Impact of tire and traffic parameters on water pressure in pavement

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ABSTRACT

It is generally believed that, irrespective of pavement type, the water on the pavement surface or water build up in the internal voids, or water pressure through cracks due to traffic action plays a significant role for the functional and structural failure of the pavement. Although extensive studies on water related material degradation have been conducted in the last fifty years, research on measuring water pressure due to dynamic action of load and its impact on pavement performance is very limited. The influence of tire characteristics on asphalt surfaces is also very limited. This study attempts to address the impact of water and tire parameters in the pavement subjected to dynamic loading. The idealised pavement consisted of 100mm concrete slab with 2mm continuous fissure. The concrete pavement was overlaid with 20mm semi permeable asphalt surface to evaluate the influence of asphalt surfaces on the water pressure. The slabs were submerged with 2mm and 4mm water and were subjected to 5kN and 10kN loads applied at 1Hz, 5Hz, 10Hz and 15Hz. The loading plate was designed to simulate new and part worn tires with a square and a square with channel pattern with up to 8mm thickness to represent tread characteristics. It was found that dynamic water pressure increases significantly when high frequency loading combined with square type of tread, and water trapped inside the groove which generates pumping action. The water pressure also increases with thread thickness. Load magnitude and depth of surface water have marginal impact on the water pressure in the pavement.

Author Keywords: pore water pressure; tread pattern; frequency; load, water depth; asphalt, stone mastic asphalt, concrete

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INTRODUCTION

The adverse impact of water on pavement performance is a well-known concern in the pavement engineering community. Studies on water related distresses are predominantly manifested towards material degradation due to loss of adhesion and/or cohesion of the mixture matrix for asphalt pavement or failure of joints and foundation in concrete pavement. In addition, many modern types of asphalt road surfaces, such as stone mastic asphalt (SMA), thin surfacing or porous asphalt, experience premature failure such as ravelling, leading to pothole and/or other structural failure. It is generally believed that the water on the surface or water build up inside the pavement exacerbates this pressure, which may result in pavement surface layer spalling or loosening, leading to localised and eventually structural damage (Kim *et al.*, 2008; Willway *et al.*, 2008; Karlson, 2005; Lindly, Jay K., Elsayed,Ashraf S., 1995).

In asphalt pavement, the water pressure is dependent on tire characteristics (tire pressure, tread shape, depth, and patterns), traffic characteristics (magnitude, speed) as well as mixture configurations such as size and gradation of aggregate, void content and level of compaction. For example, in dense and close graded surface course (voids less 4%), the water infiltration is relatively low and slow, whereas water drains freely in high void content mixtures such as in porous asphalt. Uniformly graded mix with intermediate void content, 6%-12%, may experience water infiltration and water storage within the mixture. In addition, water may also pass through cracks or blocked interconnected voids caused by debris, and creates capillary force at the interface when subjected traffic, which may eventually be damaging to interconnected bonds by adhesion failure. In concrete pavement, water infiltration through crack/joints can lead to water pressure generated at the bottom of the slab when traffic passes through the water-filled crack/joint. This can potentially lead to under stab voiding and poor load transfer efficiency of the joints/crack (Mathavan, S., Rahman,M., Martyn Stone-Cliffe Jones., 2014).

In the available literature on water pressure in pavement, most studies are found to be computational and/or analytical. Experimental studies are extremely limited. This is primarily due to the complexity of measuring water pressure under traffic load in the laboratory environment as well as in the field condition. This study therefore, concentrates on developing a laboratory test to measure water pressure under a repeated vertical load when pavement surface is subjected to flooding with various depth of water. The effect of load magnitude, load frequency, tire tread shape, and patterns, and depth of water on the surface are investigated. This paper covers two aspects of water related issues in asphalt pavement. In the first section, a brief overview of previous studies together with tire tread characteristics and the concept of tire-water-pavement interaction are reviewed. The second part describes the test set-up and presents the influence of tread pattern and depth, load frequency and load magnitude on pore water pressure on two idealised pavement structures. Finally, key conclusions are presented.

PAST STUDIES ON WATER PRESSURE MEASUREMENT IN PAVEMENT

Xiaoyong (2008) developed a theoretical model whereby the asphalt pavement was regarded as an axially symmetrical body of multi-layered saturation elastic half space(Cui<i> et al.</i>, 2009)(Cui<i> et al.</i>, 2009)(Cui<i> et al.</i>, 2009). The pore water pressure in asphalt pavement under mobile load was calculated. The results demonstrated that the pore water pressure in the internal asphalt pavement has a close relation to the permeation coefficient of surface, surface thickness, wheel speed and material parameters. The pore pressure at the interface between surface layers and the base layer of the asphalt pavement is maximized when the pore of pavement is entirely saturated, under the loading action. Under the repeated action of loading, the pavement fatigue cracking may happen, a process which accelerates the development of the cracking of asphalt pavement.

Li and Sheng (2012) applied the finite element method built on the porous elastic theory to replicate the pore water pressure produced in the base layer of rigid pavement under the vehicle load. They stated that the maximum pore pressure is created in the middle depth of the base layer. The pore water pressure of this position is investigated to evaluate the base layer performance under different vehicle speeds, the difference between pore water pressure when vehicles speed is 10m/s and 60 m/s is 1.91 kPa. The numerical simulation results indicated that the dissipation time decreases with increasing vehicle speed, 1.04s at 60 m/s and 1.37s at 10 m/s. The results also displayed that the high vehicle speed has a high impact on base erosion (Li and Sheng 2012). Other method such as the Finite Difference Method (FDM) and the Biot Dynamic Consolidation Theory were applied to investigate the dynamic response of the saturated asphalt pavement, the results demonstrated that the positive pore water pressure under wheel is associated with pumping action. However, the negative pressure refers to the suction in pavement surface where water is sucked cyclically under traffic loading. This suction increases with vehicle speed leading to increase dynamic pore water pressure (Cui et al. 2009) . A three-dimensional fluid flow model was built on Lattice Boltzmann to study the unsteady dynamic fluid flow in asphalt pavements (Kutay and Aydilek 2007). This study investigated samples with different hydraulic conductivity resulting from aggregate angularities, orientations and fine distribution. Taking into account these samples have the same nominal size of aggregate and same compaction energy. It is stated that dynamic fluid pressure influences the moisture transport inside the asphalt concrete.

There are a limited number of studies found in the literature that have experimentally tried to measure and evaluate the impact of water pressure in the overall pavement structure. The experimental study by Jiang *et al* ,

(2013) generated dynamic water pressure in a cylindrical asphalt concrete specimen by compressed air, the specimen base wrapped with epoxy resin glue to orient the flow of water through voids in the specimen into an established space. It was stated that dynamic water pressure on asphalt surface depends on the load magnitude. Jiang *el al* (2013) also reported that the excess water pressure decreases the frictional strength of the structural part of the road and foundation materials by generating buoyancy inside these materials (Cook and Dykins 1991; Kutay and Aydilek 2007). Excess pore water pressure can be formed inside the subgrade and pavement structural components by tire influences (Ridgeway 1982).

Yuan and Nazarian (2003) demonstrated from laboratory and in situ investigations that moisture content has significant negative impact on road base and subgrade materials. Since the pavement ability to transmit dynamic loads is forced by traffic, the performance can be greatly deteriorated because of deterioration of foundation support (Moulton 1980). The movement of the wheel on the asphalt pavement with a saturated subgrade can generate a moving pressure wave that in turn can produce large hydrostatic forces inside the structural section. The specific aspects of pulsating pore pressure considerably influence the load carrying capacity of the whole structural component of the flexible pavement (Cedergren et al. 1973). These conditions can create excessive deflection, cracking, decrease in the load carrying capacity, ravelling and disintegration of asphalt mixes, subgrade instability, pumping, and loss of support (Lindly and Elsayed 1995; Flynn 1991). However, none of the previous research systematically investigated the impact tire characteristics during dynamic loading on the pore pressure in the asphalt surface.

TIRE TREAD CHARACTERISCES

Tires with different tread designs are used for controlling the noise, providing good traction in wet condition and ensuring a comfortable ride for various driving styles. There are four primary types of tire tread, namely, symmetrical, directional, asymmetrical, and directional asymmetrical these characterised by the geometrical shape of the grooves, ribs, sipes, dimples, blocks and shoulder as shown in **Figure 1.**

Figure 1. Schematic diagram of tread pattern based on the geometrical shape of the tread component

The detail explanation of each tire type, advantage, and limitations can be found in the literature (Heisler 2002; Hanson et al. 2004; Gent and Walter 2006; Bodziak 2008; McDonald 1992). It is evident that the actual tread shape and pattern in real tire is complex, however, most tires tread have two general characteristics in common.

The first one is a channel to remove water quickly from the contact area (act like a water channel to avoid aqua planning) and the second one is a rain groove (voids to ensure traction) to pump water out from under the tire by the action of the tread flexing. However, under dynamic loading, the characteristics of these elements interact and there is a combination of pumping, and splashing happen at the same time. A conceptual explanation is given in the following section.

CONCEPT OF TIRE-WATER-PAVEMENT INTERACTION

When water enters the asphalt surface, it creates hydrostatics pressure due to the action of moving vehicles. The magnitude of pressure varies, depending on the surface type, tire tread depth and presences of existing distresses on the surface. The conceptual illustration of tire-water-pavement interaction is shown in Figure 2.

Figure 2. Conceptual illustration of tire-water-pavement interaction

The interaction of tire pavement can be divided into 3 zones when rolling on a wet surface (Cerezo et al. 2014) zone 1 is the major part to drain the stagnant water film covering the road surface, and this part depends on the water depth, the speed, tire tread depth and the road surface macrotexture. With increasing speed and water depth, it will be more difficult to drain the water from the road surface, thus creating a possible scenario for water infiltration and moisture damage. However, with the help of tread depths this can be minimized. After pass through the zone 1, the remaining water on the surface goes to zone 2, or middle zone and this zone is responsible for the final removal of water, this assisted by sipes and grooves along the contact patch. The squeezing of water on zone 2 will dissipate the remained fluid to all directions; especially to beneath the tread blocks and ribs, and this pressure may cause further infiltration in pavement. The water film in zone 3 has almost completely been squeezed out, so in this region the contact between the tire and pavement start, to happen.

The prone zones to develop water infiltration and overpressure on micro voids **(Figure 2)** are 1 and 2 because in these areas the amount of water still high and not totally dissipated. Thus, in roads with cracks, the possibility to create moisture damage problems is higher than new roads because of distresses already present on the surface. The water is a relatively difficult fluid to drainage when compared with air for example Dixon (1996). The density of water is approximately 999.2 kg/m³ and viscosity is 1.14×10^{-3} Ns/m². Therefore, the water after being squeezed out from the longitudinal channels will be directed sideways to help drainage. Dixon (1996) demonstrates a “drainage” number to explain the problem with water drainage through the tread channels. It is a non-dimensional measure and correlates the cross-sectional area of the channel in front view, divided by the cross-sectional area of the approaching water. According to this, if the number is greater than 1.0, the channels will be sufficient to drain the water, however if the number is less than 1.0, the tire will need the help of lateral drainage to provide good flow of water. The time of the contact of the tire is extremely important as well, for example, if the car is at in high speed it will be more difficult to drain the water compared with slow speed. According to Dixon (1996) the time that the rubber contacts with the footprint is normally 6ms at a speed of 30m/s and the water will be drained in only 2 or 3ms.

EXPERIMENTAL PROGRAMME

An investigation has been conducted to study the influence of tread depth, tread pattern, loading range and frequency range and water depth on the magnitude of water pressure under dynamic loading. It should be noted that simulating tire pavement interaction and related water pressure accurately in real pavement and even in the laboratory environment is extremely difficult due to the complexity of tire interaction with the pavement structure, material and influence of other factors such as layer deboning, vehicle speed, tread shape and pattern, for example. The primary aim of this study was therefore to evaluate how tire parameters influence water pressure in an idealised situation (simplistic pavement structure). Careful considerations were given when selecting load platen, tread characterises and test parameters. A brief explanation of loading platen and experimental set-up is given in the following sections.

Loading platen, tread pattern and tread depth

A picture of the custom build loading device and rubber pad to represent idealised tread pattern and tread depth used in the experiment is shown in **Figure 3.** The concept was adopted from earlier work by Rahman and Thom (2012). The dimension of the loading device (as shown in Figure 3a) was based on the concept that a truck tire patch is approximately 300 mm in diameter, so this was scaled down three times to 100mm. A 12mm rubber pad with different tread pattern and thickness (as given below), to simulate tire characteristics, was attached to the loading platen by adhesive.

- Tread pattern: a squared box (SQ) to represent Sipes, groove and dimple of the tire and a square box with a channel (SL) to represent block and ribs of the tire and non-treaded tires (NT).
- Tread depth: 8mm tread depth to represent new tire, 3mm to represent part worn tire and 1.5mm to represent worn tire.

Figure 3a) 100mm X100mm loading head

Figure 3b) Rubber pad representing tread pattern and shape

Figure. 3. Loading device

Idealised pavement

The idealised structure was adopted to represent two scenarios in pavement construction.

Scenario 1: Figure 4a represents an idealised concrete pavement, for which a 40mm rubber pad was used to represent the pavement foundation.

Figure 4a. Idealised pavement

Scenario 2: Figure 4b represents an idealised asphalt pavement. A 100mm concrete slab was to represent the asphalt concrete and base layers and a 40mm rubber pad to represent the pavement foundation. The concrete slab eliminates the possibility of water infiltration to a lower layer, which would be the case with an asphalt binder layer.

Figure 4b: Idealised pavement with asphalt overlay

Test Set-up

Two C40 concrete slabs (300mm x 300mm x 100mm C40 concrete slabs) were manufactured. The slab has a 150mm x 150mm x 20mm deep recess at the middle. Preliminary study was carried out to measure pore water pressure in eight pore holes under the loading patch, by using manometer (Saeed 2015). The test results showed that maximum pressure is generated at the central pore hole. Therefore, it was decided to use single pore hole measurement. As this study is mainly to evaluate the impact of tire characterises and loading frequencies on water pressure, the distribution under the contact patch was not included. Future study will address this.

A 2mm pore hole was created at the centre of the recess to representative a continuous void through the depth. The 2mm void size was the minimum practical size possible to manufacture in the laboratory. In addition, full depth continuous pore was chosen to simplify the crack pattern and evaluate the influence of a full depth crack when water passed through this under dynamic loading when the surface is flooded with water. The test setup for both scenario 1 and scenario 2 are given in Figure 5.

In scenario 1**,** the recess area in concrete surface was filled with water to simulate water pressure under the slab when water is forced through a narrow crack (2mm) during traffic loading. This scenario is also used to test experimental setup for its consistency and repeatability of the test.

Figure 5a: Scenario No. 1

Figure 5b: Scenario No. 2

Figure 5 Schematic diagrams of test scenarios

The purpose of scenario 2 is to evaluate the impact of a 20mm semi permeable asphalt surface laid on the same 100mm concrete slab with 2mm wide full depth crack. 20mm asphalt surface was chosen to maintain the overall thickness of the concrete slab to 100mm. In addition, this also represents various thin surfacing system used for asphalt overlay in urban and rural highways (Highways England 2012). The average texture of the asphalt surface was measured as 1.27mm. The asphalt surface was saturated to minimise the impact of surface texture and maximise the effect of internal voids. The concrete slab was used in the idealised pavement structure to simulate the lower layers of asphalt (binder and base). The impermeable concrete slab eliminates the complication of water saturation in lower asphalt layers, which could potentially influence the water pressure.

Data acquisition

The lower end of the pore void, at the bottom of the slab, was connected to a pressure sensor, capable of measuring low pressures in the 0-7 kPa range. The sensor range was based on the preliminary trials using a manometer to determine water pressure for 1Hz loading frequency. The sensors were connected to high-accuracy fast data acquisition device with 100 Hz sampling rate. The sensor electrical output ranges from 0-16.7 mV/V for pressure in range of 0- 6.89476 kPa. The sensor employed in this study excludes atmospheric pressure (101kPa). The test set-up is shown in **Figure 6.**

Figure 6. Experimental set-up

The testing was conducted using an INSTRON 8501 servo-hydraulic testing rig, capable of applying loads at 0.1Hz to 50Hz in the 1kN to 100 kN load range. Testing was operated in a controlled load/stress mode. The test consists of running the equipment at a required load for a given frequency and water depth, recording the resulting amplitude of water pressure under slab. By repeating the test on each tread enables the influence of tread shapes to be evaluated. Figure 7 shows an example of the load pulse at applied loads 5kN and 10kN at 1Hz and the corresponding water pressure under the slab. There are some variations in the water pressure measurement. This was due to the difficulty of maintaining constant level of surface water during load application. Each test case was repeated for three times, and the results found to be within 5% agreement.

Figure 7a) Applied load 5kN at 1 Hz

Figure 7b) Pore water pressure at 5 kN at 1 Hz and tread 8SQ4

Figure 7c) Applied load 10kN at 1 Hz

Figure 7d) Pore water pressure at 10 kN at 1 Hz and tread 3SQ4

Figure 7. Typical signals at different loading frequencies is shown in 5KN, 10KN and frequency 1Hz

TEST SPECIFICATIONS

The test specifications are shown in Table 1. A constant feed of water was supplied to maintain a specific water depth during testing. It should be noted that the depth of water was difficult to maintain, especially at high frequency due to significant splashing after each load pulse. Research is underway for a mechanical feed of water. The applied loads were chosen to as 5kN and 10kN to simulate light and heavy vehicle loading.

TABLE 1 Test specifications

In total 112 cases had been tested (7 tread shape, 2 loads, 2 water depth and 4 frequencies). Each test was named as 8SQ4, which refers to 8mm tread depth, square tread pattern and 4mm water depth and so on. Each case was tested at 5kN and 10kN and at 1 Hz, 5Hz, 10Hz and 15Hz, and was repeated for three times. This means 336 tests had been conducted. It should be noted that testing at very high frequency (25 or 50Hz) was found unsafe and maintaining water depth was extremely difficult in the current set-up. However, further works are underway to address this.

RESULTS AND ANALYSIS

The data are analysed to evaluate the influence of load magnitude and frequency, tread patterns and depth on the pore water pressure through a 2mm pore extended through the depth of the slab. The test results on average water pressure against tire characteristics are shown in Figures 8a-8d for scenario 1 and Figures 8e-8h for scenario 2.

Figure. 8a. 4mm surface water, load 5kN, no asphalt surface

Figure. 8b. 2mm surface water, 5 kN load, no asphalt surface

Figure. 8c. 4mm surface water, 10kN load, no asphalt surface

Figure. 8d. 2mm surface water, 10kN load, no asphalt surface

Figure. 8e. 4mm surface water, 5kN load, with 20mm asphalt surface

Figure. 8f. 2mm surface water, 5kN load, with 20mm asphalt surface

Figure. 8g. 4mm surface water, 10kN load, with 20mm asphalt surface

Figure. 8h. 2mm surface water, 10kN load, with 20mm asphalt surface

Influence of tread shape and pattern

In general, at a specific frequency, irrespective of applied load, the maximum water pressure was occurred with the 8mm square tread (8SQ4) whilst the pressure decreases with decreasing tread depth, reaching minimum at the no tread situation. It is interesting to note that the water pressure in the zero-tread scenario is the minimum and no change happens despite increasing either load frequency or load magnitude.

Influence of loading frequency

Irrespective of surface water depth and load magnitude, the water pressure increases with increasing frequency. The water pressure decreases as tread depth decreases. As expected, for a specific frequency, water pressure is higher in a square tread than slot cut tread shape as more water is possible to drain out during the load pulse. It is interesting to note that irrespective of loading frequency, change in water pressure on flat loading plate; i.e. no tread depth.

Influence of depth of surface water

The depth of surface water, 2mm and 4mm, appears to have only marginal impact on the water pressure (Figures 8a, 8d). The slight increase was observed at high frequency, whereas the changes is negligible at low frequencies.

Load magnitude

As with surface water, the magnitude of load appears to have only marginal influence on the pore water pressure at in all tread shape, tread patterns and loading frequency, showing only marginal increase (3%-10%) between 5kN and 10 kN load and between 4mm and 2mm depth of surface water.

DISCUSSION

Influence of tire and load parameters

The worst-case scenario was found to be high loading frequency, when water is trapped in a deep groove (8mm in this) of the tire. The tread depth in a new truck tire could be as deep as 15mm, which may increase pore water pressure significantly.

It should be noted that, overall, in the worst-case scenario (8mm square tread 8SQ4, 15 Hz frequency), maximum pore water pressure in this test was approximately 7kPa at the bottom of the slab, which equates to approximately 3%-1.5% of the actual contact stress 3kPa ($5000/150^2$) and 1.5kPa ($10000/150^2$) respectively. To extrapolate this to high speed traffic, the following equation developed by Brown (1974) was utilised.

$$\log (t) = 0.5d - 0.2 - 0.94\log(v)$$

Where, t = loading time (sec); d = pavement depth (m), 0.1m slab thickness; and v = vehicle speed (km/h). f (Hz)=1/t (NCHRP, 2004).

Brown's equation relates to loading time to vehicle speed and pavement depth profile. The loading time was considered as the average of the pulse times of the stresses in three directions as obtained from the elastic layered theory (Brown 1974). The extrapolated graph relating to water pressure and vehicle speed is shown in Figure 9.

Figure 9. Extrapolated relation between water pressure and vehicle speed

It can be seen that at 100 km/hr (~60 mph), the water pressure can be around 28 kPa, which is approximately 8% of the applied pressure. Although this is unlikely to create any immediate damage to the road, repeated action of the load will eventually lead to bond deterioration in the mixture matrix and at interface between two layers. The resulted outcome could be stripping at the bottom of the layer and eventual cracking at the road surface and deterioration to foundation. Another point to note is that if the pore opening reduced from 2mm to 1mm, the pressure will increase significantly due to capillary action of the water.

Reduction of water pressure due to asphalt surface

A comparison between two scenarios at 5kN applied load on 4mm surface water is shown in Figure 10. Depending on the loading frequency and tread shape and pattern, reduction of approximately 5% to 38% maximum water pressure was measured when concrete slab was overlaid with a semi permeable 20mm SMA asphalt. This reduction could be due to texture in the surface and water storage in side mixture matrix. The tread shape & thickness and frequencies are the main contributory factors for changes in water pressure. The load magnitude, as with scenario 1, has only marginal effect. It is interesting to note that, in the case of no tread case (NT4), the pressure at 15Hz was slightly higher in scenario 2 (Figures 8e-8h) than scenario 1 (8a-8d). It can be due to water build up in the interconnected voids forcing water through the cracks.

Figure 10. Comparison of water pressure at different frequencies on pavement with and without asphalt surface.

SUMMARY AND CONCLUSIONS

Water infiltration through a discontinuity (crack/joint) in a pavement generates water pressure at the end of the discontinuity under traffic load. If this discontinuity extends to the full depth, the generated water pressure can lead to deterioration to foundation material, which ultimately can create under stab voids resulting poor load transfer efficiency and failure of the pavement. A novel laboratory test has been developed to measure water pressure underneath a flooded concrete slab that contains 2mm continuous pore (cracks) across the full depth. The test was repeated on a slab overlaid with 20mm semi permeable asphalt surface. The slab was subjected to flooding with 2mm and 4mm water and dynamic compression load of a 5kN and 10kN with three tire patterns (square groove, square channel and no tread) and four tread depths (8mm, 3mm , 1.5mm and 0mm). The load was applied at four different frequencies, 1Hz, 5Hz, 10Hz and 15 Hz.

The key conclusions are listed below;

- Increasing load frequency increases pore water pressure in the pavement. However, water pressure increases significantly when high frequency loading combined with square types of tread with deep tread depth, when water trapped inside the groove. Square tread with channel allows water to drain, which reduces pore water pressure.

- Irrespective of tread pattern, 8mm tread thickness showed highest amount of water pressure, but the pressure reduces significantly in 1.5mm tread thickness.
- Load magnitude has marginal impact on the pore water pressure. The water pressure diffidence between 5kN and 10kN load was found only between 3% to 10% in all tread patterns, thicknesses and loading frequencies. Similarly, the depth of surface water appears to have minimum impact on the water pressure. It is likely that pore water pressure will build up if pores are filled with water and there is minimum amount of water on the surface.
- The asphalt surface can mitigate water pressure underneath the pavement between 5% to 38% depending on the vehicle speed, tread patterns and thickness. This large variation also indicates that, for given surface type, the tire characteristics and vehicles speed will have influence on the pore water pressure.
- Whilst the magnitude of water pressure is only around 8% of the contact pressure, smaller but continuous voids can significantly increase this pressure, which eventually can lead to degradation of foundation material and progressive deterioration to asphalt surface resulting ravelling or stripping.
- Although this study has been conducted on idealised condition, the results showed good repeatability. The results are analogous to limited previous studies available. Further works are underway to measure water pressure at various depths, and asphalt surface with various texture and void characterises. Furthermore, to a great extent, the approach to the research is ad hoc, with no relevant standard approach to measure water pressure in the pavement is existing. In the on-going investigations, a standard test set up is being determined, with use of multiple sensors across the contact patch that will facilitate statistical analysis of experimental data.

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TABLE 1 Test specifications

Variable	Specifications
Surface water depth (mm)	2, 4
Tire Tread Type	Square, Slot, No tread
Tread Depth	0, 1.5, 3 and 8mm
Load (KN)	5, 10
Loading Frequency (Hz)	1, 5, 10 and 15
Type of Load	Dynamic compression
Load Duration (Sec)	0.67-10
Sampling Rate	100 Hz

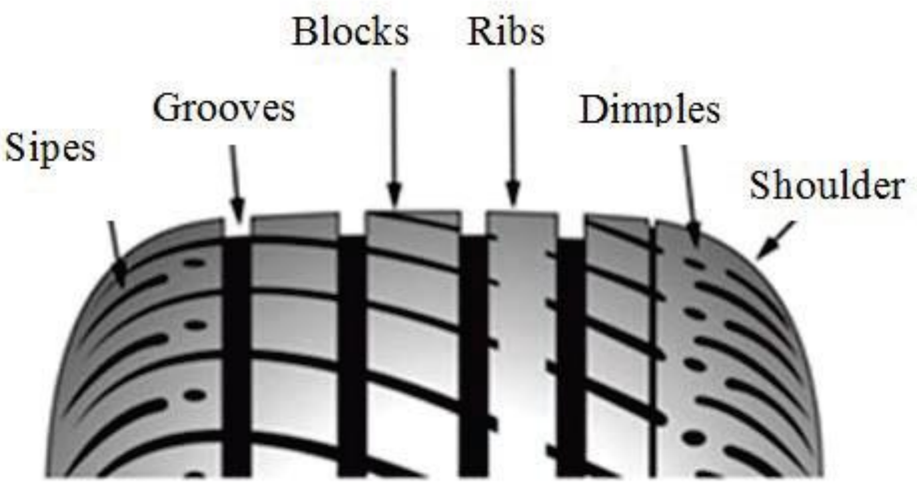

Figure1. Schematic diagram of tread pattern based on the geometrical shape of the tread component

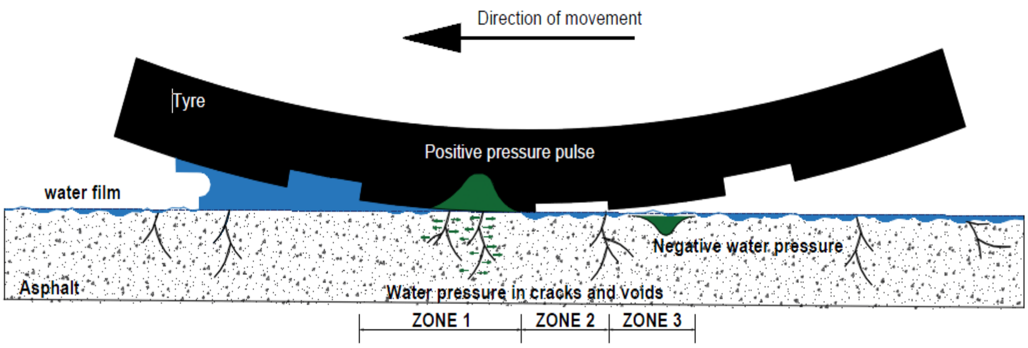

Figure 2. Conceptual illustration of tyre-water-pavement interaction

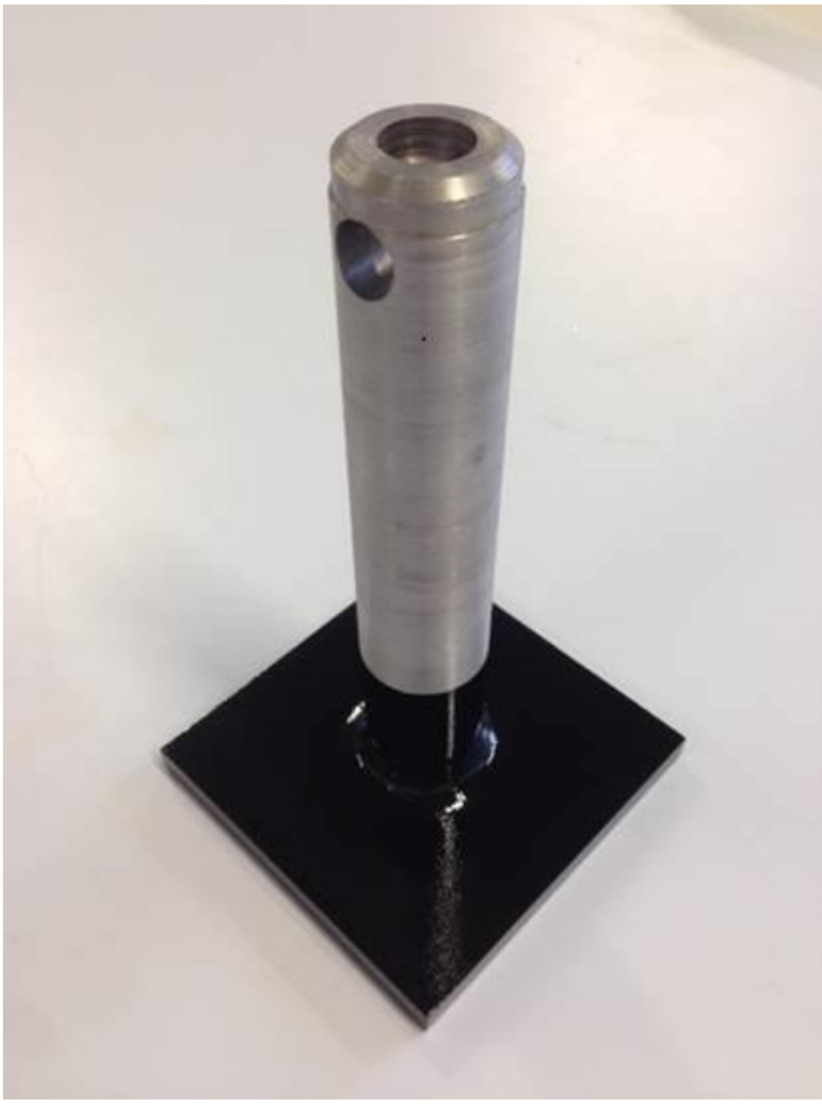

Figure 3a.100mm X100mm loading head

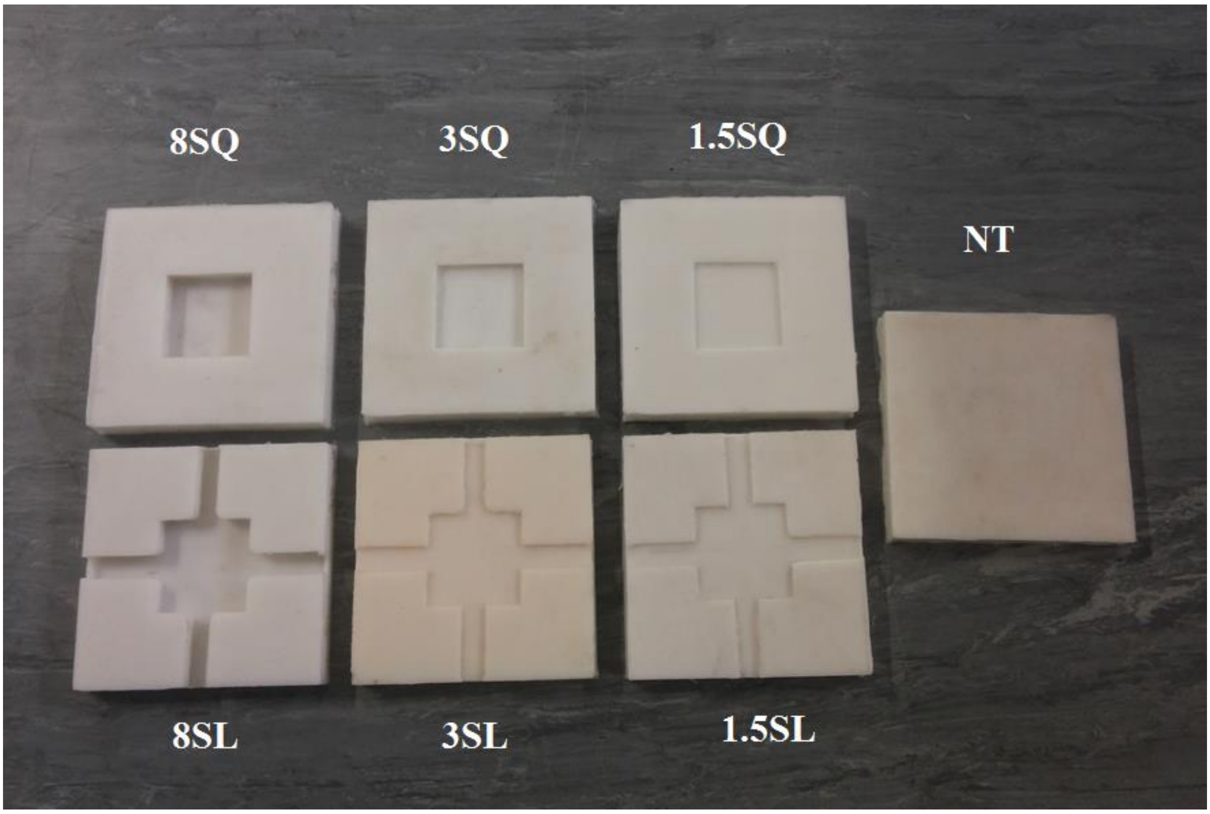

Figure 3b. Rubber pad representing treads pattern and shape

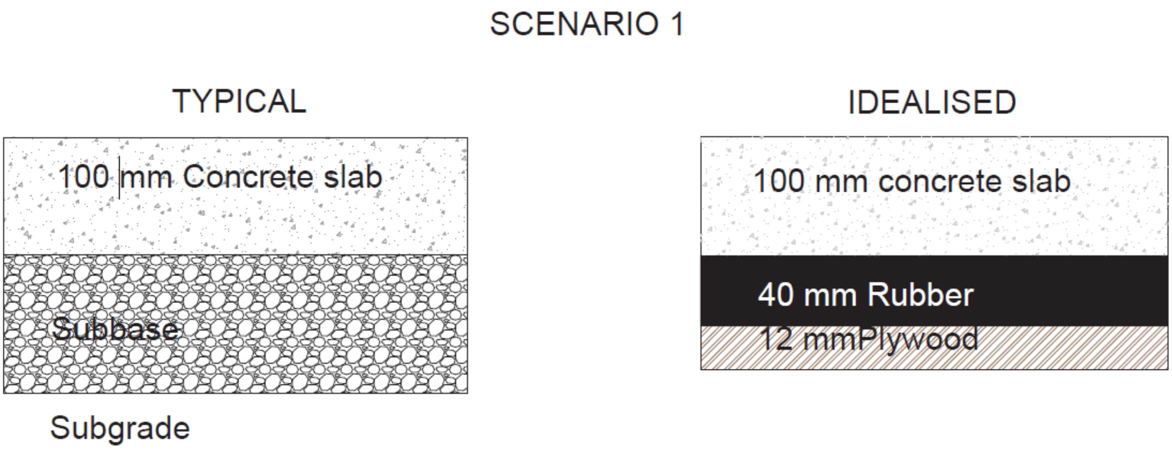

Figure 4a. Idealised pavement

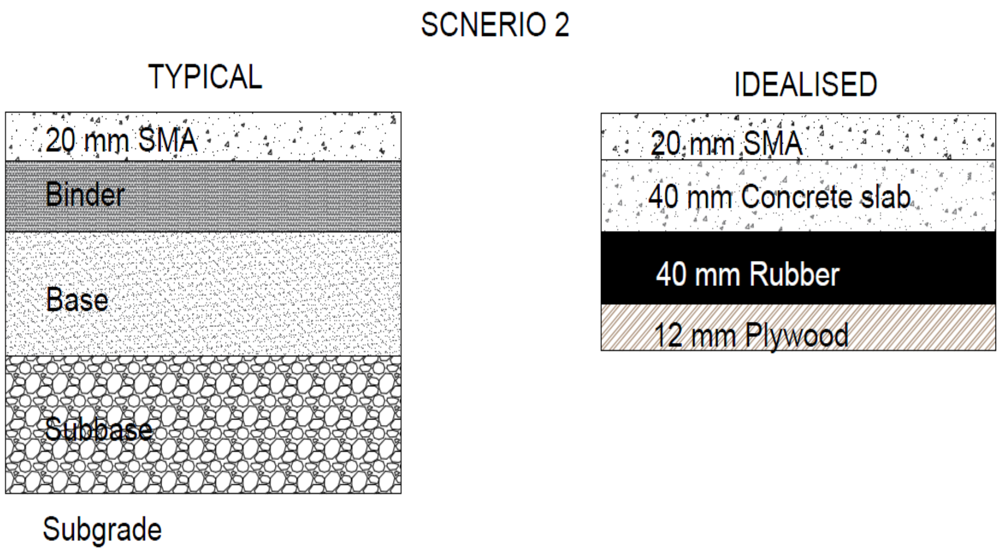

Figure 4b: Idealised pavement with asphalt overlay

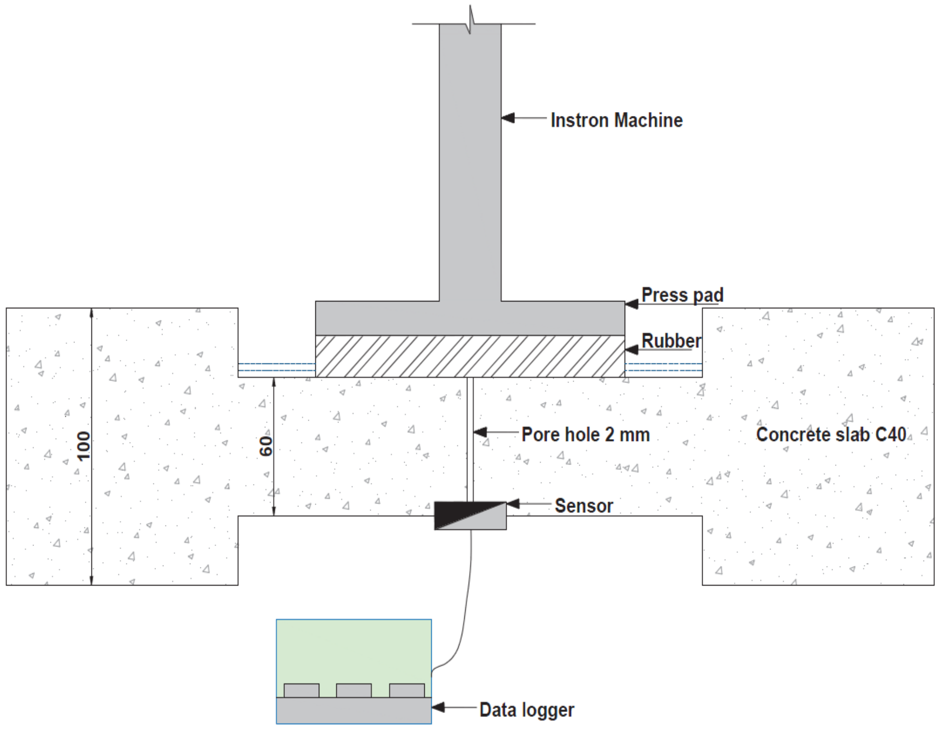

Figure 5a: Scenario No. 1

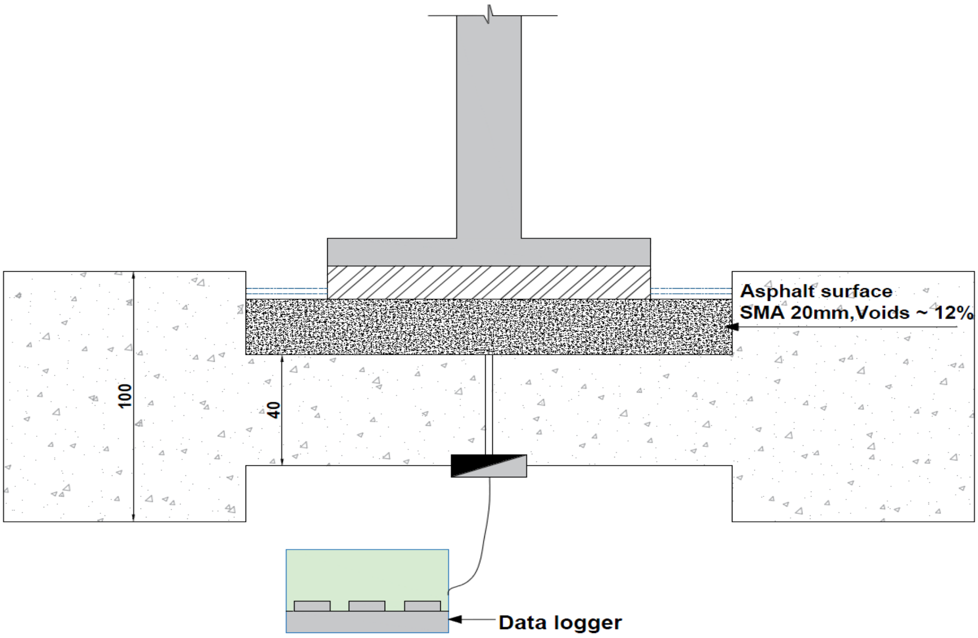

Figure 5b: Scenario No. 2

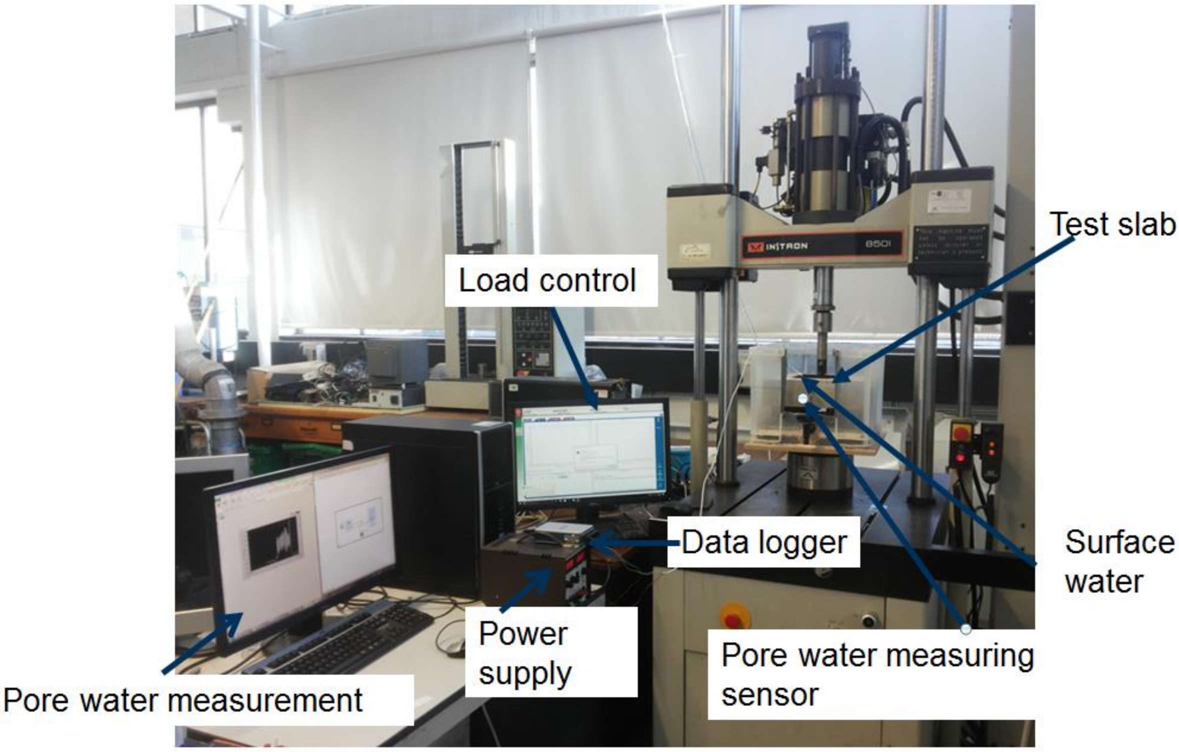

Figure 6. Experimental set-up

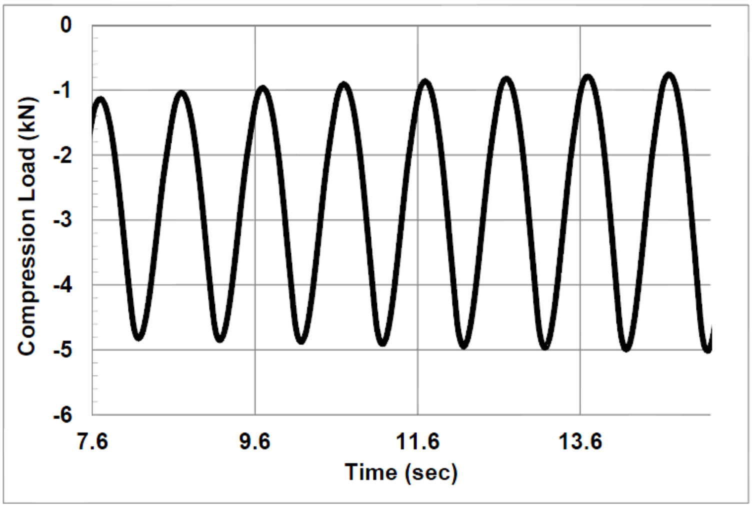

Figure 7a. Applied load 5kN at 1 Hz

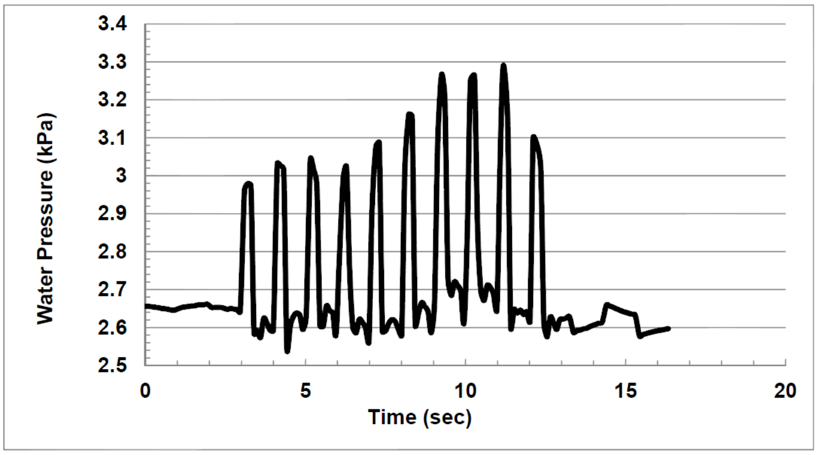

Figure 7b. Pore water pressure at 5 kN at 1 Hz

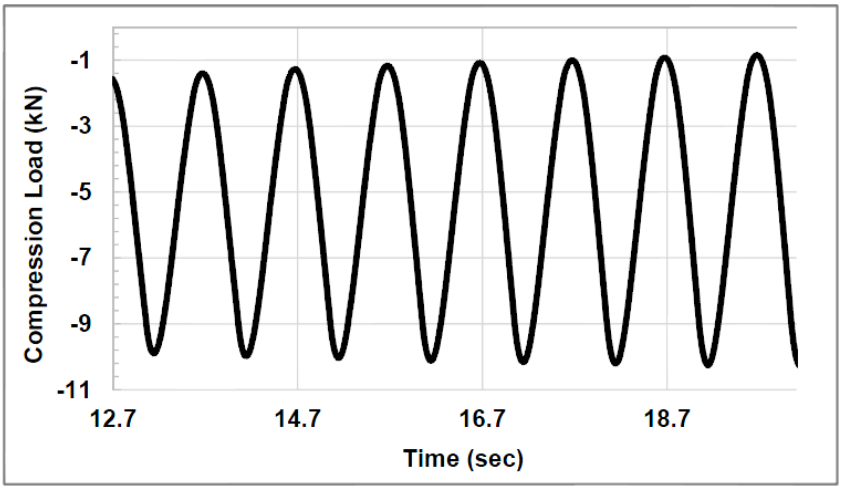

Figure 7c. Applied load 10kN at 1 Hz

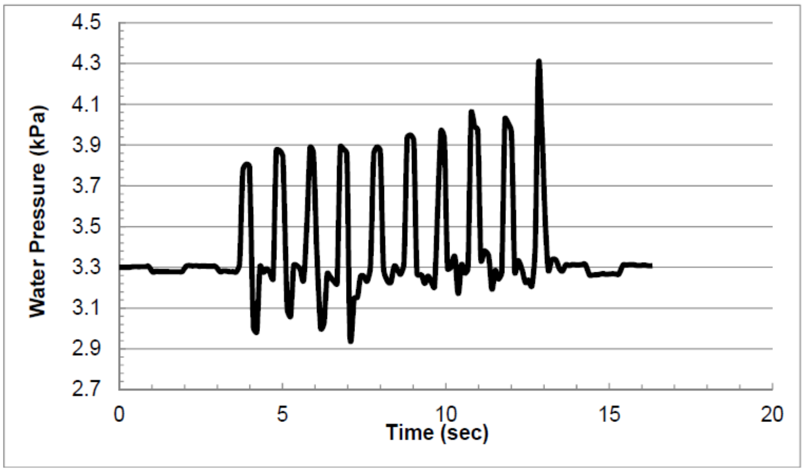

Figure 7d. Pore water pressure at 10 kN at 1 Hz

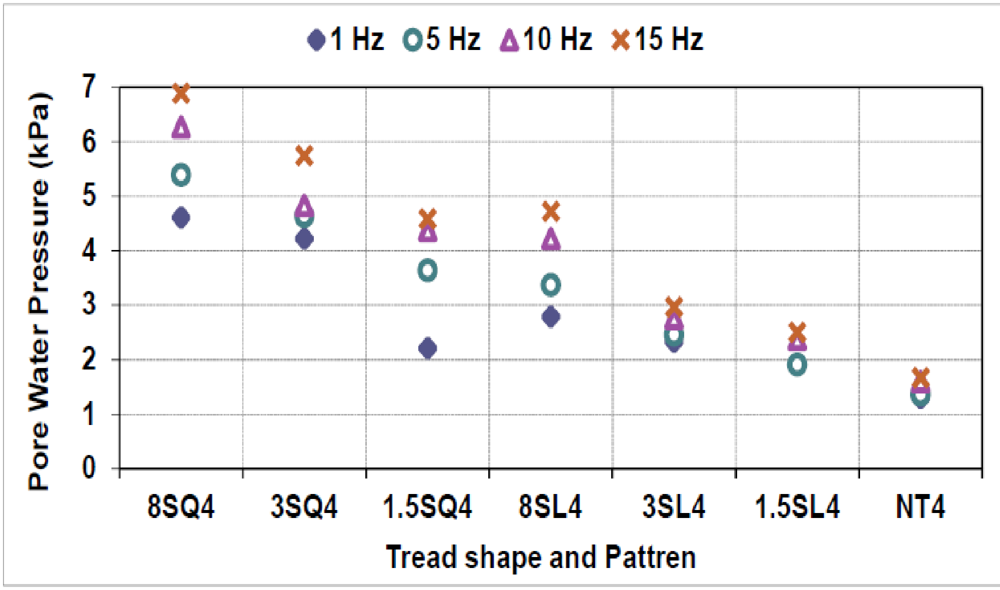

Figure 8a. 4mm surface water, load 5kN, no asphalt surface

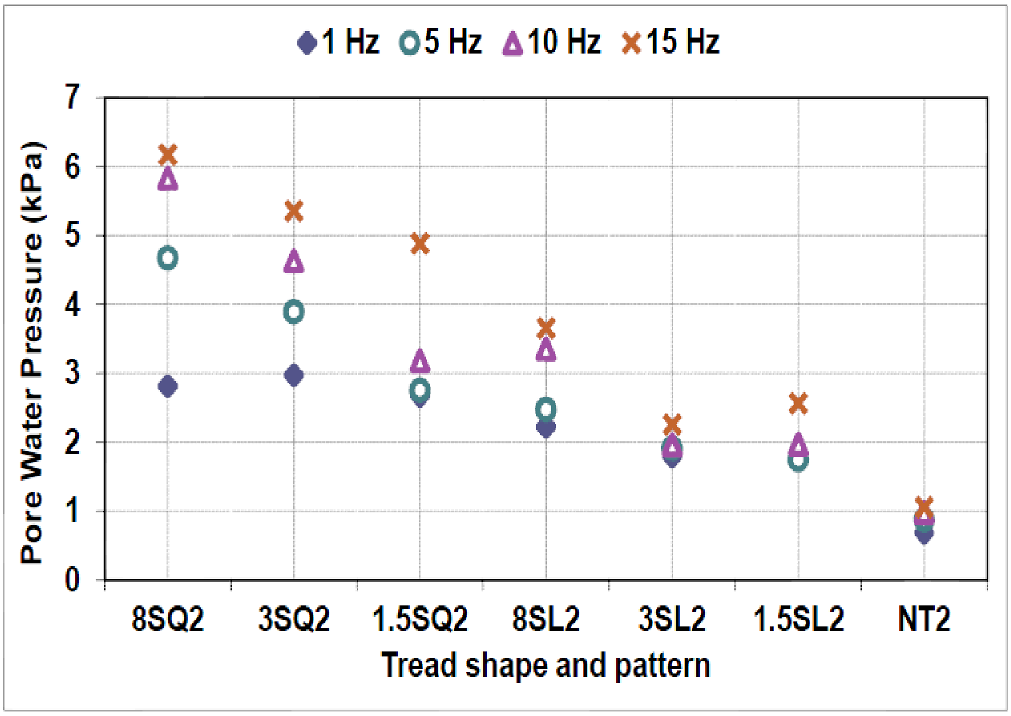

Figure 8b. 2mm surface water, 5 kN load, no asphalt surface

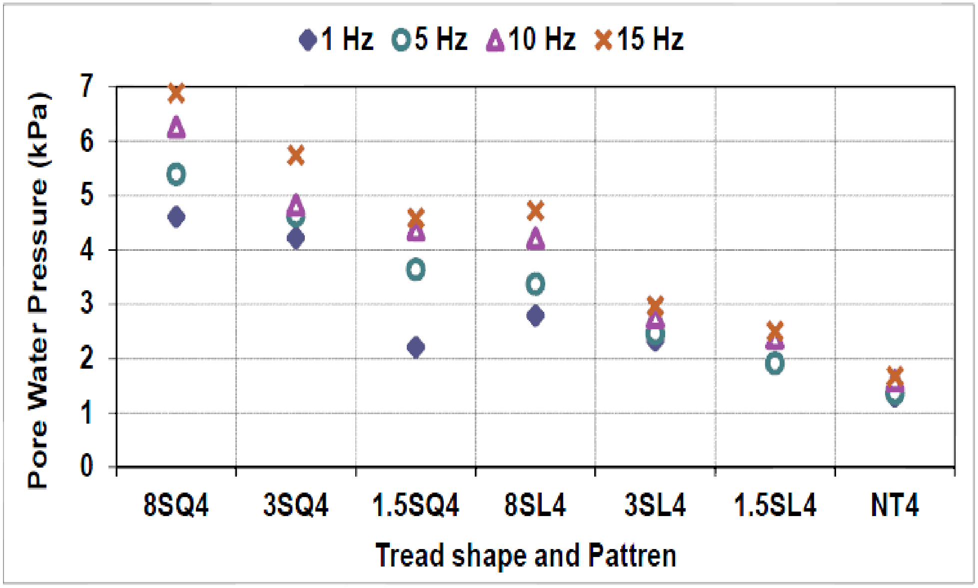

Figure 8c. 4mm surface water, 10kN load, no asphalt surface

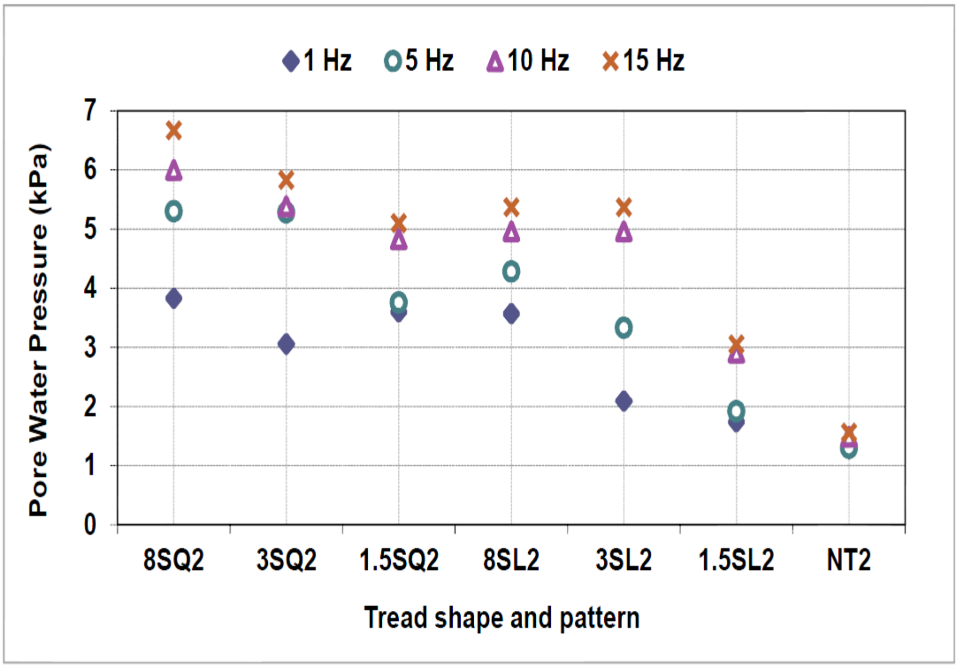

Figure 8d. 2mm surface water, 10kN load, no asphalt surface

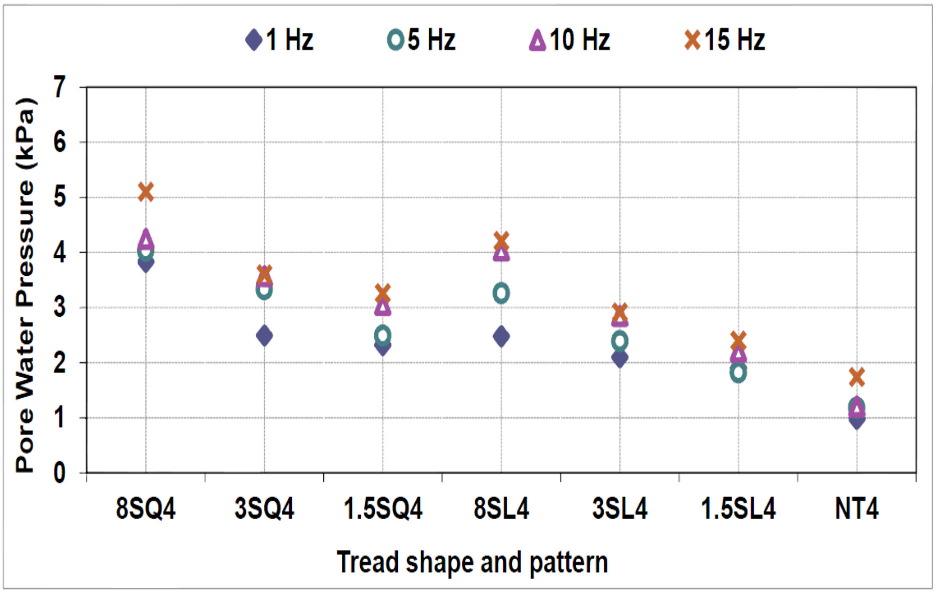

Figure 8e. 4mm surface water, 5kN load, with 20mm asphalt surface

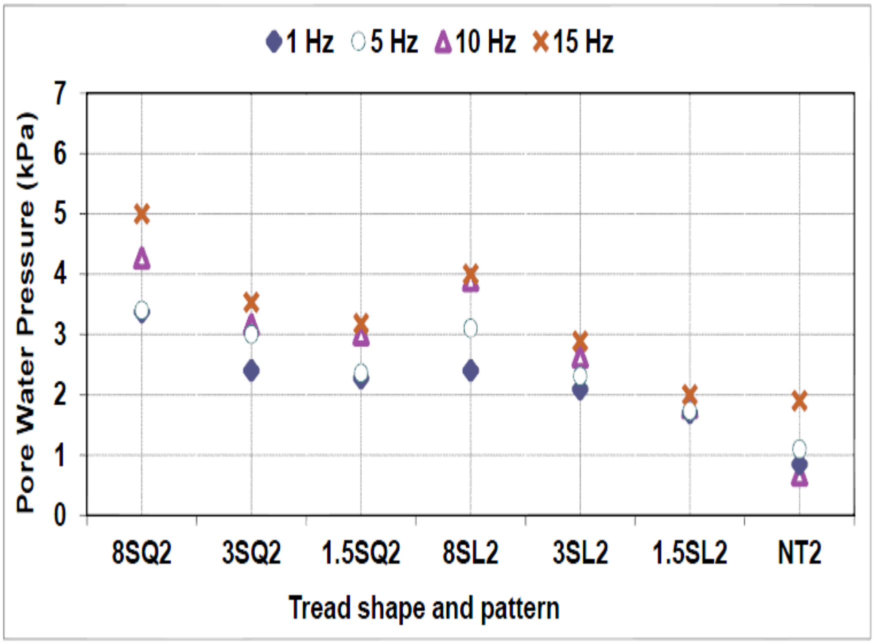

Figure 8f. 2mm surface water, 5kN load, with 20mm asphalt surface

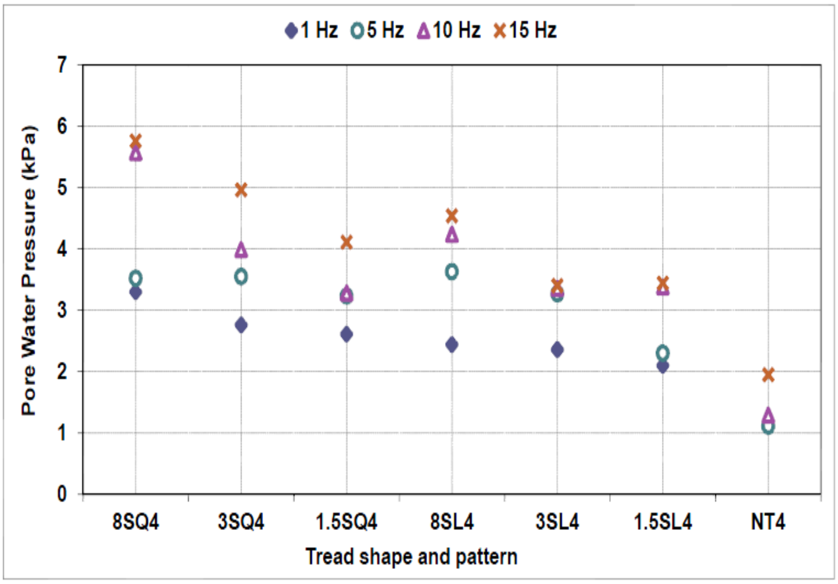

Figure 8g. 4mm surface water, 10kN load, with 20mm asphalt surface

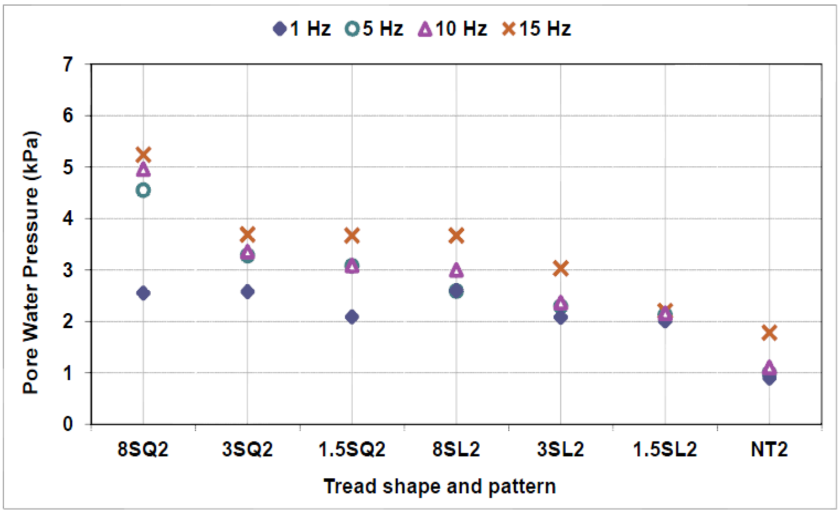

Figure 8h. 2mm surface water, 10kN load, with 20mm asphalt surface

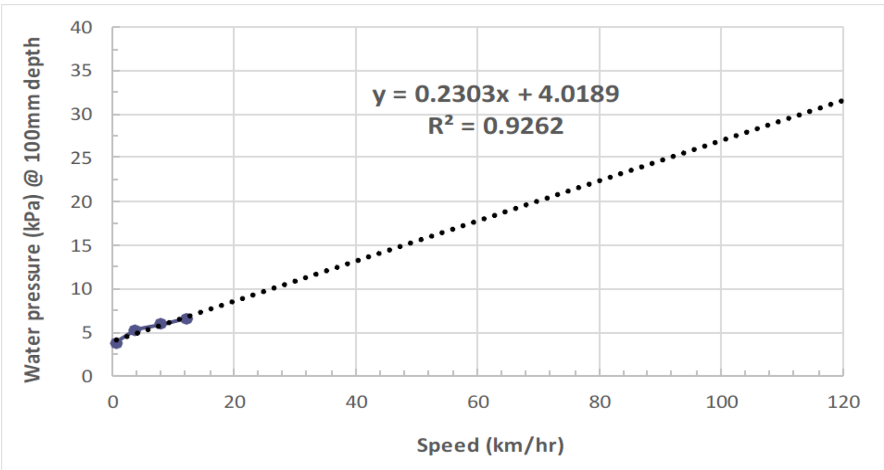

Figure 9. Extrapolated relation between water pressure and vehicle speed

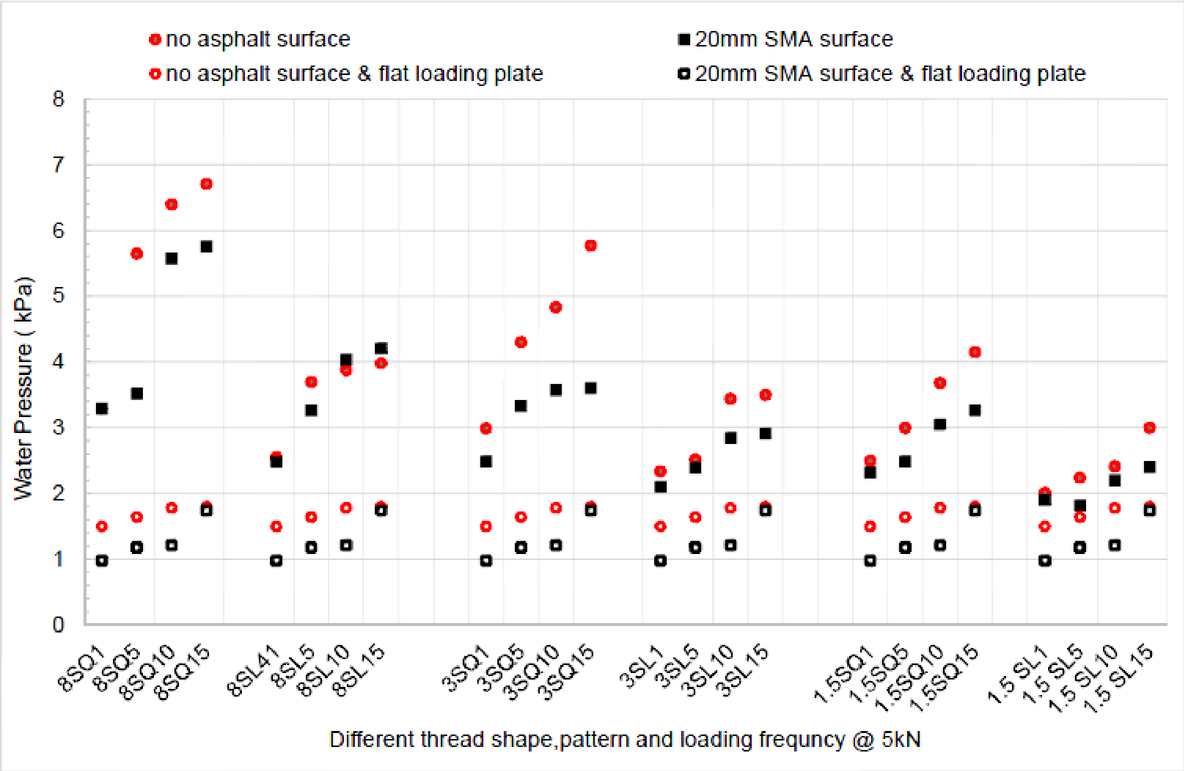

Figure 10. Comparison of water pressure at different frequencies on pavement with and without asphalt surface