FLUSHING PROCESSES IN CHIPSEALS: EFFECTS OF WATER

Transfund New Zealand Research Report No. 156

FLUSHING PROCESSES IN CHIPSEALS: EFFECTS OF WATER

G.F.A. Ball, T. C. Logan and J.E. Patrick
Opus Central Laboratories
Lower Hutt, New Zealand

Transfund New Zealand Research Report No. 156

ISBN 0-478-11564-4
ISSN 1174-0574

P O Box 2331, Lambton Quay, Wellington New Zealand
Telephone (04) 473-0220; Facsimile (04) 499-0733

G.F.A. Ball, T. C. Logan and J.E. Patrick 1999. Flushing processes in chipseals. Effects of Water. *Transfund New Zealand Research Report No. 156*. 25 pp.

Keywords: Chipseal, flushing, water, permeability, New Zealand, roads

AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transfund New Zealand which has responsibility for funding roading in New Zealand.

While this report is believed to be correct at the time of publication, Transfund New Zealand, and its employees and agents involved in preparation and publication, cannot accept any contractual, tortious or other liability for its content or for any consequences arising from its use and make no warranties or representations of any kind whatsoever in relation to any of its contents.

The report is only made available on the basis that all users of it, whether direct or indirect, must take appropriate legal or other expert advice in relation to their own circumstances and must rely solely on their own judgement and seek their own legal or other expert advice.

The material contained in this report is the output of research and should not be construed in any way as policy adopted by Transfund New Zealand but may form the basis of future policy.

ACKNOWLEDGEMENTS

This work was funded by Transfund New Zealand and a grant from Bitumix Limited.

Thanks are due to: Doug Brown , for devising the electronics for the pressure control valve in the water ingress unit, Alan Sutherland, for programming the pressure impulse electronics, Peter Hamilton, Philip Herrington and Sheryn Reilly (all of Opus Central Laboratories); the staff of the Opus Napier laboratory, for assistance in obtaining the seal samples; Mark Owen (Transit New Zealand); Bryan Pidwerbesky, Executive Director, Bitumen Contractors' Association, (BCA); John Dawson (Founding Director, BCA) for comments and advice; and the Hutt City Council Street Services for providing RAMM data on flushed sites and for permission to take samples.

CONTENTS

EXECUTIVE SUMMARY

1. Introduction

A study made of chipseal data from the New Zealand state highway system found that the two major types of surface distress that lead to the decision to reseal are alligator cracking of the seal, and flushing (the appearance of bitumen at the surface of the seal). Work was subsequently commissioned by Transfund New Zealand into possible causes of flushing, namely: texture change in seals (reported in Transfund Research Report No. 122, Flushing Processes in Chipseals – Effects of Trafficking); and water vapour in and below chipseals (described in this report).

The ultimate objective was to determine ways of minimising flushing and so extend the life of chipseals. Two possible mechanisms that could be causing moisture-induced flushing were postulated:

(a) Vapour pressure from water in the base pushing bitumen up through the seal layers.
(b) Water entering through the surface because of a loss in bond between the stone and binder or through cracks in the binder; then, when the temperature rises, the trapped water vaporises and creates bubbles.

Both mechanisms could be at work in the one seal.

2. Methodology

This research project studied both mechanisms outlined in Section 1. (a) and (b):

a) Modelling the Effect of Water Vapour Pressure. Bitumen flow in a simple model of a seal was calculated using an appropriate seal temperature regime and realistic water vapour pressures.
b) Measurement of Water Ingress through Seals. An apparatus was designed and constructed to apply a head of water to the surface of seal samples. The head was pulsed regularly at pressures typical of those caused by truck tyres on wet roads, and the rate of ingress of water (if any) measured. Water ingress under static pressure was also studied. Seal samples from a number of flushed sites and one unflushed site were tested and the results compared.

3. Results and Conclusions

a) Both proposed mechanisms for water to gain access to chipseals to induce flushing are supported by the work reported.

b) Calculations of the size of the effect of water vapour pressure pushing bitumen through seals from beneath produced results which support the proposal that this effect does, in fact, induce flushing.

c) Seal thickness and bitumen grade are second order influences in this water vapour effect. The primary requirement is for a sufficiently wide continuous passage through the seal layer for the bitumen to travel through. This passage needs to have an effective diameter of only 0.1 mm, or possibly less, for flushing to occur. Given the single stone size structure of a chipseal, it is likely that such passages exist.

d) An unresolved question is whether or not water vapour is present immediately beneath seals at sufficient pressure and at sufficiently high temperatures for a long enough time to cause significant flushing. Some calculations by Tan (1980) support the possibility, but experimental verification is needed.

e) Both dynamic and static water pressure tests support the proposal that traffic on a wet road surface can force water into the surface, from where it may vaporise and form the blisters of seal binder that can eventually result in flushing.

f) The tests indicate that water ingress under traffic may be a widespread phenomenon with chipseals, not restricted to seals that are obviously flushing.

g) Rates of water ingress under water pressure were far higher than expected, with absorption occurring not just at high pressures typical of truck tyres, but even at pressures below those found in car tyres.

h) The experimental results support the likelihood that absorption occurs at specific fault sites in the seals, rather than over the seal as a whole.

i) Under typical truck tyre pressures and at typical road temperatures, it is probable that faults through which water can enter a seal will be gradually enlarged.

4. Recommendations

Work is suggested to answer two outstanding questions about the proposed water-induced flushing mechanisms:

(i) Water vapour pressure just beneath a seal or multiple seal layer can reach a level sufficient to induce extrusion of bitumen, but does it do this for a sufficient time and at a sufficiently high temperature for the effect to be important?

(ii) Is a higher proportion of all seals (not just flushed seals) permeable to water than is commonly assumed, especially under pressure from vehicle tyres?

The proposed work is as follows:

a) Monitoring the variation over time of water vapour pressure beneath seals.

b) Applying pressure of the order of the observed vapour pressures found in seals, to the base of a seal sample to see if the formation of binder bubbles occurs at the surface. The seal would be kept at a summer daytime temperature to make the bitumen realistically fluid.

c) Monitor water-induced flushing in a proposed study of moisture in pavement seals

d) Carry out seal water permeability tests for an increased variety of seal types, bitumen grades and seal ages.

e) Design and carry out a study to develop means of identifying and correcting for site factors promoting water induced flushing.

ABSTRACT

A study was made of proposed means by which water can enter chipseals surfaces and induce flushing. The means were water transfer from the basecourse and pressure from tyres on wet roads. The data support the occurrence of both phenomena. It is possible that a significantly greater proportion of chipseal surfaces than is commonly believed are in fact permeable to water. Further research is suggested to gain additional information on the flushing process, to assess the prevalence of permeable seals, to devise means of assessing seal sites for their susceptibility to water induced flushing, and to develop ways of countering this phenomenon.

1. INTRODUCTION

A study made of chipseal data from the New Zealand state highway system (Ball and Owen, 1998) found that the two major types of surface distress that lead to the decision to reseal are alligator cracking of the seal, and flushing (the appearance of bitumen at the surface of the seal). Transfund New Zealand subsequently commissioned work into possible causes of flushing.

This report deals with an investigation of proposed mechanisms of water-induced flushing.

1.1 Causes of Flushing

At the beginning of this work evidence was available that there were at least two independent causes of flushing, traffic and rising moisture.

1.1.1 Trafficking

This is immediately apparent because flushing commonly appears first in the wheeltracks. A subsequent investigation of the relative effects of traffic levels, seal type, seal binder rheological properties and the pavement construction beneath the top seal was reported in Transfund Research Report No. 122 (Ball and Patrick, 1998).

1.1.2 Rising Moisture

Moisture rising through the pavement beneath the seal results in miniature 'volcanoes' appearing where bubbles of binder form above the water vapour and then collapse as the vapour breaks through and escapes. This phenomenon appears in seals that have significant texture depth (i.e. it is not directly associated with loss of texture depth from trafficking), with the binder rising to the surface in small pockets which eventually coalesce to cause flushing. This type of flushing can be found anywhere on a road surface, although it is often more prominent where the pavement is trafficked.

2. STUDY OVERVIEW

Two possible mechanisms that could be causing moisture induced flushing were postulated:

(a) Vapour pressure from water in the base pushing bitumen up through successive seals.

(b) Water entering the surface through cracks in the binder and/or through a loss in bond between the stone and binder; then, when the temperature rises the trapped water vaporises and creates bubbles.

Both mechanisms could be at work in the one seal.

2.1 Two Mechanisms Investigated

The work reported here was carried out to determine whether either or both of the proposed mechanisms were possible.

2.1.1 Modelling the Effect of Water Vapour Pressure (2.a)

Bitumen flow in a simple model of a seal was calculated using an appropriate seal temperature regime and realistic water vapour pressures. The results give an indication of the likelihood that this mechanism causes flushing.

2.1.2 Measurement of Water Ingress through Seals (2.b)

An apparatus was designed and constructed to apply a head of water to the surface of seal samples. The head was pulsed regularly at pressures typical of those caused by truck tyres on wet roads, and the rate of ingress of water (if any) measured. Water ingress under static pressure was also studied. Seal samples from a number of flushed sites and one unflushed site were tested and the results compared.

3. MODELLING THE EFFECT OF WATER VAPOUR PRESSURE

3.1 Calculation

To model the effect of water vapour pressure we considered bitumen flow through a capillary, under a pressure gradient corresponding to the saturated vapour pressure of water.

The formula for fluid flow through a capillary is:

$$\dot{Q} = \frac{\pi \quad R^4 \quad \delta P}{8 \quad \ell \quad \eta} \tag{1}$$

where

$\dot{Q}$ = Rate of fluid flow (volume per unit time)
R = Capillary radius
δP = Pressure differential across capillary
η = Fluid viscosity
ℓ = Capillary length

Values of the various parameters will be assigned as follows:

ℓ = 9 mm (the approximate thickness of a Grade 3 chip seal)

R = 0.05 mm

δP is assigned values for saturated water vapour pressures taken from Kaye and Laby (1973), page 173.

A good fit to the vapour pressure (in kPa) over the range 0°C to 90°C is

$$\log_{10}(Pressure) = \left[\frac{-2211.636}{Temperature(^{\circ}C) + 273.15}\right] + 7.93712 \tag{2}$$

A set of viscosities appropriate for 180/200 bitumen at various temperatures is listed in column 2 of table 1, and the corresponding mean flow rates (in m^3/s) are listed in column 4. Column 5 lists the proportion of time over a year that a seal surface at Napier experienced the different temperature ranges listed in column 1 (Ball, 1987). From this the time spent in the temperature range over a year is calculated (column 6) and multiplied by the mean flow rate to obtain the total bitumen flow (column 7). Total flow for the year, given that the fines immediately below the surface are saturated, is 26.31 mL.

Equation 1 allows us to examine the effect of varying the various parameters affecting total flow. Thus, increasing the capillary radius to 0.5 mm gives a total annual flow of 263.1 litres. Against this, other variations such as increasing the seal thickness (ℓ) and altering the bitumen grade (for 80/100, viscosity values (η) will typically be three to ten times greater than for 180/200, depending on the temperature in the range of interest) have a minor effect.

Table 1 Calculation of Bitumen Flow over a Year

1	2	3	4	5	6	7
Temperature Range	Mean Viscosity	Mean Pressure	Mean Flow Rate	%time in Temperature Range	sec/yr. in Temperature Range	mL/yr. for Temperature Range
°C	Pa s	kPa	m^3/s	Napier		
0 – 6	1500000	0.84781	1.54156E-19	3.0	946080	0.000015
6 – 12	200000	1.254898	1.71132E-18	20.5	6464880	0.01106
12 – 18	90000	1.827367	5.5378E-18	25.4	8010144	0.04436
18 – 24	20000	2.620503	3.57362E-17	22.4	7064064	0.25244
24 - 30	7000	3.704113	1.44324E-16	11.9	3752784	0.54162
30 –36	2500	5.165264	5.63516E-16	7.1	2239056	1.26174
36 - 42	800	7.111307	2.42445E-15	4.8	1513728	3.66996
42 - 48	250	9.673171	1.05532E-14	3.4	1072224	11.31535
48 - 54	170	13.00893	2.08712E-14	1.4	441504	9.21470
54 - 60	57	17.30763	5.90067E-14	0	0	0
					Total	26.31138

A typical surface void between chips on a grade 3 seal will have volume of around 0.05 mL. Thus, the calculation indicates that the action of saturated water vapour pressure below the seal can deliver, within a year, over 500 times the amount of bitumen needed to produce flushing at the seal surface, provided that there is a continuous passage of effective diameter of around 0.1 mm through the seal. Given the effectively single-size chip structure of a chipseal, it is likely that such passages exist.

Consider a much less favourable situation for causing flushing:

- a multiple seal, with thickness increased by a factor of 4 ($\ell = 36$ mm),
- bitumen viscosity increased by a factor of 10 (a hard 80/100 bitumen), and
- relative humidity beneath the seal of 25%

The flow volume over a year is now $(26.3 \times 0.25)/(4 \times 10) = 0.164$ mL, which is still over three times the volume needed to fill a typical surface void.

Flushing caused by water vapour below the seal may therefore occur for a wide range of seal types, degrees of saturation, and bitumen grades.

3.2 Discussion

The question of whether the vapour pressure of water beneath a seal surface can be a significant cause of flushing in New Zealand, depends on whether local site conditions, such as climate and topography, lead to high enough water vapour pressures occurring at sufficiently high temperatures for sufficiently long periods.

This question has not been resolved for New Zealand conditions. Tan (1980) carried out calculations for a sealed road with a berm. His calculations indicated that

a) "During the day temperature gradients (vertical and between seal and berm) encourage the liquid water to move downwards to the subbase and outwards to the berms. However the suction potential of the soil works in the reverse direction, either hindering the thermally induced flow, or actually reversing it. The total effect is the movement of moisture toward the berm and some absorption of moisture from the subbase."

b) "At night the directions of moisture movement are from the berm to the road body and from the subbase towards the upper layer. Hence, *net accumulation of water occurs in the upper layer of the road body*" (italics added).

Tan concluded that: "moisture accumulation and retention in the top fines layer is highly probable in the real road situation", and recommended field testing to check the results of the calculations.

A number of trials have been carried out to investigate the moisture regimes under New Zealand pavements (McLarin, 1987, 1989; Patrick and McLarin, 1998). In all cases investigated ingress through the road surface from above was a significant contributor to water content in the road structure. However, there were faults in the surface associated with the installation of the instrumentation and seal age (up to 10 years). Newer seals may be impervious to water, so that Tan's proposed mechanism of moisture accumulation may occur.

A number of recommendations for further research are listed in Section 6.

4. SURFACE INGRESS OF WATER

4.1 Overview

The possibility to be tested is that flushing of the seals can be caused by the vaporisation of water which has previously penetrated the seal surface under the pressure of vehicle tyres.

The proposed method of checking this possibility was to apply pulsed water pressure at a realistic level (around 500 kPa, typical of truck tyre pressures) to the surface of lightly bleeding seals retrieved from the field, and to measure the degree to which water penetrated the surface.

The samples to be tested were 250 mm diameter cored seals. It was necessary to devise apparatus:

(i) To apply the pressure at a controlled level and fixed temperature, and
(ii) To measure the quantity of any water absorbed by the seal.

4.2 Site Inspection and Sampling

Samples of 250 mm diameter were wet-cored from a number of sites at Wainuiomata, in the Hutt Valley, and on hill suburbs (Maungaraki and Stokes Valley). Care was exercised to minimise the possibility of seal bending and cracking, with the cores being transported to the laboratory seal surface downwards on flat boards. A heavily flushed/bleeding sample was also received, as a rectangular sawed slab, from State Highway 2 in Hawkes Bay. The slab was cored in a face down position, to produce a test sample of the same dimensions as the other samples.

Details of each site were noted, and information on sealing history and traffic levels was obtained from the relevant authorities. The information is listed in the Table 2.

4.3 Test Specimen Preparation

The core samples displayed differing numbers of seals (Table 2), while the thickness of basecourse adhering to each sample varied from 10 to 50 mm. Samples were inspected to ensure they were free of visible damage, and prepared for testing in the following manner:

(i) A layer of open sand/cement mix was placed on the basecourse while the sample was still in the "as received" inverted position, to produce a uniform cylinder 250 mm diameter x 80 mm high. The sand/cement layer was designed so that it had sufficiently high permeability for the maximum water flow from a bench tap to not overflow a 150 mm sand/cement sample contained in a CBR mould.

(ii) When the sand/cement mix had cured, the sample was turned over to expose the surface of the chip seal. Any soil adhering to the surface was removed using water and/or light brushing.

Table 2 Sites Sampled

All sites unless indicated have water-induced (spot) flushing.

No.	Location	Site Description	Sample Description	ADT
1	Entrance to Central Laboratories Drive, Gracefield	Level site, altitude ~ 5 m, industrial area	Grade 4 seal over ~6 mm Fine Mix over a Grade 4 Seal	-
2	Dowse Drive at Oakleigh St., Maungaraki, Lower Hutt Western hills	Residential/shopping area at crest of hill, altitude ~ 210 m	Grade 5 void fill, 180/200 (Jan 1988) over a Grade 3 seal	3500
3	Pedestrian Crossing, Boulcott St at High St, Lower Hutt	Residential level site abutting heavily trafficked road	Grade 4 seal on ~15 mm Mix 10	499
4	67 Mohaka St, Parkway, Wainuiomata	Residential, level. Sampled adjacent to grass berm	Grade 3, 180/200 (March 1989), possibly over another Grade 3	51
5	20 Kaponga St., Parkway, Wainuiomata.	Residential, level, off Mohaka St. Sampled adjacent to grass berm. Stream conduit approximately 50 m away	Grade 3 reseal, 180/200 (1977?), over at least one Grade 4 seal, probably first-coat.	5
6	Kaponga St	As above, sampled at crown of road	As above, but unflushed	5
7	180 Holborn Drive, Stokes Valley, Lower Hutt	Residential level site, with uphill road at either end.	Grade 3/5 two-coat seal, unflushed, (Dec 1998) over Grade 4 reseal (1991) Grade 6 voidfill (1985) Grade 2 seal	500
8	State Highway 2, RP 483/13.93 (SH Region No. 6, Wairoa District)	Gradual curve approach to bridge, outer wheeltrack. Level, but in rolling country. altitude ~ 18 m.	Completely flushed surface Grade 2 seal, 130/150, Grade 5 drylock (24/1/97), over Grade 4, 130/150 (1/12/93) Grade 3, 80/100 (28/3/90) Grade 3, 80/100 (25/12/82)	1300

(iii) The surface of the chip seal was allowed to air dry at room temperature.

(iv) A 50 mm wide polyurethane seal was cast onto the chip seal, leaving a 150 mm diameter test area exposed in the centre of the sample.

(v) The prepared samples were placed on top of three layers of 3 mm thick geotextile fabric lying on the base-plate. The top-plate was then carefully secured in place, on top of the chipseal, by progressively tightening nuts on the eight connecting rods.

(vi) The 150 mm diameter void between the chip seal test area and the top-plate was filled with de-aired water.

4.4 Test Procedure

The test equipment, comprising a base-plate, connecting rods, top plate and measuring cylinder is shown in Figure 1.

The test procedure initially proposed was a dynamic pressure test involving repeated application of 500 kPa pressure to the test area for a period of one second, with a rest interval of one second.

The procedure was modified to include a preliminary series of static tests at pressures ranging from 100 kPa to 500 kPa, as a result of very high flow rates measured during the first dynamic test. Subsequently dynamic tests were not performed on samples showing high flow rates during the initial static test.

4.4.1 Static Testing

Static pressure testing was performed using standard test facilities in a laboratory maintained at a temperature of 20-22°C. The drainage port of the test apparatus was connected to a regulated supply of de-aired water, via a burette to monitor water flow, while the top of the measuring cylinder was sealed. After setting the water pressure, the drainage port tap was opened to apply pressure to the test area and any water flow was monitored using a burette and a stopwatch.

Typically the samples showed an initial and very rapid "apparent" flow, followed by lower flow rates attributed to the passage of water through the sample. Water was generally visible exiting the base of the sand/cement mix or exiting between seal layers, indicating that continued low flow rates were not simply related to sample deformation.

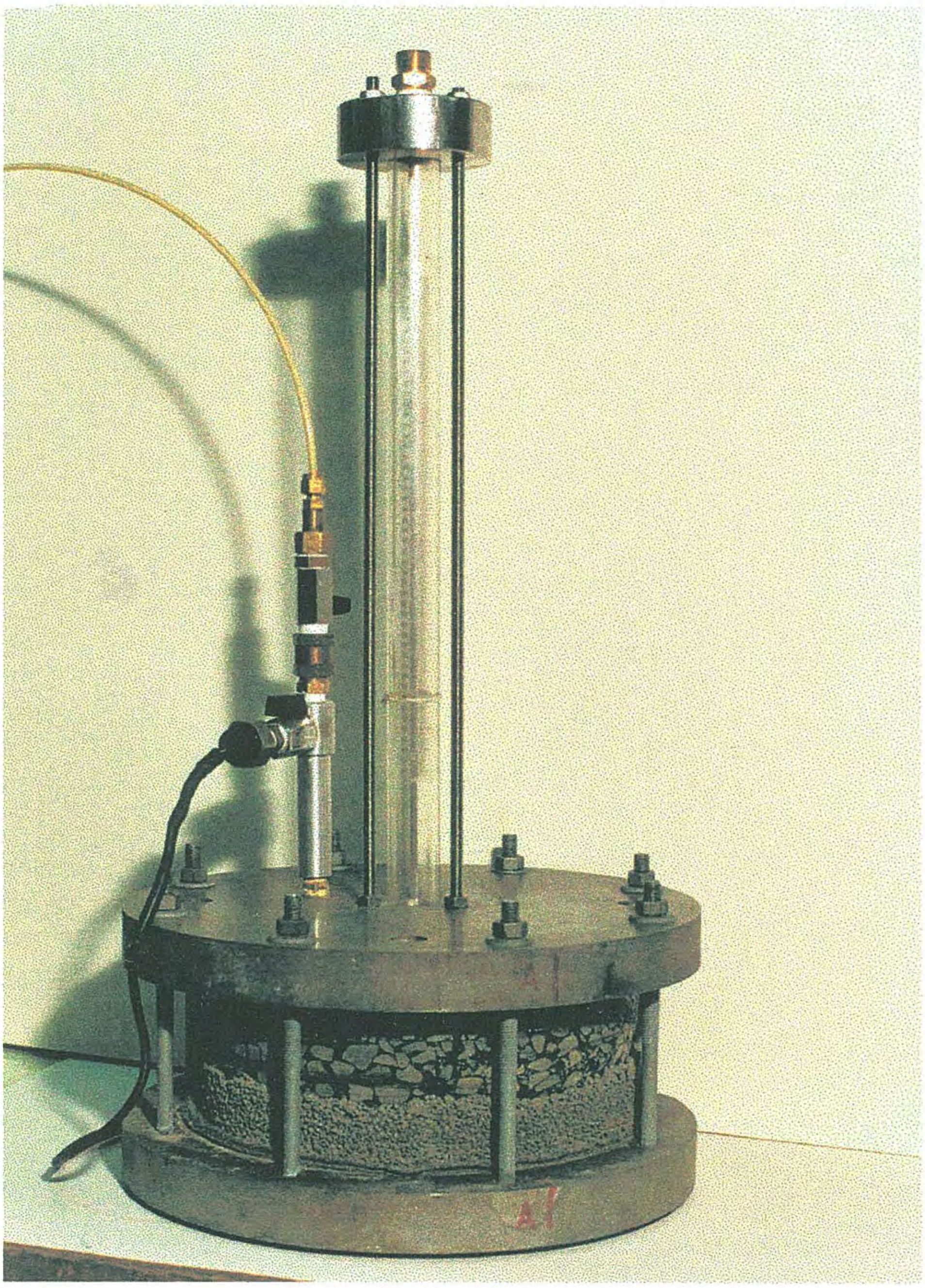


Figure 1. Water Permeability Seal Testing Apparatus

4.4.2 Dynamic Testing

The dynamic tests were conducted at controlled temperatures, by placing the sample and test apparatus in plastic bags immersed in a water bath.

Pressure was applied to the sample test area via a stainless steel piston inside the measuring cylinder, located at the centre of the top-plate. The piston, with two "O" ring seals, was used to monitor water flow by recording its position relative to a calibrated volume scale on the cylinder, when the pressure was applied.

For the initial series of dynamic tests an unregulated pressure supply was applied to the test area. The supply pressure of 500 kPa ±40 kPa was monitored using a Honeywell pressure transducer and datalogger, which provided graphical output during the test as well as a digital record of the test pressure.

4.4.3 Post Test Sample Examination

On completion of testing examinations were carried out to investigate issues including:

- The integrity of the contact between the aggregate and the polyurethane seal (initial tests only).
- Removal of surface aggregate to check for presence of water beneath the surface and the possibility of water channels.

4.5 Test Results

In the following discussion the sites sampled will be referred to by their number labels as listed in Table 2.

4.5.1 Dynamic Testing

Flow data for tests carried out at low temperatures for sites 1 to 6 are shown in Figure 2.

The flows have been normalised from the initial mL/minute values to mm depth values by dividing the flow by the area of seal exposed to the water (for the equipment used a 18 mL transfer of water corresponds to a layer of water over a seal of approximately 1 mm being absorbed into the seal).

All low temperature measurements except one (a sample from site 1, indicated by the asterisk, tested at 6.2°C) were carried out at 4°C.

Figure 2. Low Temperature Pulsed Water Pressure Tests (500 kPa). Sites 1 to 6.

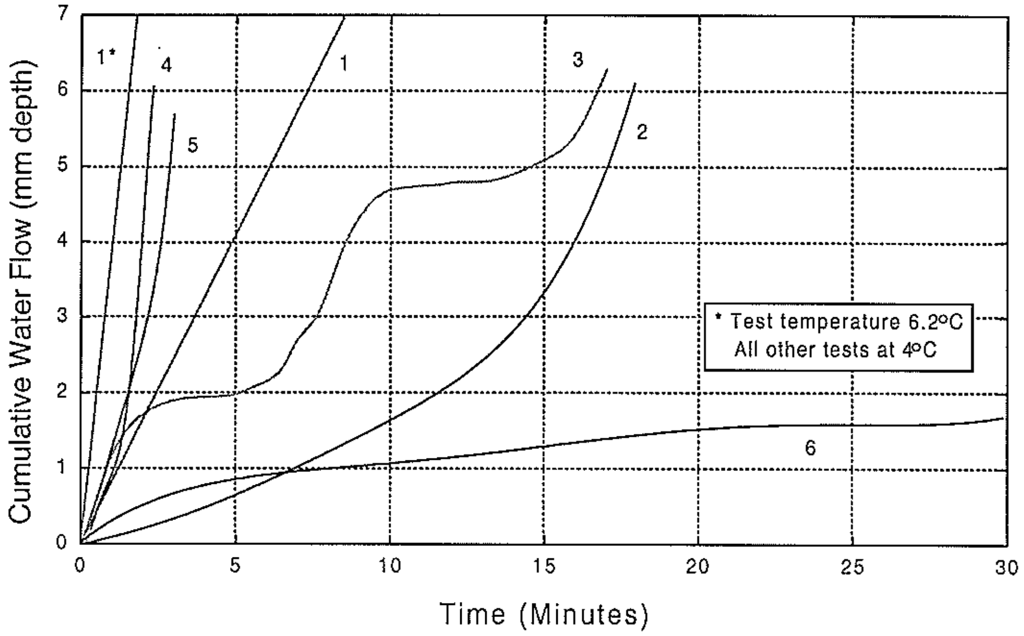
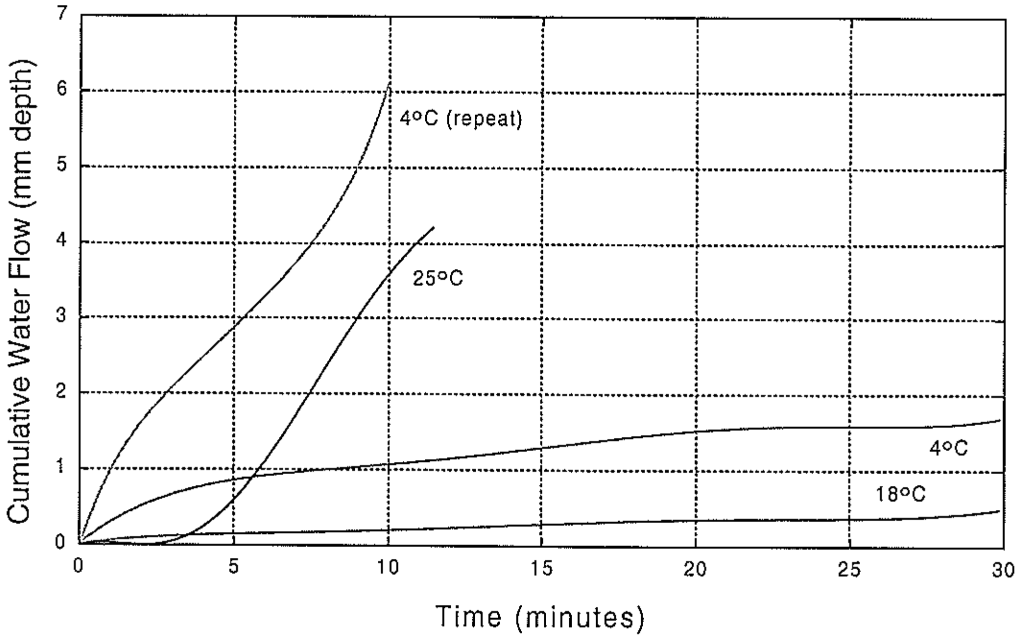


Figure 3. Pulsed Water Pressure Testing (500 kPa) for Site 6



The 500 kPa pressure impulses were applied at a rate of approximately 40 per minute. The flow rates observed were surprisingly high, so that it was generally necessary to terminate the tests within minutes rather than the hours or even days originally anticipated. For the sites with the lower flow rates, with the exception of site 6, (which was the only site without spot flushing), the flow rate increased with time, while for the other sites the flow rates were too fast and the testing over too quickly to tell whether the rates were increasing. The increasing flow rates suggest that over a period of time there is a widening of the passages (or an increase in the number) by which water enters the seals. The reason for the erratic flow rates for site 3 is unknown. Possibly there was a flow blockage which was periodically cleared.

For site 6 (from an area of unflushed surface at the crown of a 22 year old seal with a very low level of trafficking) tests were carried out at 18°C (room temperature), followed, in order, by ones at 4°C, 25°C, and then, finally, at 4°C. The resultant flow data is shown in figure 3.

Although the flow rate at 4°C is initially greater than that at 18°C, after approximately 25 minutes the slopes of the two curves were approximately equal, and this remained the case over the following 35 minutes (not shown in figure 3). The flow rate at 25 °C is much higher, and that for the repeat measurement at 4°C is similarly high. It is proposed, in view of these results, that at low temperatures flow rates do not depend to any significant degree on temperature variation, whereas at higher temperatures the pressure is sufficient to enlarge passages through the seal by movement of the now more fluid bitumen. This damage is irreversible; hence the increased flow for the repeat 4°C experimental run.

Several chips were removed from the seal surface after testing a sample from site 1. Water was found beneath the chips, and in several cases there were holes in the surface which extended down into the seal as far as could be observed.

4.5.2 Static Testing

With the surprisingly high flow rates obtained for the dynamic testing, it was decided that other varieties of seal condition should be investigated, to see if the high rates were characteristic only of spot flushed areas. Two extra seals were chosen:

a. A recent two-coat seal (December 1998) from a residential site (Site 7), and
b. A completely flushed multilayer seal (Site 8).

For initial testing it was planned to compare these seals under static testing at 100 kPa water pressure with other seals that had been both dynamically and statically tested. Representative flow rate levels (in units of mm depth per minute) are listed below in Table 3.

Table 3. Constant Pressure Flow Rates at Room Temperature (all pressures 100 kPa unless otherwise indicated)

Site No.	Sample No.	Water Flow Rate mm/minute	Comment
1	1	0.78	Dynamic test at 6.2°C
1	2	0.83	Dynamic test at 4°C
6	1	0.16	Dynamically tested at various temperatures
6	2	0.65	Static test only
7	1	0.51	
7	2	4.53	
8	1	3.62	Atmospheric pressure test. Flow too high to test at 100 kPa. One sample only was available

Dynamic pressure testing for samples from sites 7 and 8 was not proceeded with since the relatively high static permeabilities indicated that no new insight would be forthcoming on the behaviour of low permeability seals.

Notes:

(1) There is a correlation between the static (100 kPa) and dynamic (500 kPa) test results, with the larger static results corresponding to larger dynamic results.

(2) The second unflushed area from site 6 did not have the same low permeability as its predecessor.

(3) For one of the Site 7 samples several hemispherical bitumen bubbles approximately 8 mm diameter formed at the edge of the seal below the top surface. The binder viscosity is therefore sufficiently low for extrusion to take place at the ambient temperature (20-22°C) under a pressure of 100 kPa. The behaviour also indicates that in at least some surfaces it is possible for ingressing water to collect between seal layers, from whence it may produce water vapour induced flushing.

(4) There is some evidence that leakage through the seals takes place at specific points rather than uniformly across the seals, namely:

- In general water eventually appeared initially at the sides of the supporting sand/cement at a few positions, rather than uniformly around the sample,
- On one occasion a fountain of water squirted from a pinhole at the base of a seal, and
- The appearance of bubbles at the side of a sample from site 7 indicated that water was emerging from restricted areas.

5. DISCUSSION AND CONCLUSIONS

5.1 Both of the proposed mechanisms for water to gain access to chipseals to induce flushing are supported by the work reported above.

5.2 Calculations of the size of the effect of water vapour pressure pushing bitumen through seals from beneath produced results which support the proposal that this effect does, in fact, induce flushing.

5.3 Seal thickness and bitumen grade are second order influences in this water vapour effect. The primary requirement is for a sufficiently wide continuous passage through the seal layer for the bitumen to travel. This passage needs to have an effective diameter of only 0.1 mm, or possibly less, for flushing to be possible. Given the single stone size structure of a chipseal, it is likely that such passages exist.

5.4 An unresolved question is whether or not water vapour is present immediately beneath seals at sufficient pressure and at sufficiently high temperatures for a long enough time to cause significant flushing. Some calculations by Tan (1980) support the possibility, but experimental verification is needed.

5.5 Both dynamic and static water pressure tests support the proposal that traffic on a wet road surface can force water into the surface, from where it may vaporise and form the blisters of seal binder that can eventually result in flushing.

5.6 The tests indicate that water ingress under traffic may be a widespread phenomenon with chipseals, not restricted to seals that are obviously flushing.

5.7 Rates of water ingress under water pressure were far higher than expected, with absorption occurring not just at high pressures typical of truck tyres, but even at pressures below those found in car tyres.

5.8 The experimental results support the likelihood that absorption occurs at specific fault sites in the seals, rather than over the seal as a whole. From the area of the seal sizes used, and taking two fault sites per sample as typical, it follows that there would be around 110 fault sites per square metre on the road surface.

5.9 Under typical truck tyre pressures and at typical road temperatures, it is probable that faults through which water can enter a seal will be gradually enlarged.

6. RECOMMENDATIONS

6.1 Further Investigation of Vapour Pressure Flushing Mechanisms

The work described above has supported the viability of the two proposed mechanisms by which water may gain access to chipseals so as to induce flushing. There are some outstanding questions, as noted above. Specifically:

(i) Water vapour pressure just beneath a seal or multiple seal layer can reach a level sufficient to induce extrusion of bitumen, but does it do this for a sufficient time and at a sufficiently high temperature for the effect to be important?

(ii) Is a higher proportion of all seals (not just flushed seals) permeable to water than is commonly assumed, especially under pressure from vehicle tyres?

Proposed research into question (i) is outlined in 6.1.1, 6.1.2 and 6.1.3; and question (ii) in 6.1.4.

6.1.1 Measurement of Water Vapour Pressure beneath a Seal (i)

A small pressure-sensitive probe would be inserted just below a seal exhibiting spot flushing, and its entrance point sealed to prevent access of water. Another probe would measure air pressure over the seal. Thermistors attached to the two probes would be used to measure temperatures and allow calculation of relative humidity from the pressure data. The pressure probes would need to be able to measure pressure differences of up to 20 kPa between atmospheric pressure and the sub-seal environment pressure. Monitoring should be carried out after a period of wet weather in summer, to ensure that the subseal conditions have been re-established; it should last at least several days to see whether or not the relative humidity of the sub-seal environment changes significantly with time. A site at least one year old where spot flushing has not occurred should be similarly monitored.

6.1.2 Duplicating Proposed Mechanism by Applying Pressure below Seal Sample (i)

A cored unflushed seal sample would be heated to near the maximum temperature it attains in the field (approximately 55°C) and an excess air pressure of the order of the maximum observed in 6.1.1 (possibly around 20 kPa) applied to the base. This pressure differential should be applied for several hours, and the surface monitored for the appearance of bitumen bubbles.

6.1.3 Correlating Spot Flushing with Field Conditions (i)

Patrick and McLarin's (1998) report on proposed research on New Zealand pavement moisture recommends a monitoring program for a minimum of at least 20 sites, covering the range of seasonal moisture conditions expected over a year. The proposal is to periodically measure variations in pavement strength using a falling weight deflectometer. If this program goes ahead it is recommended that these sites be also inspected for the appearance of spot flushing, to see if its appearance is associated with relatively high water content below the surface.

6.1.4 Further Seal Permeability Testing (ii)

Since the experimental results suggest that seal permeability may be more widespread than is commonly assumed, it is appropriate to test this possibility on a greater variety of seals. A further selection of road seal types with varying binder grade and age should be tested.

6.2 Reduction of Water-induced Flushing in the Field

It is suggested that a study be carried out of with the aim of identifying the types of road site that are liable to unduly high water content levels just below the seals, and of identifying possible ways to reduce these levels. The ultimate aim would be to devise trials to see whether water levels beneath flushing-prone seals could be lowered and flushing prevented.

7. REFERENCES

Ball, G.F.A. 1987. Temperature measurements in pavements - Napier. *Central Laboratories Report 6-87/1*, Ministry of Works and Development, Lower Hutt.

Ball, G.F.A. and Owen, M.T. 1998. Chip seal lifetimes in New Zealand. Proceedings of the 9th Road Engineering Association of Asia and Australasia Conference (REAAA), Wellington, New Zealand, 3-8 May, 1998, Vol. 1: 452 - 458.

Ball, G.F.A. and Patrick, J.E. 1998. Flushing processes in chipseals. Effects of Trafficking. *Transfund New Zealand Research Report No. 122*, Wellington.

Kaye, G. W. C. and Laby T. H. 1973. *Tables of Physical and Chemical Constants and Some Mathematical Functions (14th Edition)*, Longman Group Limited, London. 386pp.

McLarin, M. W. 1987. Variations of moisture conditions in pavement and subgrade. *New Zealand Roading Symposium 1:* 149 – 160

McLarin, M. W. 1989. Water in roads – an update. *Central Laboratories Report 89-B2416,* Works Consultancy Services Limited, Lower Hutt

Patrick J. E. and McLarin M.W. 1998. Moisture in pavements: directions for New Zealand research. *Transfund New Zealand Research Report No. 111*

Tan, S. K. 1980. Thermal moisture movement in a multilayered basecourse. *University of Auckland School of Engineering, Department of Civil Engineering, Report No. 224 (National Roads Board Project BC/17 CII)*