010). Another study showed that macrotexture affect the accident rates due to low skid resistance value, and wet condition road surface also increase the accident rates in France if the texture depth is less than 0.5mm(Harun and Sarif, 2010).

The aim of this study is to identify the extent of hydroplaning on wet surface. The main purpose of the work is to discover the knowledge about hydroplaning so that, accident related with hydroplaning can be prevented from happening.

1.2 Problem Statement

Traffic accidents have been a major concern in Malaysia. In the year 2000, there were 5.6 fatalities per 10,000 registered vehicles. This figure is amongst the highest in the South East Asia region. Factors contributed to traffic accidents can be divided into three main categories which are human, vehicle and road. However, engineers can only address the engineering aspects through proper design procedures and audits. There are many well developed design procedures either for geometry or structural design of the roadways. However, it appears that the importance of road surfacing, bituminous roads in particular, has been undermined by the absence of requirements on the texture depth or skid resistance (Harun and Sarif, 2010).

Changes in precipitation and extreme event were due to climate changes. The revolution of rainfall pattern in Malaysia is cause by this phenomenon. The study shows that, the phenomenon started to occur during state of Kelantan, Terengganu, Pahang, Perak and Johor in Peninsular Malaysia were hit by a catastrophic flood in December 2014. The study also shows that the value of rainfall depth at East Coast Area is in the range 20 – 100 mm. The East Coast area of Peninsular Malaysia receives heavier rainfall due to the effect of the North East Monsoon, the probability of heavy rainfall occuring is more frequent with rainfall depth more than 100 mm (Othman *et al.*, 2014)

The study location covers the area of Nibong Tebal in Seberang Perai Selatan, Pulau Pinang. New road network in Nibong Tebal was developed due to residential areas and education hub growth in the area.

This study is important to highlight the importance of road safety. The importance of this study is to identify the extent of hydroplaning on roads and how they influence road crashes. No hydroplaning studies in the Nibong Tebal area has been carried before. Further research about hydroplaning need to be explored to enhance the safety of road users while driving.

1.3 Objectives

The objectives of this study are as follow:

1. To identify the extent of pond accumulation on roads.
2. To determine the pavement quality on roads.
3. To study the relationship between parameters related to the extent of pond accumulation on roads.

1.4 Scope of Study

Chapter 2 is the literature review chapter where basic concept of hydroplaning is being defined and explained, this chapter also covers facts about important parameters with reference to previous related studies. Chapter 3 is the methodology chapter and it explains about the procedure used to conduct the tests on the road surface. The results of length and width of pond, skid resistance test and sand patch test on the road are presented in Chapter 4 which is the results and discussion chapter. This chapter also explains the quality of road based on the pavement texture including the discussion on regression and correlation analysis carried out. Chapter 5 is the conclusions and recommendations chapter and it contains conclusions that could be drawn and suggestions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Road crashes cause fatality in Malaysia. There are two types of factor that cause road crashes which are transport demand and unsafe operation. Generally, the first factor is related to traffic exposure such as high volume of vehicles and road traffic characteristic, while the another factor is basically related to risky vehicle operation pertaining to drivers, vehicle condition, roads as well as environmental influence (Andrey, Mills and Vandermolen, 2001).

Weather or particularly adverse weather condition is one of the environmental risk factors that affect the performance of all main components in a moving vehicle which includes the driver, vehicle condition and its performance, and lastly current road condition. Even now, there are insufficient research work that is related to adverse weather and road accidents carried out from local perspective but research works in many countries have proven that adverse weather in the form of snow, rain, storm, strong wind, excessive heat and fog are safety treats to all road users. Generally, adverse weather that is by and large associated with precipitation will reduce road friction, reduce the driver visibility and worsen one's driving performance (Andrey, Mills and Vandermolen, 2001).

Presently, despite Malaysia having the best road systems in Asia accident rates in the country has elevated at an average rate of 9.7% yearly (Mustafa, 2010). The reasons for high road accident in Malaysia were caused by many aspect such as the driver's carelessness, vehicle speed, braking distance, inadequate head distance and skidding especially on wet condition (Ahammed and Tighe, 2012). Connection between vehicle tyre and pavement through skidding is the major factor contributing to road crashes. During rainy day especially on wet pavement condition, severe skidding can happen. Wet pavement skidding due to insufficient surface texture or friction contributes to 20% to 35% of all wet weather crashes (Ahammed and Tighe, 2012). In addition, skidding is also one major factor contributing to road accidents during wet weather condition. When water film presents between the tyre and pavement, it reducing the friction of tyre onto the road surface that leads to skidding during wet weather (Yaacob, Hainin and Baskara, 2014).

Hydroplaning also occur on during wet pavement. It is important to understand the hydroplaning concept and the factors that affect hydroplaning. This chapter will provide better understanding on problems associated with wet surface. In addition, it also provide summary of findings from the literature in the area of hydroplaning based on pavement texture. This study will provide the knowledge on hydroplaning as it relates to road user safety.

2.2 Statistical Accident Data Related to Weather

When it comes to serious risk factor in road transportation, there are several evidence regarding weather factor especially in term of rains and snow. A synthesis of empirical studies indicates that during precipitation, road crashes usually increases from 50% to 100%. Snowfall has a greater effect than rainfall on road crashes occurrence. However, snowfall related to collision tend to be less serious that other road crashes. Canadian studies found that injury rates were elevated during snowfall relative to normal driving conditions (Andrey, Mills and Vandermolen, 2001).

In addition, risk differs depending on the form and intensity of precipitation. The greatest risk appears during freezing rain or sleet and the first snowfalls of the season. After all, the lowest risk appears when light drizzle or snow flurries. Inflated risk usually occur during rainfall related to visibility since road crashes rates will return to nearly normal after rain has stopped even when the road continues to be wet (Andrey, Mills and Vandermolen, 2001).

High winds and fog are associated with a small proportion of road crashes but have increased the risk of a traffic collision, whether acting alone or in combination with precipitation. The effects of sunlight glare, heat stress and barometric pressure had been considered from a few research studies about the road crashes risk but the evidence is inadequate to draw any definitive conclusion. Few research studies consider the interaction between adverse weather and other risk factors, but there is some evidence showed that weather effects are particularly acute at night and on roadways with a gradient with and without curve (Andrey, Mills and Vandermolen, 2001). Table 2.1 and Table 2.2 shows the empirical research on the relationship between weather and traffic accident risk.

Table 2.1: Empirical Research on the Relationship Between Weather and Traffic Accident Risk (Andrey, Mills and Vandermolen, 2001)

Reference and Author Affiliation	Spacial and Temporal Context of Study	Main Conclusions
Andrey, Mills, Leahy & Suggett, 2001 Geography, U. of Waterloo	6 Canadian cities 1995-1998	Precipitation was associated with a 75% increase in traffic collisions and a 45% increase in related injuries.
Khattack & Knapp, 2001; Knapp, 2001; Knapp, Smithson & Khattak, 2000 Iowa State University	Iowa interstates 1995-1998	Crash rates increased by approximately 1000% during severe winter storms.
Suggett, 1999 U. of Regina	Regina, Canada 1991-1994	Driving during a snow event was twice as likely to result in a crash, and 70% more likely to result in injury. The risks of collision and injury were lower for rain than for snow. Periods of elevated risk caused by residual snow lasted up to a week after measurable snow had fallen.
Edwards, 1996 U. of Wales College	England and Wales 1980-1990	In most counties of England and Wales, 4% of road collisions occurred in high winds, 1 to 2% in fog, and less than 1% in snowfall.
Lane, McClafferty, Green & Nowak 1995, Victoria Hospital and U. of Western Ontario	401 Highway and feeder highways near London, Ontario. 1984-1990	8% of fatal accidents and 9% of injury accidents occurred during rain. 12% of fatal accidents and 16% of injury accidents occurred during snow. 13% of fatal crashes and 16% of injury accidents occurred on wet roads, while 13% of fatal accidents and 18% of total injury accidents occurred on snow covered roads.
Levine, Kim & Nitz, 1995 University of Hawaii	City and County of Honolulu 1990	For every inch of rainfall, there were approx. 13 more collisions per day.
Shankar, Mannering & Barfield, 1995	I-90 in east Seattle, USA	A 1% increase in the number of rain days resulted in a 0.26%

Table 2.2: Empirical Research on the Relationship Between Weather and Traffic Accident Risk (Andrey, Mills and Vandermolen, 2001)

Reference and Author Affiliation	Spacial and Temporal Context of Study	Main Conclusions
University of Washington	1988-1993	increase in collision frequency. A 1% increase in the number of snow days resulted in a 0.10% increase in collision frequency. There is an interaction between weather and roadway geometrics.
Edwards, 1994 U. of Wales College	England and Wales 1980-1990	The presence of high winds (>22 knots) appeared to double collision risk.
Andrey and Yagar, 1993 University of Waterloo	Calgary and Edmonton, Canada 1979-1983	Collision risk during precipitation increased by 70%.
Pike, 1992 Meteorological Magazine	United Kingdom March 29th, 1986	3 major traffic collisions occurred on motorways when drivers reacted in variable ways to heavy hail showers.
Perry and Symons, 1991 Geographical Magazine	Wind storms in England Especially January 1990	Winds storms can result in death, injury and structural damage. Strong winds effect vehicle steering and can cause overturn. Wind can also cause instability in bridges, due to static and dynamic forces.
Andrey & Olley, 1990 Geography, U. of Waterloo	Edmonton, Canada 1983	2% of summer accidents occurred on wet roads, while 40% of winter accidents occur on wet/snowy/icy roads.
Brodsky and Hakkert, 1988 Geography, U. of Maryland	Israel, 1979-1981 United States, 1983-1984	Rain is responsible for approx. 14% of injury accidents.
Campbell, 1986 City of Winnipeg	Winnipeg, Canada 1974-1984	Temperatures below -15°C contribute to greater rates of vehicle collisions than do temperatures between 0 and -15°C.
Mercer, 1986 CounterAttack Program, BC	British Columbia, Canada 1984	Weather related traffic accidents constituted 11.1% of total accidents. Of these, it was raining 42% of the time and snowing 19% of the time.

2.3 Statistical Accident Data Related to Surface of Road

Figure 2.1 and Figure 2.2 shows the percentage of accidents on different type of surface condition such as dry, flood, wet, oily, sandy and being repaired in year of 2004 until in 2014. In Malaysia, the highest accidents occur during dry condition for about 89.7% and 8.89% accident occur during wet condition. Majority accidents occur during wet condition compared to flood, oily, sandy and repaired road. Even though, the value is relatively small but accident still can occur and are influenced by wet condition surface.

In Seberang Perai Selatan, the highest accidents also occur during dry condition for about 79.84% and 7.51% accident occur during wet condition. From the figure, accident during wet condition was high compared to flood condition.

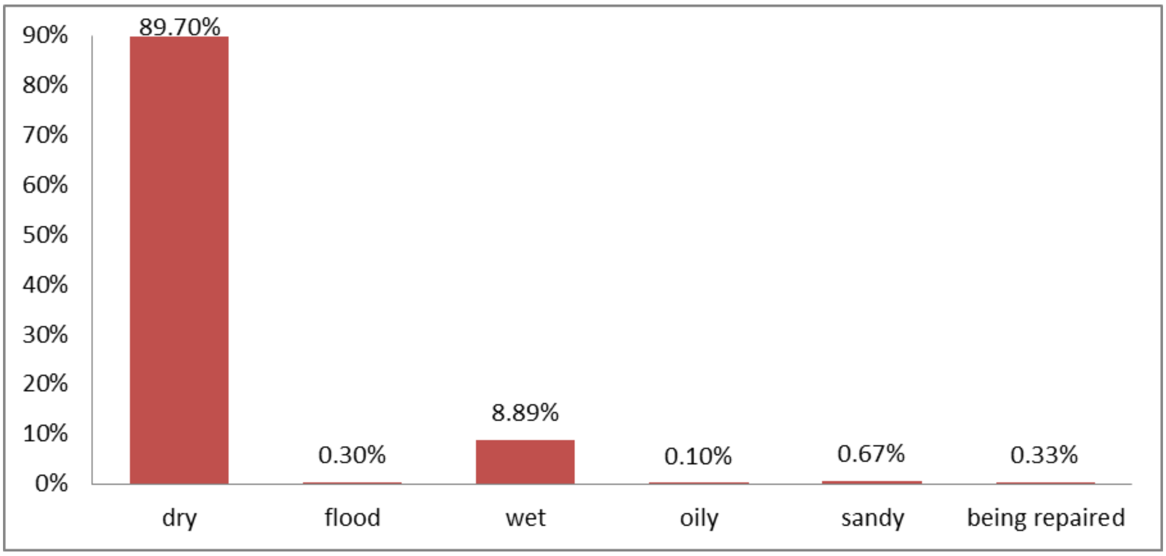

Figure 2.1: Percentage of Accidents on different Surface Condition from year 2004 to 2014 in Malaysia (MIROS, 2016)

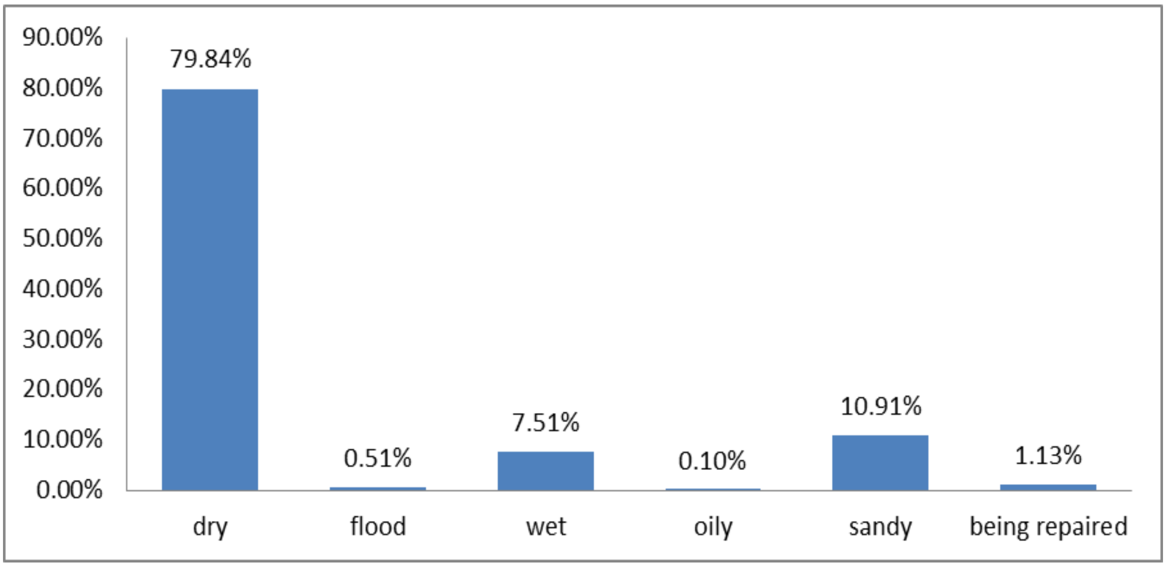

Figure 2.2: Percentage of Accidents on different Surface Condition from year 2006 to 2014 in Seberang Perai Selatan (MIROS, 2016)

2.4 Statistical Accident Data Related to Hydroplaning Phenomenon

Accidents related to hydroplaning are relatively rare but could have fatal effects. Less than 1% total amount of road crashes was classified by police to be related to hydroplaning in the year of 1992 until 1998. The low rate of road crashes shown associated with the phenomenon, hydroplaning seems to be a small problem. Even though small, it is a problem that should be eliminated if it was still possible to create danger the road user. Majority of driver do experience partial hydroplaning phenomenon on road compared to full dynamic hydroplaning (Nygardhs, 2003). Partial hydroplaning will occur as long as there is any significant amount of water present (Gallaway, 1975). Meanwhile, full dynamic hydroplaning occurs when the drainage capacity of the tire tread pattern and the pavement surface is exceeded and the water begins to build up in front of the tire. As the water builds up, a water wedge is created and this wedge produces a force, which can lift the tire off the pavement surface (WSDOT, 2010).

Another report by the Road Research Laboratory Report studied the influence of road surface condition towards traffic safety. From this research study, it shows that rut depth influences the rate of hydroplaning accidents compared to crossfall did in the year of 1992 until 1998. However, this study looked upon the rut depth and crossfall unrelated to other road surface characteristics, but with the amount of precipitation per day as an additional influencing factor (Nygardhs, 2003).

Water on the roadway was a major factor in road crashes. Others reason include hydroplaning phenomenon, skid resistance reduction which will adversely affects vehicle control. Basically, wet pavements as the result of hydroplaning are the reason for many road crashes or accidents. In particular, the correlation between surface texture and hydraulic roughness will help an engineer to determine whether a hydroplaning problem exists for a given rainfall intensity (Design, 1994).

It will be observed from the foregoing analysis that 97% of the accidents suspected of hydroplaning occurred during actual rain, a great majority being under medium and heavy rain. 81% of the time, water was accumulating on the road to some degree. Ruts in the wheel paths did not appear to have much bearing on hydroplaning since they were reported in only 25% of the cases (Enustum, 1976).

2.5 Issues or Problems Related to Road Surface during Rainfall (Weather Factor)

According to Institute of Road Safety Research in Netherlands, they modelled the daily numbers of casualties under both dry and wet weather condition and studied the impact of precipitation under various combination of condition. The conditions are including the season, type of road and crash. This study is to estimate the effect of precipitation on road safety. Models that relate to the total number of crashes proven that the amount of precipitation cannot identify whether more crashes coinciding with more precipitation are in fact crashes caused by that precipitation (Bijleveld and Churchill, 2009).

Even when fewer casualties are registered under wet conditions, it may still be far more dangerous. Therefore, careful consideration is needed as to precisely what effect was measured such as the effect on crash rate or the aggregated effect. It much more dangerous during rainfall as lesser people travel lead to lesser road crashes happened (Bijleveld and Churchill, 2009). Highway pavement covered by a layer of water can become hazardous when driving. It may difficult to control the vehicle especially at higher speeds when a pavement with a layer of water fails to offer the needed amount of friction even for a highly skilled and alert driver (Design, 1994).

The dominant issue encountered during the heavy rainfall is the erosion activity created by surface runoff due to flow of water across the roads. The erosive impact due to flow of water cause potholes on roads. The second issues encountered when drainage system is used in carrying surface runoff and loosened soil particles. Normally particles often settle out where there are blockages in the drainage system, thus decreasing the carrying of the ditch and in turn causing water accumulation on roads. Water ponding is formed cause by the surface runoff and impact of roadway erosion. The drainages are blocked with manmade material or non-source materials because of deficiency of drainage system on roads. It disallows the flow of water to rivers, stream or dams and frequently causing water ponded in the adjacent road. It is also proven that the type of drainage system does not contribute to road deterioration but it related to the bad effect of surface runoff on the roads (Musa, Abdulwaheed and Saidu, 2010).

During rainfall, the physical effects of weather on road surface friction and driver visibility were focused. Road surface friction can be predicted with a fair degree of accuracy given detailed information on the storm, road, vehicle, and traffic conditions. Similarly, a number of factors are known to affect driver visibility especially precipitation and fog intensity but also focus on droplet size, blowing snow, snow bank obstructions at intersections, wiper speed, and splash and spray from other vehicles (Andrey, Mills and Vandermolen, 2001).

For wet roads and light rain and snow, adjustments are usually minimal and travel speeds typically exceed the posted speed limit. For more intense precipitation and for situations where compound hazards are present such as slippery roads and reduced visibility, average speed reductions of 15 to 50% have been reported (Andrey, Mills and Vandermolen, 2001).

Snow accumulated along the road usually becomes heavily loaded with traffic pollutants via splash and spray if let them lying a long period of time. Furthermore, the deposition rates of pollutants to the snow banks along heavily trafficked roads may be high. Increased amount of snowfall resulting increased the concentration in the snow banks. Resulting from deicing with NaCl with the help of ions, it increased the solubility of heavy metals. Often occurring without a coinciding heavy rainfall which would have diluted the solution, the first flush following the snow melt has high concentrations of most water-soluble pollutants. This flush mobilises considerable amounts of pollutants, often over a short period of time (Dawson, 2008).

Poor road condition is primarily caused by overloaded vehicles on the road and it lead to distress of pavement. Repeatedly pavement distress leads to increase of maintenance costs and more frequent repairs. The overloaded vehicles affect significantly the fatigue life of pavement structures. The analysis has shown that the increase of percentage of overloaded vehicles from 0% to 20% can reduce the fatigue life of asphalt pavement in a range of 50% (Rys, Judycki and Jaskula, 2015).

2.6 Definition of Hydroplaning

Aquaplaning or in American literature referred as hydroplaning usually occurs when the tyre of a vehicle is totally separated from the pavement by a continuous layer of water (full dynamic aquaplaning). The friction is then almost zero and the driver will have severe difficulty steering the vehicle. The condition of small, but not zero, friction is called partial hydroplaning. These can be divided into the viscous, the dynamic, and the tyre-tread-rubber reversion hydroplaning (Nygardhs, 2003).

2.6.1 Dynamic Hydroplaning

Dynamic hydroplaning occurs when a moving tire is completely separated from the pavement by a layer of water. As the tire moves over a wet surface, the bulk of the water is normally removed by the normal force of the tire squeezing the water from beneath the tire footprint through the grooves in the tire and the texture in the pavement. Dynamic hydroplaning usually occurs at speeds above 72 km/h.

Other research study also shows, dynamic hydroplaning typically occurs when vehicles travel at speeds in excess of 80km/h which resulting in inadequate time for water to be removed from underneath the tyre (Cenek *et al.*, 2014). Even if the surface of the road is drained and texture is high, dynamic hydroplaning may occur, because the tyre is incapable of transporting water away from the road fast enough. The risk of dynamic aquaplaning increases with speed.

2.6.2 Viscous Hydroplaning

Viscous hydroplaning occurs on a flat surface with low texture, viscous aquaplaning can occur. A continuous water film between the tyre and the road surface is then the result of too little microtexture. Viscous aquaplaning happens mostly when speed is high but can occur at any speed at small water amounts.

2.6.3 Tyre Tread Rubber Reversion Hydroplaning

A third type is the hydroplaning which occurs at high pressures between tyre and road surface when heavy vehicles such as lorries and aeroplanes lock their tyres at roads with good macrotexture but bad microtexture. The temperature between the tyre and the road increases when brakes. The result of the warmth is that the vehicle slides on a mixture of heated rubber from the tyre, water and fumes. Accidents due to full dynamic aquaplaning are comparatively rare. However, partial aquaplaning is a phenomenon experienced by many drivers and could have serious road crashes.

2.7 Factors Affecting Hydroplaning

A sudden loss of directional control usually startled most drivers who experience hydroplaning phenomenon. Hydroplaning usually happened under a wide variety of wet weather conditions. Even though sudden loss control can occur under heavy rainfall with very high vehicle speeds but it also can occur right after rainfall with moderately high vehicle speeds on pavement with very little texture. Therefore, if pavement had wheel ruts with long pavement drainage that allows critical water depths hydroplaning can form during moderate rainfall.

After a while, road crushes involving hydroplaning phenomenon become more apparent as the vehicle speed increased, wider pavement were built, asphalt pavements become more wide spread and greater pavement were occurred because of traffic increased and heavier loads. Hydroplaning known to be associated with several factors. When hydroplaning on wet pavements increases with roadway and environmental factors that increase water depth and with driver and vehicle factors that increase the sensitivity to water depth as follows:

- Roadway Factors (affecting water depth)
- Environmental Factors (affecting water depth)
- Driver Factors (affecting sensitivity to water depth)
- Vehicle Factors (affecting sensitivity to water depth)

2.7.1 Roadway Factors

2.7.1.1. Compacted Wheel Ruts

The meaning of rut depths is the depth made by heavy vehicles and wear caused by studded tyres in the wheel trucks. With the help of regression analyses from 1992 until 1998, it shows that rut depth influences the rate of hydroplaning road crashes compared to crossfall factor. According to a study by the Department of Civil and Environmental Engineering at the University of Wisconsin Madison in the USA treated pavement rutting and safety consequences, statistical analyses revealed that the accident rate was significantly increased for rut depths exceeding 7.6 mm. This value was also the water depth limit at which hydroplaning could occur, according to laboratory tests carried out (Nygardhs, 2003).

Water that was situated at slopes was considered to flow down the road. Thus, other important possibility was due to heavy rainfall the ruts in the road were filled with water at the same rate as it was flowing down the slope. The result from this would therefore be a continuous accumulation of water. Moreover, hydroplaning may occur on ponded ruts. Irrespective of whether hydroplaning does occur or not, a wet surface will have lower skid resistance than its dry spot (Nygardhs, 2003).

2.7.1.2. Pavement Texture

The main properties that highlight involving skid resistance of road are their macrotexture and microtexture. Generally, macrotexture in the range of 0.5 to 15 mm and microtexture in the range of up to 0.5 mm but both texture were important in determining overall skid resistance on road. Figure 2.1 below shows the both texture of a pavement surface. The texture depth is the depth between the emerge edge of the aggregates to the binder (Harun and Sarif, 2010).

Fine texture of the exposed aggregates is important in the design of non-skid flexible surfaces. It can be examined microscopically, but for routine purpose, it is generally assessed by measurements of the coefficient of friction determined by a rubber slider moving over a prepared sample of the aggregate set in cement mortar bed (Harun and Sarif, 2010).

Basically, both textures affect the skid resistance of a pavement. The microtexture contributes largely for skid resistance at low speed whereas both the microtexture and macrotexture are relevant for skid resistance at high speed, but the macrotexture is more predominant under wet conditions. Road surfacing with relatively high macrotexture depth also has better drainage capability and this can reduce the risk of hydroplaning. Normal considerations consider the wet surface especially during rains as the most critical level for skid resistance. Hence, skid resistance testing is carried out with the present of water. Dry pavements are usually not slippery, but there are a number of things that can make a pavement slippery which sometimes worse than wet surface. Slippery may also develop from surface contamination, such as the oil spillage or certain types of loose particles (Harun and Sarif, 2010).

Macrotexture, which provides rapid drainage routes between the tyres and the road surface, contributes to skidding resistance particularly at high speeds. The measurement of macrotexture is referred to as ‘texture depth’ and is most commonly estimated by the sand patch test and by laser (eg. the British TRL Mini Texture Meter). The characteristics of aggregates, such as geological group, particle size and differential wear of mixtures of two or more stones have also been thought to influence resistance to skidding (Harun and Sarif, 2010).

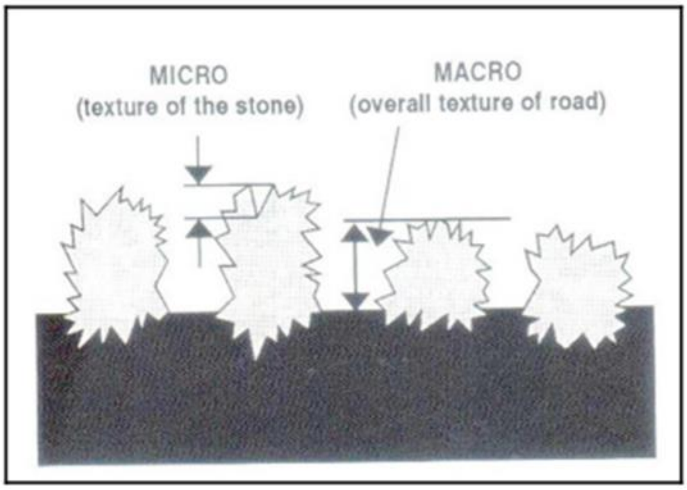

Figure 2.3: Texture Depth (Public Works Institute, Malaysia (IKRAM), 1994)

2.7.1.3. Pavement Crossfall

Insufficient of pavement crossfall and pavement surface characteristic can cause skidding on road. If there is sufficient friction between tyre and pavement, skidding can be prevented. As discussed before, pavement surface characteristic play important roles in providing comfortable driving and safety to drivers. Pavement crossfall is another important element in providing friction between tyre and pavement. Whenever water available on road, it can eventually create hydroplaning thus contributes to skidding. Thus, crossfall in highway construction also take important as to reduce water ponding on pavement during rainfall (Yaacob, Hainin and Baskara, 2014).

From the study research about Effect of Rainfall Intensity and Road Crossfall on Skid Resistance of Asphalt Pavement prove that the lower rainfall intensities, bigger crossfalls and bigger surface texture generate a bigger Pendulum Test Value (PTV) which indicates a good tyre pavement contact. Bigger crossfall and bigger surface texture will eventually help to minimize skid thus increasing the safety of road users (Yaacob, Hainin and Baskara, 2014).

2.7.2 Environmental Factors

2.7.2.1. Rainfall

Influential parameter that can affect transportation performance on road was weather. The intensity of light and rainfall are among other factors that contribute to the changes of speed and travel time during driving (Tsapakis, Cheng and Bolbol, 2012). Presently, there are only a few research works on tropical weather impacts on transportation system especially rainfall at night. Impact on road safety in Malaysia can be influenced by snow, fog, hurricanes although is not that extreme (Hassan *et al.*, 2016).

Basically, the water accumulation on the pavement surface is both due to the local rain and to the water flow coming from neighborhood. In addition, highest declivity cause water to flow according the line (Cerezo *et al.*, 2010). Ruts in the road were full filled with water due to heavy rain may had the same rate as it was flowing down the slope. Therefore, there were form a continuous accumulation of water (Nygardhs, 2003).

The precipitation term referred to the products from the process of condensation in the forms of snow, rain or hail. It is proven that relationship of precipitation and road transportation toward accident rate was significant compared to accident rate during dry weather. Moreover, rainfall will principally affect the road surface performance and visibility of the driver. The two important aspect of tyre pavement friction problems are depth of water on road surface and the duration of time that the road is in wet condition. Other than that, it also focused on pavement texture, travel, speed, tyre thread, tyre air pressure and temperature.

Rainfall cause the presence of water or film on water on road surface creates hydroplaning phenomenon. When frictional force is reduced between tyre and road surface that caused by the pressure increase of the water film above the contact pressure of tyre and road during hydroplaning phenomenon. Furthermore, thin film of liquid on the road surface can formed from drizzle. When water meet road surface that consist of oil and dust for a long time it can cause viscous hydroplaning. This situation also decreases the road friction especially during heavy rainfall. All the findings depended on the methodology used and also the limitations of related data (Jawi *et al.*, 2009).

2.7.3 Driver Factors

2.7.3.1. Speed

Hydroplaning speed is defined as the maximum speed reached by the vehicle under given conditions, where hydroplaning phenomenon occurs. This speed depends both on infrastructure characteristics and vehicles characteristics. Previous studies proved that the following characteristics managed hydroplaning speed which is water film thickness on the road, pavement texture, tire pressure and thread depth and load (Cerezo *et al.*, 2010).

When the vehicle speed is rather low as 30 km/h, the water film thickness is the same on the front and the rear wheels. The recovering speed of the water is superior to the speed of displacement of the wheels. When the vehicle speed increases, the water film thickness can decrease until 30% between the front and the rear wheels, which make an important change in hydroplaning speed considering the fact that the hydroplaning forces are not the same. Moreover, hydroplaning occurs in most of the case at high speed as 80 km/h to 90 km/h when the water thickness is rather different between the two axles. Considering the fact that the tire treads depth and the tire pressure are not necessarily the same for all the wheels in the model, the model can determine the first wheel, which is hydroplaning by assuming the fact that in specific case hydroplaning can occur on the rear wheels before on the front wheels (Cerezo *et al.*, 2010).

In another research study defined hydroplaning occurs when the vehicle's wheel speed was sufficiently high to raise the fluid uplift force to the magnitude of the wheel load. At this situation, there was no contact between the tyre and the pavement surface. The force between the tyre and pavement surface was diminish. Hydroplaning speed known as a speed so that hydroplaning phenomenon can happened. Hydroplaning speed was one of the measures used for investigating the hydroplaning potential of wet pavement with a known water film thickness. It shows that the higher the hydroplaning speed, the higher the hydroplaning potential (Ong and Fwa, 2007).

The determination of hydroplaning involves a trial and error process. Starting at zero vehicle speed, the model computes the initial footprint of the tire created at the tire–pavement contact surface under the action of the wheel load. The wheel load is transmitted from the rim through the tire. With this initial footprint, the sliding of the locked wheel is simulated by application of a predefined increment of sliding speed. The hydroplaning simulation analysis is conducted in two stages. First, from the speed of 0 km/h, a relatively large increment of sliding speed of 5 m/s (18 km/h) is applied, and a simulation run is executed, followed by another speed increment and a simulation run. The process is repeated until the fluid uplift force matches or exceeds the wheel load. This result provides a rough estimate of the hydroplaning speed. Next, starting from a sliding speed slightly lower than the rough hydroplaning speed estimated in the first stage, the sliding speed is increased at a small speed increment of 0.1 m/s (0.36 km/h) to determine the hydroplaning speed more accurately (Ong and Fwa, 2007).

2.7.4 Vehicle Factors

2.7.4.1. Tyre Tread

Skidding appears when there were insufficient friction between the pavement surface and the tyre of vehicle when driver aim to make some movement. This happens when the vehicle is move by the exerted forces at that stationary area where the friction between the tire and the road surface opposes to the force movement. Generally, dry road surface condition had higher tyre friction compared to wet road surfaces had lower tyre friction that can easily cause skidding accident (Yaacob, Hainin and Baskara, 2014).

An experimental study on road surface was carried out. The study was conducted to find significant differences in performance between tyres of different widths. Dynamic hydroplaning was not accomplished even for speeds over 100 km/h when condition of tyre thread of 4 mm and water depth above the aggregates about 7 mm. However, partial hydroplaning caused an unacceptable low friction value. The study justify that at least down to 4 mm tyre tread depth, the tyre width could not be concluded to be of significance for gripping power (Nygardhs, 2003).

At a given speed, the braking force between the road surface and the tyre depends on road characteristics, tyre characteristics and the amount of water. At dry and pure wet surfaces the braking force was acceptable, independently of the type of tyre used, if texture was rough enough. Even on smooth surfaces with good