The Waterproofness of First-Coat Chipseals
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Abbreviations

AADT: Annual Average Daily Traffic

SH: State Highway

Contents

Executive summary

This research, undertaken in 2006–2008, has confirmed that traffic can force water through first-coat chipseal surfacings that do not visually show signs of cracking. This will occur where a water film collects on the surface, which is associated with the pavement geometry and rainfall intensity. This can occur either through rutting of the pavements, or if the crossfall and longitudinal shape is such that a sheet of water can form above the surface texture of the pavement.

A test was carried out on the waterproofness of the chipseal at a total of 10 sites in Nelson, Taupo, Rotorua and Wairarapa. Tests measured the moisture content of the basecourse before and after rain. These tests confirmed the idea that water can be forced through a seal by traffic, though not to the extent expected.

The research then reviewed relevant literature to find a mechanism to explain how and when water can be forced through a chipseal.

This research has highlighted the need to ensure the shape of a pavement is maintained, not just for safety but also to retain the integrity of the pavement.

The research also highlights the need when using marginal aggregates to ensure that the crossfall is maintained even in areas such as intersections.

Modelling of the hydrodynamic pressures generated under a tyre suggests that water ingress will be exacerbated under faster traffic. Thus the permeability of chipseals under tyre pressure may not be of major significance in urban areas. The quantity of water forced through a seal will obviously also increase in areas of high traffic.

Recommendations

- Road Controlling Authorities should review their specification requirements to ensure that the allowable rutting on a pavement is made a function of the crossfall.
- It is also recommended that granular basecourse specifications be reviewed to ensure that the allowable deformation that may occur on a pavement in a guarantee period includes requirements to ensure that water does not pond.
- Pavement designers also need to ensure that the geometry of a pavement is such that it can be constructed using normal techniques so that water ponding does not occur, especially in areas subjected to high traffic volumes.
- The specification and use of high-build road markings on pavements should also be reviewed to ensure that they are constructed in such a manner that they do not contribute to water ponding.
- Further research should be conducted into the effect of water film thickness on the rate of water infiltration, and the effectiveness of treatments such as prime coats and second-coat seals to impede water ingress.

Abstract

This research project, undertaken in 2006 to 2008, confirms that traffic can force water through first-coat chipseal surfacings that do not visually show signs of cracking. The research measured the change in moisture content after rain on a number of newly sealed sites. Although this testing showed a statistically significant increase in moisture over all sites, the increase was not dramatic. The research concludes that water ingress can occur where a water film collects on the pavement. The film of water can occur either through rutting of the pavements, or if the crossfall and longitudinal shape is such that a sheet of water forms above the surface texture of the pavement.

1 Introduction

1.1 Background

The consequences of water being forced through a surfacing are that the pavement could suffer potholing, shallow shear or rutting. If the basecourse material is moisture sensitive, it has a higher likelihood of problems than a more tolerant material. In the current push to use more marginal aggregates and recycled materials, the ability of the surfacing to keep water out of the basecourse is critical. Based on current knowledge, the use of these alternative materials under higher traffic loadings where traffic may push the water through the surface is regarded as a high risk.

Hanson, who is famous for developing the first rational method for seal design in the 1930s, noted that chipseals leak. He noted in 1956 that, under pressure from tyres, water could be forced through a chipseal, ultimately resulting in potholing of the pavement (Hanson 1956). He observed potholing in a pavement at Ngauranga Gorge in Wellington that developed over a number of days. The potholes appeared where water had ponded but took three days of rain to develop. He also observed potholing develop in a pavement in Plimmerton. In this case, he noted “staining” at the surface caused by an underlying granular base with a high plasticity index (7–14). This pavement did not have sheets of water over the pavement but the potholes developed over a prolonged wet period. Hanson concluded that in the Plimmerton case, the high plasticity and fine hair-line cracking contributed to the water ingress.

In the early 1980s, the New Zealand National Road Board Road Research Unit commissioned research into the permeability of chipseals (Cornwell 1983). A low head (30mm of water) permeameter was used and water penetration was not observed.

McLarin (1987) measured two pavements in Lower Hutt to monitor moisture movement in the 1980s. In both pavements, he found higher than expected moisture content under the surface that fluctuated with rainfall. He was unsure if the installation of the sensors and cables through the surface created a ‘leak’ or if the moisture was coming in through the surface.

In the 1990s, Ball et al (1999) confirmed Hanson’s observations that water can penetrate through a chipseal. Their research recognised that the low head used in Cornwell’s research (1983) was not modelling reality and a higher pressure was generated by testing the permeability of cores taken from existing pavements. In Ball et al’s research, a head of water was placed over the chipseal to mimic the pressure from vehicle tyres. Although pressures of up to 700kPa could be generated, it was found that water flowed through the chipseal at a pressure of approximately 100kPa. It was noted that although water could be forced through the surface, it sometimes spread between chipseal layers rather than penetrating fully into the base. The sites selected in that project were those that were showing signs of water vapour-induced flushing and may not therefore reflect the performance of chipseals that are not showing any signs of distress.

1.2 Aim

This research, undertaken in 2006 to 2008, aimed to detect moisture penetration through measuring the change(s), if any, in moisture content in the top of a basecourse after rain. Measurements were made on a range of pavement surfacings and over a range of traffic loadings before and after rain.

A mechanism associated with the ability of water to be pushed through a chipseal by tyre pressure was sought through a review of literature associated with tyre/road interaction.

2 Test methods

This research attempted to determine if water penetrated through a chipseal under traffic loading. This was performed by measuring the water content in the basecourse before and after rain. It is not necessary to have a precise measure of water content; instead, it is only necessary that the method can determine if the water content has changed. The method that was adopted was to use a nuclear density meter in backscatter mode on top of the chipseal.

The ability of the meter to be able to be able to operate in this manner had been demonstrated in a previous project (Patrick 1998).

The results of measurements on one site from that research are given in table 2.1

Table 2.1 Nuclear density readings with and without the chipseal layer at the same location (from Patrick 1998)

Test no.	Dry density (kg/m^3)		Moisture content %	
	Chipseal on	Chipseal off	Chipseal on	Chipseal off
1	2026	2043	6.8	6.7
2	2028	2039	6.2	6.0
3	2006	1956	6.5	6.4
4	2033	1931	5.6	6.1
5	2074	2060	4.8	4.9
6	2155	2065	4.8	4.5
7	2058	2038	4.8	4.7
8	2108	2022	4.8	4.6
9	2042	2121	4.6	4.4
Average	2059	2031	5.4	5.4

In this current project, the technique was again confirmed on a site where the first-coat chipseal was physically removed. The results are given in table 2.2.

Table 2.2 Nuclear density moisture readings before and after removal of a first-coat chipseal (in percent)

Test no.	Top of chipseal	Seal removed	Difference
1	6.5	7.1	+0.6
2	5.8	5.2	-0.6
3	5.6	4.9	-0.7

Although the moisture readings associated with the precision of the test appear to vary, it is concluded that if a number of tests are performed, the nuclear density meter will be able to distinguish when a significant change in the average moisture condition occurs.

3 Site selection

An attempt was made to find a range of chipseal types that covered a range in traffic volumes. Despite extensive enquiries, a single-coat grade 4 first-coat chipseal (which has traditionally been used on all roads) could not be found on a state highway. It appears that the default first-coat chipseal on a state highway is now a two-coat chipseal. Grade 4 first-coat chipseals were found on low-traffic back country roads.

A total of nine sites were tested after a dry period of more than five days and then immediately (within 12 hours) after significant rain. Traffic volumes varied from an annual average daily traffic (AADT) of 50 to over 8000.

Sites were tested in Nelson, Taupo, Rotorua and Wairarapa. All sites were on open roads and not in an urban area. This selection was to ensure reasonable geometry and minimise the risk of water ingress from sources other than the water on top of the seal. Table 3.1 overleaf gives the details of each test site.

Table 3.1 Location, chipseal type and AADT of all test sites in this research

Site	AADT	Chipseal type	Test location
SH* 6 RP** 73/4.910	3000	Grade 3/5 (Nelson A)	Information not available
		First coat (Nelson B) (Nelson C)	Information not available
Rakaunui Road RP 29/3.08	<50 (estimate)	Grade 3/Grade 5	50 m from end of seal (Rakanui A)
			140m from end of seal (Rakanui B)
Wairakei SH1	7895	Grade 3/Grade 5	52m from Wairakei Bridge 6957 (Wairakei A)
			122m from Wairakei Bridge 6957 (Wairakei B)
Galaxy Road SH5	5376	Grade 3/Grade 5	Chainage 1020 (Galaxy A)
			40m from Duncan Processors Ltd entrance, Rotorua end (Galaxy B)
Mamaku side road	200 (estimate)	Grade 3/Grade 5	4km from SH5 (Mamaku A)
			4.2km from SH5 (Mamaku B)
SH 5 Oturoa Road RP 29/3.08	5376	Grade 3/Grade 5	Information not available
Rainbow Mountain	5271	Grade 2/Grade 4 First coat (Rainbow A) Second coat (Rainbow B)	50m (Rainbow A and B)
			80m (Rainbow C)
		Grade 3/Grade 5 Second coat	80m (Rainbow D)
			120 (Rainbow E and F)
SH 53	2159	Grade 3/5	70m (Wairarapa A) 100m (Wairarapa B) 170m (Wairarapa C)
Kahutara Road	2689	Grade 4 single coat	50m (Kahutara A) 100m (Kahutara B) 150m (Kahutara C)

* SH: State Highway

** RP: Route Position

4 Results

4.1 Change in moisture content at test sites

The results of the tests are given in table 4.1 and are summarised in table 4.2.

Table 4.1 Test results showing soil moisture content (in percent) before and after rain in all locations

Test	Dry								Wet							
								AVG								AVG
Nelson A			7.9	7	7.6	7.8	8	7.7			8.4	7.7	7.8	7.8	8.8	8.1
Nelson B			8	7.9	7.5	7.7	7.1	7.6			8.2	7	7.6	8.4	7.2	7.7
Nelson C			7.8	7.8	7.4	8.8	7.8	7.9			7.5	8.7	7.9	8	7.9	8.0
Rakanui A			4.6	4.4	4.5	4.2	4.7	4.5			5.7	4.7	4.7	5.0	7.2	5.5
Rakanui B			4.7	4.8	5.0	4.6	5.0	4.8			4.6	4.5	4.1	4.8	6.7	4.9
Wairakei A			8.0	6.0	6.7	8.7	6.5	7.2			9.3	7.3	8.3	11.6	7.1	8.7
Wairakei B			4.9	5.4	5.5	5.7	6.0	5.5			6.4	5.9	6.2	7.3	5.4	6.2
Galaxy A			5.7	6.4	6.4	6.0	6.0	6.1			6.0	7.0	6.7	6.9	6.4	6.6
Galaxy B			6.0	6.1	6.7	6.4	6.0	6.2			6.3	6.2	6.3	6.2	6.2	6.2
Mamaku A			9.8	8.3	9.0	8.5	9.7	9.1			10.1	9.3	9.2	9.4	9.5	9.5
Mamaku B			8.8	9.0	9.2	10.0	9.1	9.2			8.7	9.1	10.0	9.8	9.6	9.4
Oturoa	7.4	7.1	6.8	6.9	6.6	5.4	5.9	6.6	6.9	6.8	6.3	6.3	6.6	5.8	5.4	6.3
Rainbow A	5.7	5.5	4.7	4.9	5.5	5.3	5.4	5.3	6.4	5.7	5.2	4.5	4.7	5.7	4.9	5.3
Rainbow B	5.3	5.7	5.9	6.1	5.8	5.1	5.4	5.6	6.3	6.6	6.5	6.4	6.2	6.3	6.6	6.4
Rainbow C	5.2	5.5	5.2	5.2	4.7	5.2	5.5	5.2	4.4	5.6	4.8	4.6	5.0	4.4	4.4	4.7
Rainbow D	4.9	5.6	4.8	5.9	5.0	5.0	5.0	5.2	6.5	6.2	6.4	6.4	5.0	5.3	5.7	5.9
Rainbow E	5.4	5.8	5.0	5.0	4.7	4.2	4.5	4.9	4.9	4.9	4.4	4.2	4.9	4.6	5.3	4.7
Rainbow F	5.0	5.3	5.3	5.6	5.4	5.1	6.1	5.4	6.1	5.7	5.1	6.0	5.1	6.0	6.2	5.7
Wairarapa A			8.4	6.5	5.9	5.6	7.1	6.7			8.9	9.6	6.2	7.5	7.8	8.0
Wairarapa B			6.8	7.0	7.0	6.2	6.9	6.8			9.3	9.1	8.1	7.9	9.9	8.9
Wairarapa C			5.2	5.2	5.4	5.0	5.1	5.2			5.5	5.5	5.6	5.8	6.6	5.8
Kahutara A				4.2	4.2	3.7	3.5	3.9				5.7	3.8	4.5	4.3	4.6
Kahutara B				4.1	3.7	3.9	3.9	3.9				4.1	4.0	4.4	3.6	4.0
Kahutara C				3.6				3.6				3.6	4.9	3.4	4.1	4.0

The results are summarised in Table 4.2.

Table 4.2 Summary of tests results

Location	Site	Seal type	Dry	Wet	Diff
Nelson	SH 6	Gd3/5	7.74	7.93	0.19
Taupo/Rotorua	Rakaunui Rd	Gd3/Gd5	4.65	5.20	0.55
	Wairakei	Gd3/Gd5	6.34	7.48	1.14
	Galaxy Rd	Gd3/Gd5	6.17	6.42	0.25
	Mamaku	Gd3/Gd5	9.14	9.47	0.33
	Rainbow Mt	Gd3/Gd5	5.25	5.43	0.18
	Oturoa Rd	Gd3/Gd5	6.59	6.30	-0.29
Wairarapa	SH 53	Gd3/Gd5	6.22	7.55	1.33
	Kahutara Rd	Gd4 single-coat	3.90	4.30	0.40

4.2 Conclusions

This research, combined with New Zealand experience and previous research by Ball et al (1999) and Patrick et al (1998) does tend to confirm that water can get forced through a chipseal, though not to the extent that was initially envisaged.

In general, these results do not show a significant increase in water content after rain. Only in the Wairakei and SH 53 sites is the increase in moisture statistically significant (student t-test of paired samples).

Overall, however, moisture content increased by 0.44% on average, which is statistically significant at the 0.05% level (student t-test of paired samples).

The range of traffic volume on the sites is significant and does not reveal a pattern between traffic volume and possible permeability of the chipseal.

5 Factors affecting water ingress

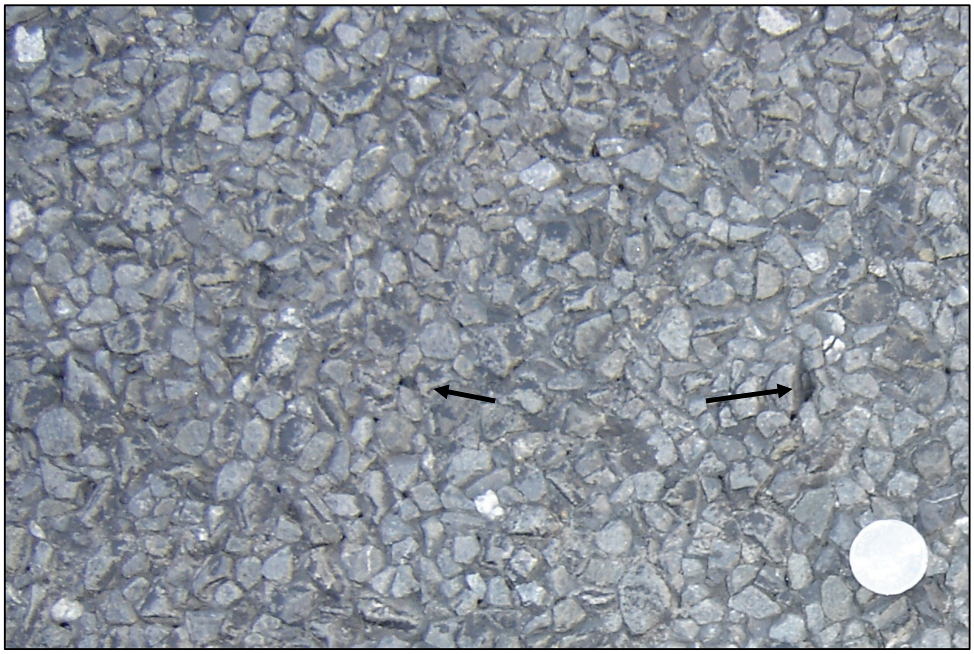
5.1 Basecourse material

Ferry and Major (1987) reported that the number of potholes decreased by an order of magnitude on state highways as a result of increasing the permeability of granular basecourse by changes in the basecourse specification introduced in 1960.

One example of a new chipseal with visible damage occurred on SH1 north of Wellington, where a newly constructed pavement developed shear and pothole failure soon after completion. The distress appeared after rain. The granular pavement had a Grade 3/5 two-coat chipseal as the first coat.

A photograph of the seal is shown in figure 5.1. The small "dots" that are apparent are holes in the seal that go through to the basecourse. It is obvious, in this case, that the seal is not waterproof.

Figure 5.1 Pin holes in first-coat chipseal on SH1 near Wellington



This pavement had a moisture content after a period of fine weather of approximately 4% and the optimum moisture content was 6%. The degree of compaction that was achieved during construction was greater than 98% of maximum dry density.

5.2 Tyre pressure

5.2.1 Aquaplaning

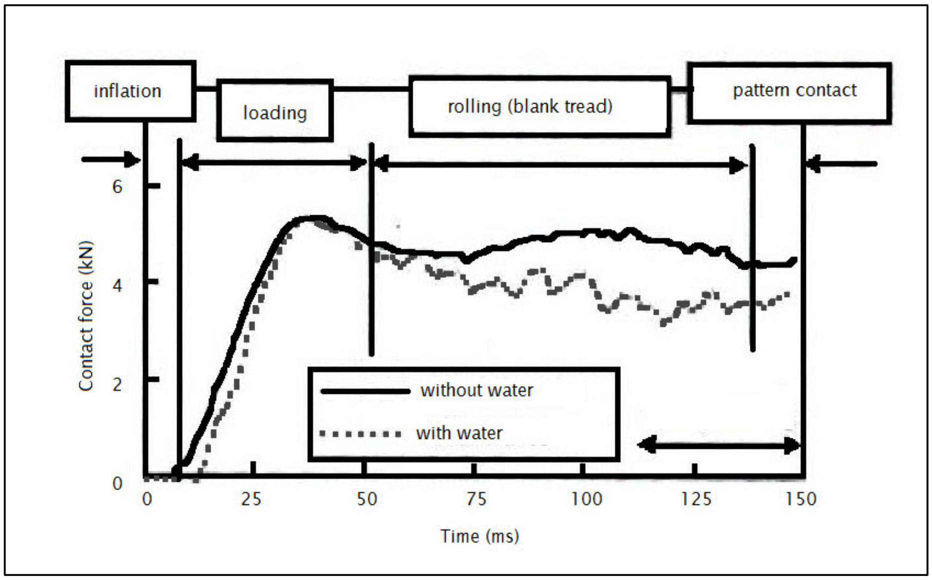
If a tyre footprint of 200mm diameter is assumed, it can be shown that 180ml of water would need to be pushed through the chipseal to increase the saturation level in a 100mm deep pavement segment from approximately 55% (equivalent to 4% by mass of moisture) to 90% saturation. This is also equivalent to a layer of water 5mm deep being pushed into the basecourse. Saturation levels greater than 90% can lead to rapid failure in repeated load triaxial tests.

The research has shown that under pressure, water can penetrate a seal; the lack of a change in water content in all sites tested in this research could be associated with the fact that water was not ponding on the surface and therefore the water pressure was not high.

In previous research, measurable flow rates on multiple seal coats were found at pressures around 100kPa. This pressure may be considered well below the tyre pressure of a car or heavy vehicle.

A brief review of the literature associated with aquaplaning (Seta et al 2000) has shown that the pressure generated under a tyre may not approach that of the tyre until aquaplaning occurs. Seta et al modelled the water flow under a tyre as it went through a 10mm deep water film. The illustration (figure 5.2) shows that the pressure on the pavement with and without water is different in the area noted as “rolling”. This difference in pressure is the hydrodynamic uplift force caused by the water not being removed from under the tyre.

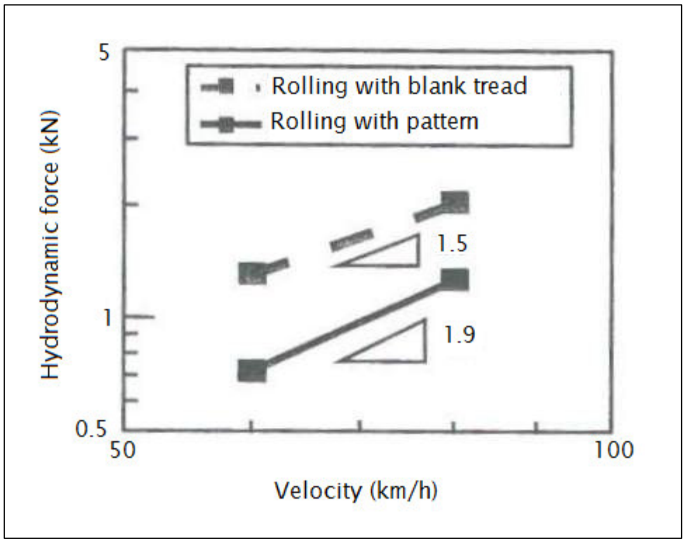
Figure 5.2 Pressure on a pavement under a rolling tyre (from Seta et al 2000)



Seta et al (2000) also modelled the effect of vehicle speed and tyre tread, which is illustrated in figure 5.3. This figure shows the effect of tyre tread on the hydrodynamic force and also that this force can double from approx 0.7kN at 60 km/h to approx 1.4kN at 80km/h.

An estimate of the pressure in terms of kilopascals has been made from the details given by Seta et al (2000) and 1kN of force approximates a pressure of 100kPa.

Figure 5.3 Hydrodynamic force as a function of vehicle speed (from Seta et al 2000)

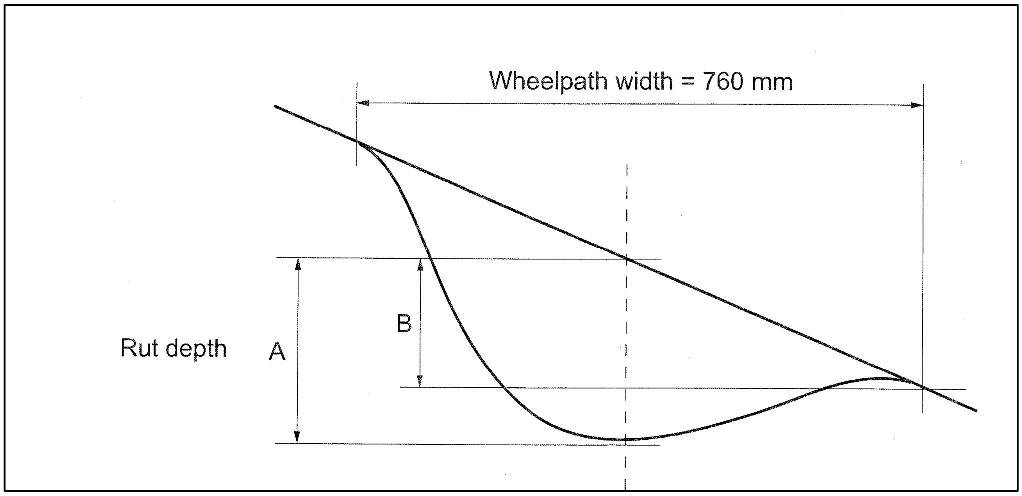


This analysis shows that water pressures in the order of 100kPa can easily be generated under vehicle tyres. This pressure is of the same order as found in the previous research that generated significant water flow through a chipseal. It is contended that this pressure exerted on a film of water can result in significant water pressure under traffic that is enough to force water through the seal. If the traffic volume is high then the water pressures will not have time to dissipate and the build-up of pore pressure will lead to shear and potholing in the basecourse.

5.2.2 Factors contributing to ponding

The Queensland Department of Transport (2002) has also looked at water ponding and developed a simple equation relating pavement geometry to water ponding. The relationship is illustrated in figure 5.4. This figure also includes the equation (equation 5.1) required to calculate the depth of water (puddle) that can be formed.

Figure 5.4 Relationship between rut depth and water puddle depth



$$D = A - (3.8 \times C) \qquad \text{(Equation 5.1)}$$

Where:

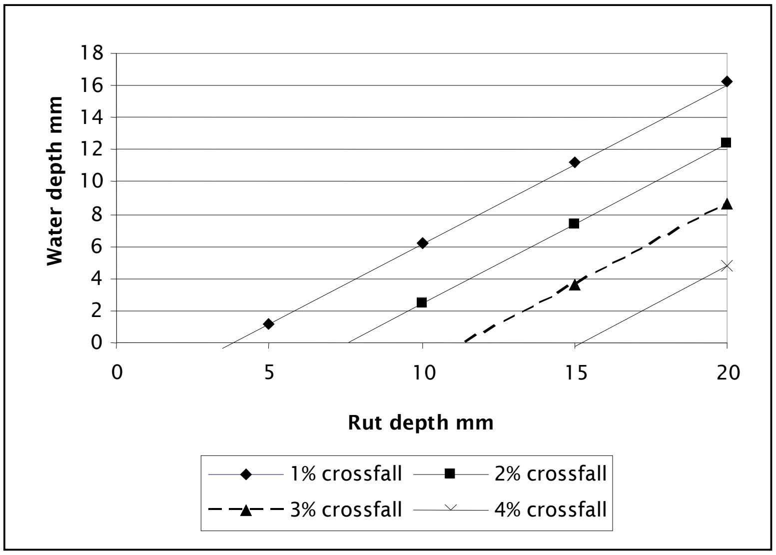
D = puddle depth in mm

A = rut depth in mm

C = crossfall in percent

The results of an analysis using equation 5.1 are shown in figure 5.5. It can be seen that a 4mm water depth will form on a 1% crossfall with a rut depth of 7-8mm but a rut depth of 19mm is required to result in the same water depth when the crossfall is 4%. Using this relationship, the water depth that will form on a pavement is illustrated in figures 5.6 and 5.7 for two crossfalls.

Figure 5.5 Relationship between rut depth and water film depth as a function of crossfall



Water can also run along the road and the depth of water can accumulate without any rutting. The effects of drainage length and rainfall intensity on a pavement with a 0.8mm texture depth are shown in figures 5.6 and 5.7 for a 3% crossfall and a 1% crossfall, respectively (also taken from Queensland Department of Transport 2002).

Figure 5.6 Relationship between rainfall intensity, drainage path and water film depth for a 3% crossfall and 0.8mm texture depth

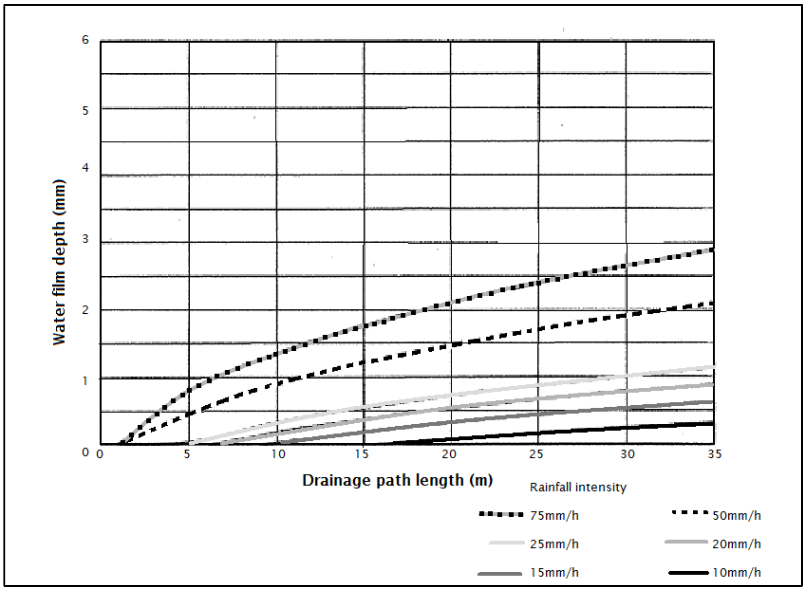
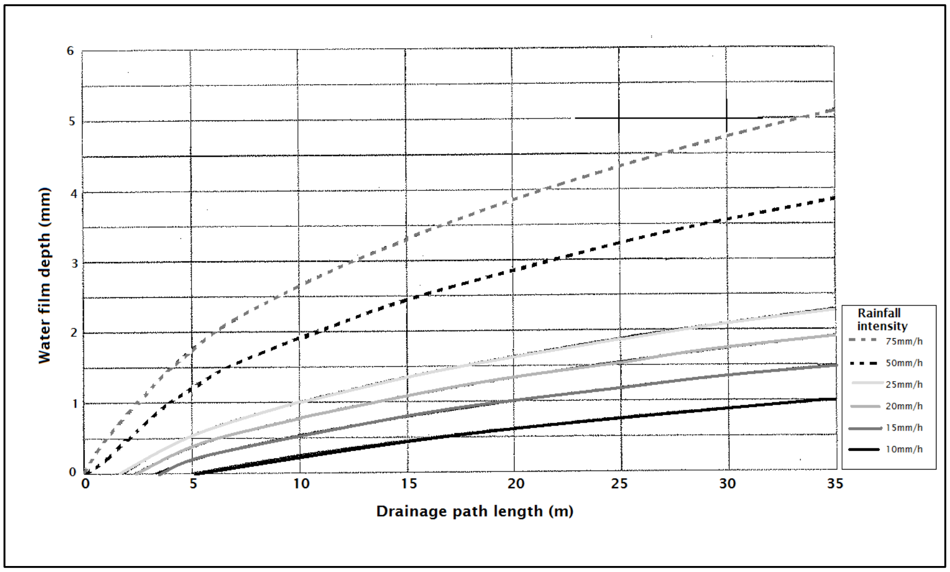


Figure 5.7 Relationship between rainfall intensity, drainage path and water film depth for a 1% crossfall and 0.8mm texture depth



For a 50mm/hr rainfall and a 20m drainage path, the water film thickness increases from 1.5mm for the 3% crossfall to 2.8mm for the 1% crossfall.

These examples illustrate that a significant film of water can develop on a pavement which has rutting and/or a long drainage path and a low crossfall.

6 Conclusions and recommendations

This research has confirmed that water can be forced through chipseal surfacings that do not show visual signs of cracking. This will only occur where a water film appears on the surface associated with the pavement geometry and rainfall intensity. This can occur either through rutting of the pavement, or if the crossfall and longitudinal shape are such that a sheet of water can form above the surface texture of the pavement.

This research has highlighted the need to ensure the shape of a pavement is maintained not just for safety but to retain the integrity of the pavement.

The research also highlights the need when using marginal aggregates to ensure that the crossfall is maintained even in areas such as intersections.

Modelling of the hydrodynamic pressures generated under a tyre suggests that water ingress will be exacerbated under faster traffic (>70km/h). Thus the permeability of chipseals under tyre pressure may not be of major significance in urban areas.

Our conclusions lead to the following recommendations:

- Road Controlling Authorities should review their specification requirements to ensure that the allowable rutting on a pavement is made a function of the crossfall.
- It is also recommended that granular basecourse specifications be reviewed to ensure that the allowable deformation that may occur on a pavement in a guarantee period includes requirements to ensure that water does not pond.
- Pavement designers also need to ensure that the geometry of a pavement is such that it can be constructed using normal techniques so that water ponding does not occur, especially in areas subjected to high traffic volumes.
- The specification and use of high-build road markings on pavements should also be reviewed to ensure that are constructed in such a manner that they do not contribute to water ponding.
- Further research should be conducted into the effect of water film thickness on the rate of water infiltration, and the effectiveness of treatments such as prime coats and second-coat seals to impede water ingress.

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