PERMEABILITIES OF CHIPSEALS IN NEW ZEALAND

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ABSTRACT

The predominant pavement type used in New Zealand State Highways is an unbound granular sub-base and basecourse, with a chipseal wearing course. These pavements are very susceptible to the presence of moisture, which may induce both cracking and flushing of the surface under traffic and climatological stresses. It has been believed in the past that chipseals were impermeable providing there was at least 1.5 l/m^2 of bitumen. However, recent tests have suggested that water may gain access to the pavement undersurface by being forced through from the top of the chipseal by tyre pressure. This paper describes a laboratory study which duplicated the effect of tyres on wet roads. Core samples were taken from a selection of seals and the water permeability of these seals measured under pressure. The results support the proposition that water access occurs through the upper seal surface and may be a possible factor in causing chipseal distress.

BACKGROUND and 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 (i.e. appearance of bitumen at the surface of the seal). Transfund New Zealand subsequently commissioned work into possible causes of flushing.

At the beginning of this work evidence was available that there are at least two independent causes of flushing:

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).

2. Moisture rising through the pavement beneath the seal. This 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 can appear 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. An investigation of the effects of water in the flushing processes in chipseals was reported in Transfund Research Report No. 156 (Ball, Logan and Patrick, 1999).

The experimental results from Transfund Research Report No. 156 suggest that seal permeability may be more widespread than is commonly assumed. The report recommends that this possibility be explored by carrying out permeability testing on a greater variety of seals. It was recommended that a further selection of road seal types with varying binder grade and age should be tested.

This report deals with selection and permeability testing of a further seven core samples, in addition to samples tested for Transfund Research Report No. 156.

STUDY OVERVIEW

The water permeability of seals was measured under pressure using an apparatus designed and constructed for the Transfund New Zealand Research Report No. 156 ("Flushing processes in chipseals: effects of water"). The apparatus was designed and constructed to apply a head of water to the surface of seal samples. The head can be pulsed regularly at pressures typical of those caused by truck tyres on wet roads, and the rate of ingress of water measured. Experience showed that samples were permeable even under static pressures, and the work described here was carried out under these conditions.

Water permeability testing for this study was first carried out at 100 kPa water pressure, proceeding to 200 and 300 kPa if there was no obvious sign of seal failure. After any seal failure occurring above 100 kPa, retesting at 100 kPa was performed to provide an indication of the degree of damage. The room temperature during testing was controlled to 21 ± 1°C.

Seal samples from a number of flushed and unflushed sites were tested and the results compared.

SURFACE INGRESS OF WATER

Overview

The experiment was originally set up to explore the possibility that flushing of 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. Subsequently it was found that samples were generally permeable even under static pressures of much lower magnitude, and flow rates at high pressures were too high to accurately measure with the apparatus available. Consequently, the work to be described here was carried out at static water pressures up to 300 kPa.

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.

Site Inspection and Sampling

Samples of 250 mm diameter were wet-cored from a range of locations in the Wairarapa on SH 2 and SH 53. Samples for the original Transfund Research Report No. 156 were collected from a number of sites at Wainuiomata, in the Hutt Valley and on hill suburbs (Maungaraki and Stokes Valley), plus a heavily flushed/bleeding sample from State Highway 2 in Hawkes Bay. 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.

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 Tables 1 and 2.

Test Apparatus

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. For this purpose the 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.

As a result of very high flow rates measured during dynamic testing the equipment was modified to carry out a series of static tests at pressures ranging from 100 kPa to 300 kPa.

Test Specimen Preparation

The core samples displayed differing numbers of seals (Table 1), 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.

(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 test equipment 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.

Test Procedure

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 the burette and a stopwatch.

Test Results

In the following discussion the samples will be referred to by their site labels as listed in Table 1.

Testing was first carried out at 100 kPa water pressure, proceeding to 200 and 300 kPa if there was no obvious sign of seal failure. After any seal failure occurring above 100 kPa, retesting at 100 kPa was performed to provide an indication of the degree of damage. The room temperature during testing was controlled to 21 ± 1°C.

Generally, the water level in the test gauge fell rapidly at first (probably compression of residual air in the apparatus) and then settled down to a slower linear flow. Water was generally visible exiting the base of the sand/cement mix or exiting between seal layers.

Several types of behaviour were found:

1. A final flow rate of at 100 kPa pressure of 0.2 to 0.8 mm/minute. This was the most common behaviour. A typical example (Site B) is shown in **figure 2**.

2. Sudden increases in the flow rate, suggesting the creation of new passages for the water through the seal. This was found for sample D (**figure 3**). Similar behaviour had previously been observed during the dynamic pressure testing project.

3. Relatively low flow rates (Sites E and H) (**figure 4**) increasing slightly with increased pressure. Reversion to the lowest pressure (100 kPa) gives a larger flow rate than initially. Some damage has evidently occurred within the samples.

4. High flow rates which are too rapid for the apparatus to measure accurately (Site I)

The Site 8 seal has a higher permeability than most seals (though not exceptionally high), but differs from the other surfaces in being completely flushed

The rates of flow, expressed as rates of change of water level on the samples (cross sectional diameter 150 mm), are listed below in Table 2. Results from the Transfund research project (samples 1, 6, 7 and 8, corresponding to their site labelling in the report) are included for comparative purposes.

Table 1

Seal Sample Locations

Site Label	Location	Sample Description (layers are listed youngest to oldest)
1	Entrance to Central Laboratories Drive, Gracefield	(1)Gr 4 : AC(2) : Gr4 Spot flushing
6	20 Kaponga St., Parkway, Wainuiomata.	Gr 3 : Gr4
7	180 Holborn Drive, Stokes Valley, Lower Hutt	Gr 3/5 : Gr 4: Gr 6 voidfill : Gr 2
8	SH 2, RP 483/13.93 (SH Region No. 6, Wairoa District)	Gr 2 (130/150) & Gr 5 drylock : Gr 4 (130/150) : Gr 3 (80/100) : Gr 3 (80/100) Completely flushed surface
A	SH 2, RP 883/6.63	Gr3 : Gr 2 : Gr 3 : Gr 5
B	SH 2, RP 883/8.75	Gr 2 : Gr 2 : Gr 3 : AC: Gr 2 : AC : Bitumen bound basecourse
C	SH 2, RP 883/18.58	Gr 3 : Gr 5 VEM(3) : Gr 4 : Gr 2 : AC : Gr 2
D	SH 2, RP 905/0.5	Gr 2 : Gr 4
E	SH 2, RP 905/5.9	Gr 2 : Gr 5 VEM : Gr 2 : AC : Gr 4 : Gr 5 : AC : Bitumen bound basecourse
H	SH 53, RP 0/2.77	Gr 3 on polyester paving fabric : AC : Gr 2 : AC : Gr 3
I	SH 53, RP 0/9.8	Gr 5 : Gr 2 : Gr 4

Notes on Table 1:

(1) The layers in the pavement samples, from top to bottom, are listed from left to right. Gr 4 indicates a Grade 4 sealing chip single coat seal, Gr 3/5 a two-coat seal constructed with Grades 3 and 5 chips, etcetera. New Zealand sealing chip Grades 2, 3, 4 and 5 would pass sieves of sizes approximately 16, 13, 10, and 9 mm respectively.
(2) 'AC' indicates fine hotmix smoothing coat.
(3) 'VEM' indicates 'voidfill emulsion mix'.

Table 2

Seal Sample Properties

Site Label	ADT	Age Years	Approx Total v/l	Water Flow Rate mm/min 100 kPa	200 kPa	300 kPa	100 kPa(4)	Bitu-men Cont % vol
1	-	?	?	0.78 0.83(5)				
6	5	21.24	19 400	0.16 0.65(5)				
7	500	10.40	950 000	0.51 4.53(5)				
8	1300	2.32	551 000	3.62(6)				
A	8000	8.37	12 230 000	0.59				18.8
B	8000	4.37	6 380 000	0.22				17.2
C	6884	3.45	4 340 000	0.21	0.57	56.5	0.38	15.5
D	6240	10.45	11 910 000	0.05 – 0.25 - 2.14(7)				
E	4860	7.37	6 540 000	0.007	0.007	0.92	0.17	15
H	2000	2.37	866 000	0.007	0.010	0.011	0.108	20
I	2000	13.45	4 910 000	48.4				18.2

Notes on Table 2:

(4) Repeat flow test at 100 kPa after apparent failure of surface. (Column Heading)
(5) Second sample tested.
(6) Flow rate at atmospheric pressure; rate at 100 kPa too high to measure.
(7) Progressive failure of seal at 30 seconds and 80 seconds after commencement of test.

TYPES OF FAILURE

The point of seal failure was not always apparent, in which case the open sand cement mix supporting the sample would gradually become visibly wet. The following special cases were noted:

Site7:	Water exiting to form bitumen bubbles between the top and second seal.
Site C:	Water exited at the top of the smoothing coat layer on application of 300 kPa pressure.
Site D:	Water exiting between top (Grade 2) and bottom (Grade 4 first coat) seals (100 kPa pressure).
Site E:	Very low permeability at 100kPa and 200 kPa pressure. At 300 kPa water issued from above the upper smoothing coat.
Site H:	Very low initial permeability at 100 kPa, increasing gradually with increased pressure. At 300 kPa water was observed emerging from beneath the top seal, in the region of the polyester paving fabric. It is not certain that the fabric resisted the water pressure, as there is an asphalt smoothing coat immediately below it which could have acted as a water barrier.

Several pinholes, approximately 0.5 mm in diameter, could be observed in some, but not all seals, after testing. Where they were visible, there would typically be two or three holes on the 150 mm diameter exposed surface. In some instances the pinholes could be observed to extend well into the seal. Besides this no other forms of surface distress were visible.

OBSERVATIONS

In most cases, rates of water absorption were quite similar, typically 0.2 to 0.8 mm/minute. Seals E, H, and I are exceptions, with the first two having low rates of water absorption, and seal I showing rapid absorption.

Seal coats are thus generally permeable at 100 kPa water pressure (marginally less than one atmosphere), with the smoothing coat mixes and possibly the bitumen saturated polyester paving fabric providing effective barriers to the water, even at 300 kPa pressure. Further investigation is required to establish the reasons for the improved impermeability of the smoothing coat mixes and the seal containing a fabric layer.

There is no evident relationship between the water permeability of a seal and the amount of traffic the surface has experienced since resealing. For example, the seals with the two lowest permeabilities (sites E and H) have experienced since resealing total trafffic flows per lane of approximately 6.5 million and 870000 vehicles respectively; the very permeable site I has experienced 4.9 million vehicles.

DISCUSSION

In conclusion, most New Zealand chipseals will be permeable to water under pressure, at least on the top seal layer. The actual amount of water absorbed will depend on the rainfall and on the amount of heavy traffic. The laboratory results, in particular the increased rates of flow after some testing, suggest that the permeabilities of the seals are likely to be progressively increased by traffic, whether or not the seals are initially impermeable. Hardening of the bitumen with time may also make the seal more susceptible to damage.

Traditionally in New Zealand, chipseals have been considered to be impermeable. An issue that needs to be explored in relation to highly permeable chipseals is that it limits basecourse design to the saturated CBR method. A Transfund sponsored project called "Appropriate Subgrade Moisture Conditions for Pavement Design" is to be carried out by Bartley Consultants. The project objective is to determine if the current practice in New Zealand of using soaked subgrade parameters for design is overly conservative, and if so, recommend a more appropriate method of characterising the subgrade for design. Through minimising the access of water to the basecourse layers, more cost effective road design may be possible.

The main effect on chipseal performance arising from high permeability is the flushing of bitumen on the road surface, as stated previously in this paper. The detailed processes leading to flushing in New Zealand are at present unknown, but water vapour pressure is one of the causes. The present situation in New Zealand is that not all the contributing factors are known, e.g. why does one seal flush faster than another? Some areas seem more prone to flushing than others, and not always for entirely obvious reasons.

Recent research in South Africa (De Beer, Kannemeyer and Fisher) has found that as much as 3 times the tyre pressure can be exerted on the road. This is up to 1.25 MPa for a large truck, which can lead to surface deterioration of the road, particularly in wet weather. There may be healing of the asphalt between occurrences, but this is unknown at this stage. Fabric layers may improve the ability of the road to remain impermeable under high pressures.

Optimum performance may not be achieved from a seal by just constructing a fabric or an AC paving layer (as a waterproofing first coat) and then subsequent chipseals on top of that. There is no reason to think that water will not permeate into the newer chipseals on top of the waterproof layer, and pool there. Water vapour pressure build-up in the seal layers above the waterproof layer could cause damage to both the lower waterproof layer (perhaps making it permeable) and the surface above, probably by flushing.

It would be ill-advised to apply AC paving layers as a fix to flushing chipsealed surfaces. Generally the flushing will break through the AC top surface after a short time.

This paper does not promote an immediate switch to using fabrics, or more widespread use of hotmix paving (AC) where it is not otherwise justified, as fixes for flushing or permeable seals. For a start, both these treatments have a relatively high cost compared with chipseal. Further, more research is needed. Our knowledge of what surfacings are actually impermeable to water is incomplete (for example, the effect of surface thickness needs quantifying; the 6mm thick AC layer in site no. 1 was clearly permeable, whereas 20 - 30 mm layers stopped water), and many people regard fabric as an unproven technology.

CONCLUSION

In conclusion, most New Zealand chipseals will eventually be permeable to water under pressure, at least on the top seal layer. The actual amount of water absorbed will depend on the rainfall and on the amount of traffic, particularly of heavy traffic.

Seals with a layer of hotmix paving and possibly the bitumen saturated polyester paving fabric did however provide effective barriers to the water.

The issue of how to adequately waterproof chipseals needs to be addressed. Through minimising the access of water to the basecourse layers, more cost effective road design may be possible. There also needs to be exploration of a fix for some types of flushing, which could be to move away from the use of chipseal in areas prone to flushing and move to using more fabric and AC paving. There are many reasons why such a transition may be difficult. If a fabric seal or AC turns out to be the cure for some types of flushing, the implementation of such layers may involve having to dig out all pavement layers and start again with one of these materials.

A general switch to using fabrics or more widespread use of hotmix paving (AC) may be premature. Fabric is considered by many to be an unproven technology, although it is considered important to encourage roading authorities to increase our common experience by trialing fabric as a treatment for flushing.

Chipseals are a lot more permeable to water than was ever thought, and more testing and research is needed to address the issues arising from this revelation.

REFERENCES

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AUTHOR BIOGRAPHIES

George Ball

George Ball received his PhD in physics from Canterbury University in 1977. After a year with the Christchurch Industrial Development Division of the Department of Scientific and Industrial Research he joined the Road Transportation Research Group at Opus International Consultants Central Laboratories in 1979. His research interests include the effects of additives on road bitumens, bitumen quality assurance, and the factors determining the lifetimes of asphaltic concretes and chipseals.

Joanna Towler

Joanna Towler was appointed to the position of Roading Engineer at Transit New Zealand Head Office in the Highway Strategy and Standards team in April 2000. Joanna is responsible for specifications relating to road surfacings and delineation for New Zealand State Highways.

Since arriving at Transit Joanna has been involved in a wide variety of surfacing projects including P/17 performance based chipseal specifications and research on high skid resistant sealing chip. Prior to joining Transit New Zealand Joanna had 5 years at Wellington City Council in various roles in the Roading Department. Her roles have been heavily involved with road asset management, including RAMM, and implementation of the "Confirm" Asset Management System. Her most recent role at Wellington City Council was Contracts Co-ordinator, which included involvement with the tendering, letting and managing of Wellington City Council road resurfacing contracts.

Joanna is originally from Hokitika, New Zealand. She studied civil engineering at Canterbury University, Christchurch before graduating with a B.E. Environmental in 1995.

FIGURES

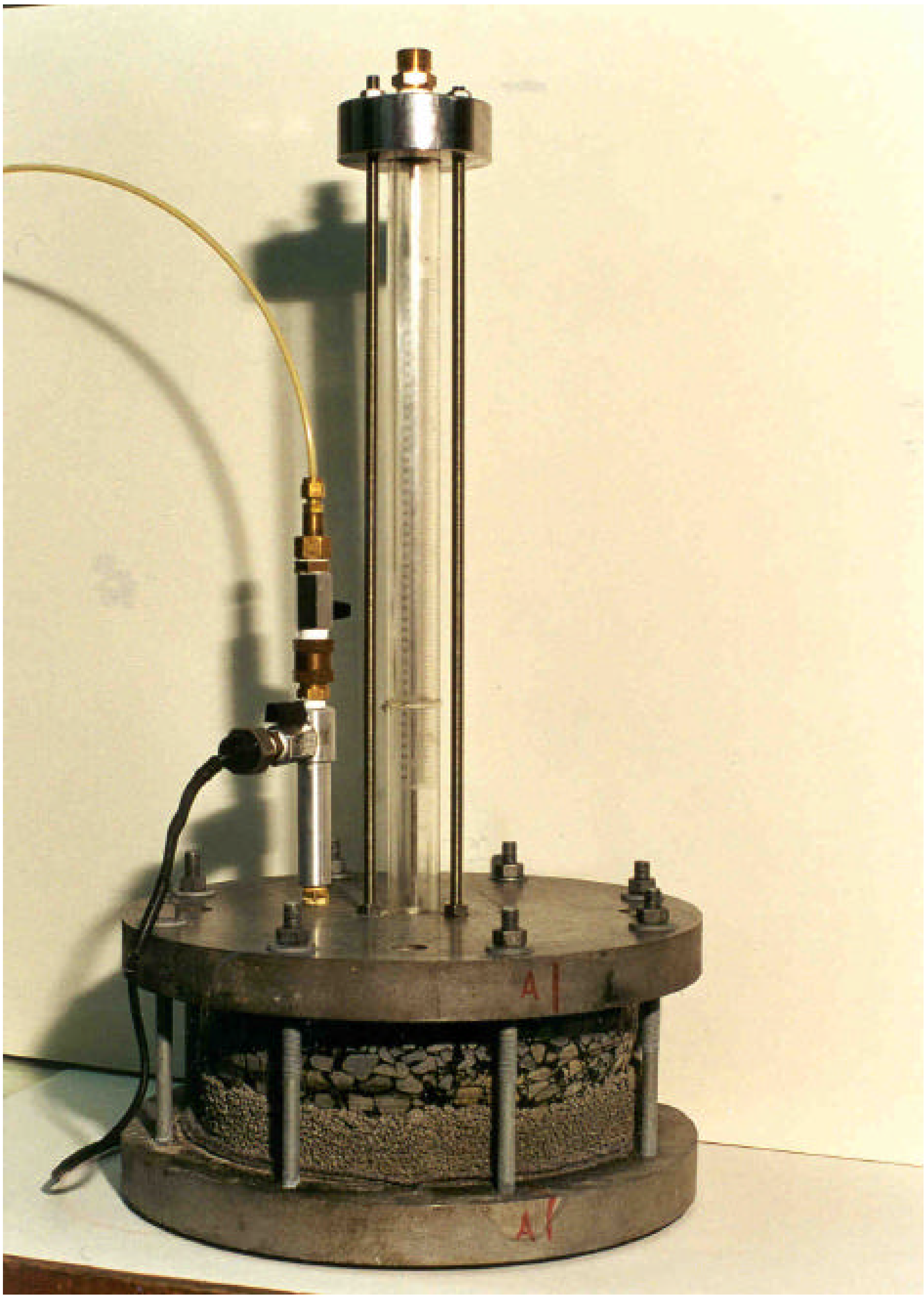

Figure 1. Water Permeability Seal Testing Apparatus

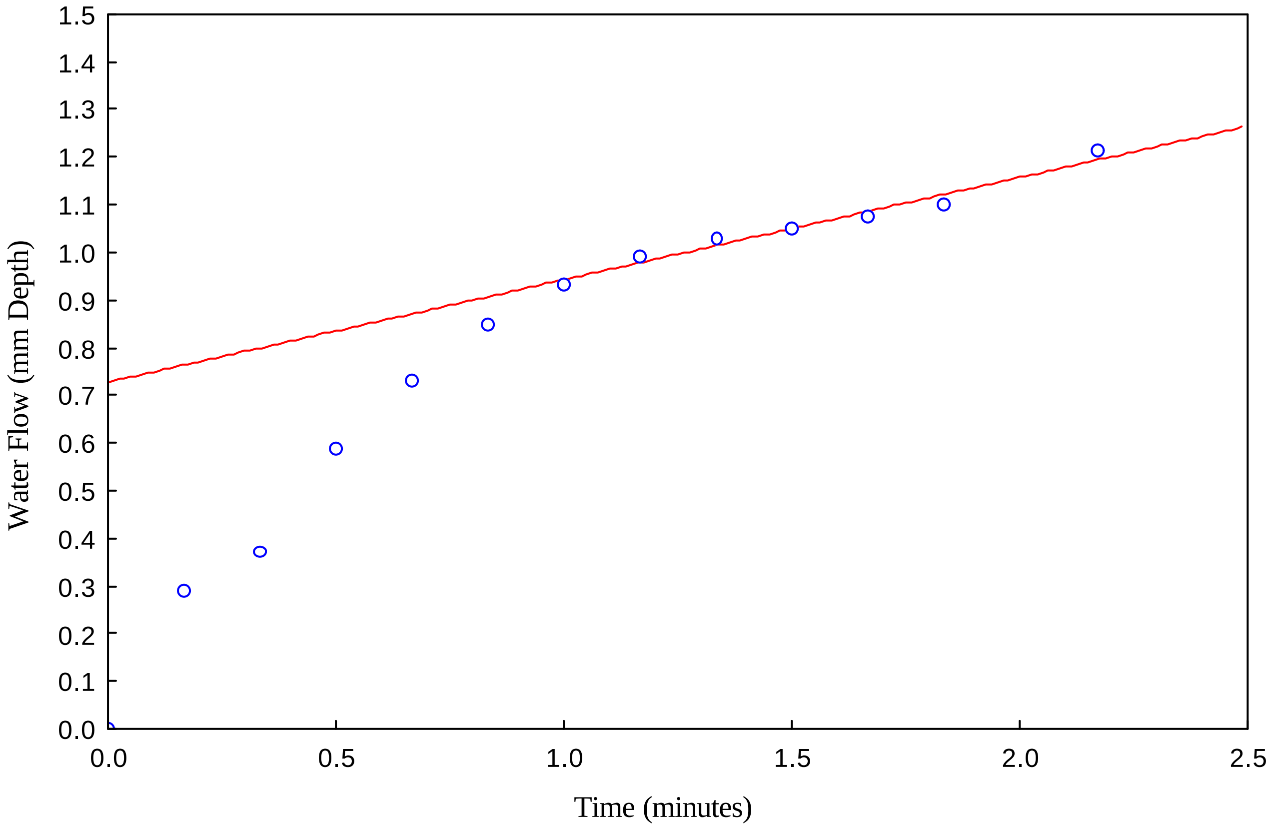

Figure 2: Site B Water Flow at 100 kPa Pressure. Linear Fit: Flow = 0.728 – 0.215 □ Time

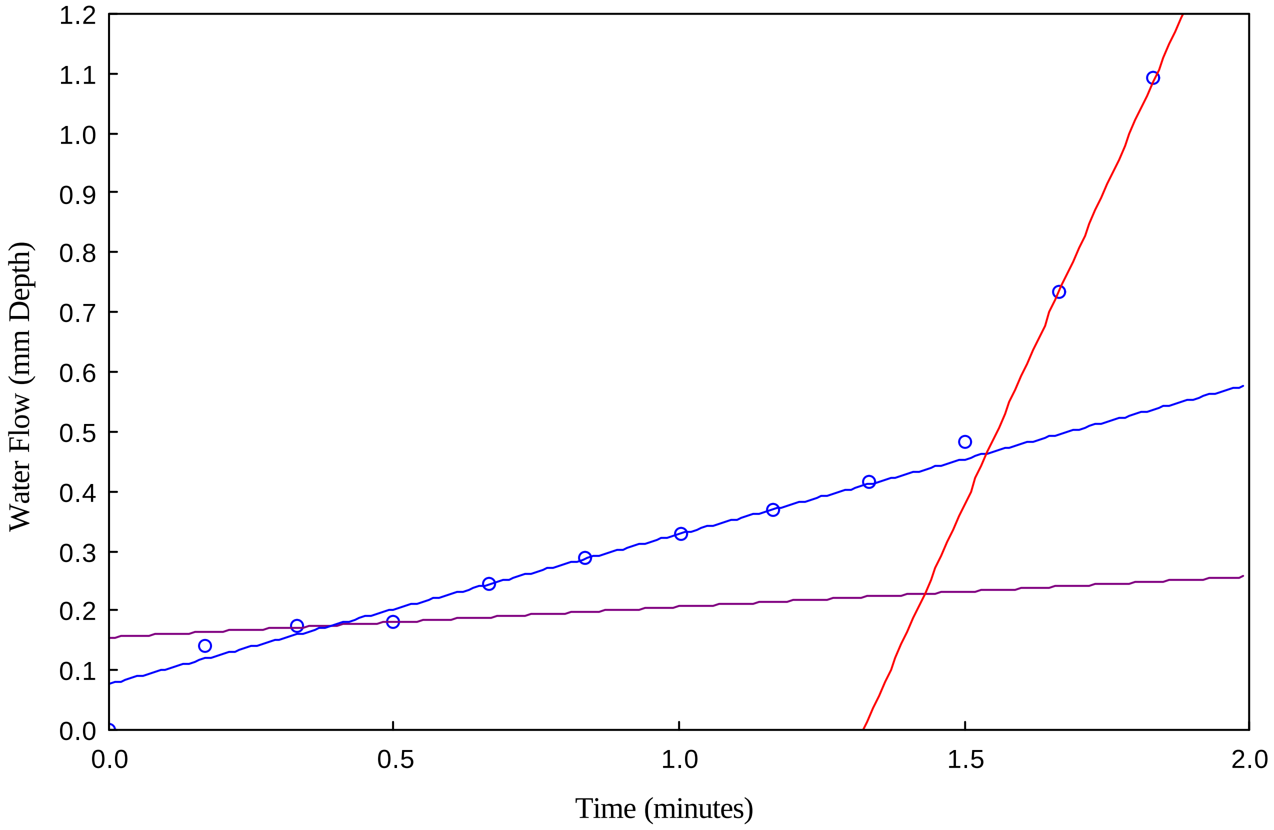

Figure 3: Site D Water Flow at 100 kPa Pressure. Progressive Flow Rates by Linear Fits: 0.051, 0.251, 2.139 mm/minute

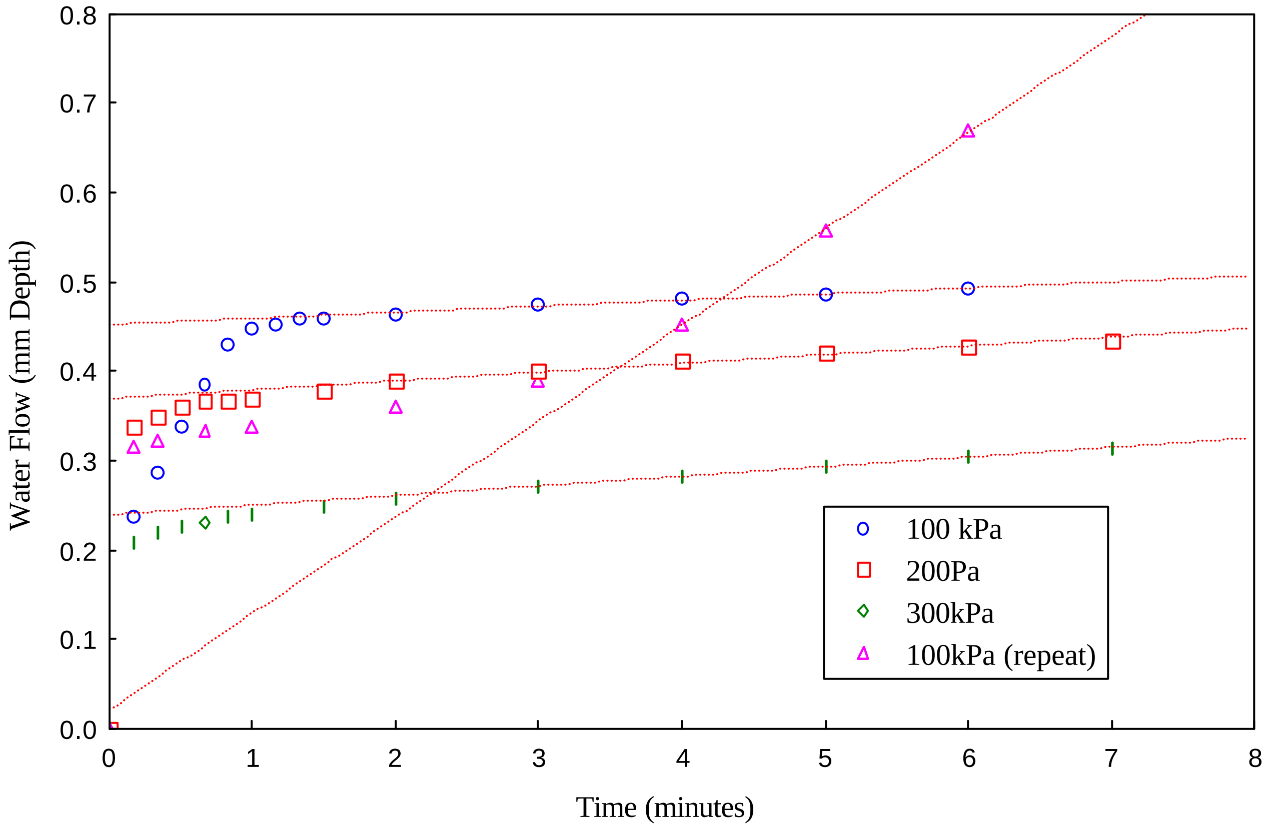

Figure 4: Site H Water Flow at Different Pressure Final Flow Rates (mm/minute): 0.007 (100kPa), 0.010 (200 kPa), 0.011 (300 kPa), 0.108 (100kPa repeated)

Permeability of Chipseals

Frequently Asked Questions

Unit Conversion to m^2/s	Q: How many m^2/s were the flow rates? A: Multiply by 0.001 and divide by 60 to convert from mm/minute to m^2/s
Head of Water	Q: What is the head of water which 100 kPa equates to? round 14.5 psi pressure, or if you like about 10.2 metres (33.4 feet) of water. A ere.
Unconfined samples	Q: In testing the seals without the backing of an undisturbed, compacted basecourse layer, aren't you subjecting them to a pressure differential that is unlikely in a well-constructed seal? erally there is quite a bit of basecourse on the retrieved samples and the porous applied to the back of the basecourse, without removing it from the seal. We t is is a pretty realistic test.
Effect on pavement performance	Q: What effect do high permeabilities have on pavment or suface performance? A: The main effect on chipseal performance arising from high permeability is the flushing of bitumen on the road surface. An issue that needs to be explored in relation to highly permeable chipseals is that it limits basecourse design to the saturated CBR method. A Transfund sponsored project called "Appropriate Subgrade Moisture Conditions for Pavement Design" is to be carried out by Bartley Consultants. The project objective is to determine if the current practice in New Zealand of using soaked subgrade parameters for design is overly conservative, and if so, recommend a more appropriate method of characterising the subgrade for design. Through minimising the access of water to the basecourse layers, more cost effective road design may be possible.
Areas prone to flushing	discussion refers to "areas prone to flushing" but does not elaborate on why t ses are tentative. Clearly in some cases water is responsible, but the present situ aland is that we do not know all the contributing factors to flushing, e.g. why d h under traffic faster than another seal?

Water visible

did the water penetrate? How visible was the water.

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ting. Where they were visible, there would typically be two or three holes on the
exposed surface. In some instances the pinholes could be observed to extend well into
this no other forms of surface distress were visible.

ere no cracks visible on the surface as it dried

as no obvious interface between each chip and the bitumen layer that appeared
f the water

ere just pin-hole sized holes forming in the bitumen film.

Info on sand and cement layer

This sand and cement layer was added to each sample to produce a uniform cylinder of 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.