FLUSHING PROCESSES IN CHIPSEALS:
EFFECTS OF TRAFFICKING

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EFFECTS OF TRAFFICKING

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AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transfund New Zealand.

Transfund New Zealand is a Crown entity established under the Transit New Zealand Act 1989. Its principal objective is to allocate resources to achieve a safe and efficient roading system. Each year, Transfund New Zealand invests a portion of its funds on research that contributes to this objective.

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Deven Singh of the Wellington City Council Streetworks Division arranged for locating flushed sites on city roads, and gave approval for sampling.

Opus International Consultants Ltd staff at Masterton located flushed sites on state highways in the Wairarapa, and arranged permission for sampling.

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- Doug Brown, for adjusting the laser profilometer to take suitable texture depth readings and performing the texture depth measurements,
- Murray Forbes, for carrying out rheological measurements on flushed seal site bitumens,
- Peter Hamilton and Sheryn Reilly, for obtaining seal samples,
- Nick Locke and Neil Jamieson, for organising the construction of the temperature control system and adjusting it to give stable control and uniform temperatures,
- Bob Stevenson, for re-designing and altering the laboratory rolling apparatus to allow its use at controlled temperatures,
- Neil Jamieson, Doug Brown, Bob Stevenson and Chris Varoy for sample preparation and carrying out the rolling procedures.

CONTENTS

EXECUTIVE SUMMARY

Introduction

A study made in 1992-93 of chipseal data from the New Zealand state highway system found that the two major types of surface distress that lead to a decision to reseal a road are alligator cracking of the seal and flushing (i.e. appearance of bitumen at the surface of the seal). This report is of the consequent investigation carried out in 1997-1998 of one of the possible causes of the flushing process, i.e. of embedment of chip in soft surfaces by trafficking.

The objective is to determine ways of minimising the effect of flushing and so extend the life of chipseals.

Method

Flushed and unflushed seal samples were taken near sites where flushing had occurred on state highways in the Wairarapa. The unflushed seals were tracked with a weighted wheel in a temperature-controlled cabinet, and the changes of texture depth occurring during approximately 100,000 wheel passes were measured. Bitumens from flushed seal samples were characterised rheologically. The results were analysed to determine factors controlling the occurrence and degree of flushing resulting from trafficking of chipseal surfaces.

Conclusions

1. The seal compaction apparatus used with chipseal samples produces a realistic reproduction of the seal texture loss process that is associated with trafficking in the field. However, a large number of passes of the tracking wheel (possibly several million) would be needed to confirm with confidence that the texture depth loss versus traffic level relationship followed the relationship found for trafficking in the field, and used in Transit New Zealand Specification P/17:1995 for assessing expected lifetimes before flushing becomes apparent.

2. Seals sprayed over asphaltic concrete (including one over a smoothing mix) were confirmed to be very susceptible to early flushing, possibly from embedment of chip in the asphalt. The emphasis of the current study has been on the more common situation on state highways, which is of reseals and second coat seals sprayed over other seal layers.

3. The compaction test results confirmed that the variation in bitumen viscosity related to field ageing had no significant effect on the rates of texture change.

4. The laboratory compaction results indicated that, below a "critical" bitumen viscosity level of approximately 1400 Pa s, the rate of change of seal texture depth was effectively constant.

5. Given the design of the testing apparatus, there is probably a critical bitumen viscosity level of approximately 1400 Pa s for cars on the open road. However, the critical viscosity level for heavy vehicles may be significantly different.

6. At any given site, the use of 80/100 or 130/150 penetration grade bitumens, rather than a 180/200 bitumen, could be expected to delay the time to flushing of a seal considerably, and contribute to lengthening seal life.

7. Using bitumens that are more temperature-susceptible than those used on New Zealand roads in the past, results in a significant risk of reducing seal life through earlier flushing.

Recommendation
A sealing field trial should be constructed, using a range of seal and bitumen types, to investigate further the factors affecting rates of seal texture loss and the flushing that eventually results.

ABSTRACT

Flushed and unflushed chipseal samples were taken, in 1997-98, near sites where flushing had occurred on state highways in the Wairarapa, New Zealand. The unflushed seals were tracked with a weighted wheel in a temperature-controlled cabinet, and the changes of texture depth occurring during approximately 100,000 wheel passes were measured. Bitumens from flushed seal samples were characterised rheologically. The results were analysed to determine factors controlling the occurrence and degree of flushing resulting from trafficking of chipseal surfaces.

1. INTRODUCTION

A study of chipseal[1] data from the New Zealand state highway system (Ball & Owen 1998) found that the two major types of surface distress that lead to a decision to reseal a road are alligator cracking of the seal and flushing (i.e. appearance of bitumen at the surface of the seal). This report describes the first part of a consequent investigation carried out in 1997-98 on aspects of the flushing process (Transfund New Zealand Research Project PR3-0204).

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

1. Trafficking causing embedment of chip. This is usually the cause of the flushing that first appears in wheeltracks. The investigation of the relative effects of traffic levels, seal type, rheological properties of the seal binder, and the pavement construction beneath the top seal is described in this report.

2. Moisture rising through the pavement beneath the chipseal. This cause results in miniature "volcanoes" appearing where bubbles of binder are formed by vapour pressure of water beneath the seal surface. These 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. It may be unique to New Zealand, or at least to moist climates, because when it was shown to some Australian experts they stated that it did not occur in Australia.

   The investigation of this second process is planned as Part 2 of the Transfund New Zealand Research Project PR3-0204.

1 Chipseal is hereafter called 'seal'

2. STUDY OVERVIEW

The objective of the study is to assess the relative importance of these flushing processes and to assess how materials and construction procedures affect them under the different environmental conditions characteristic of New Zealand roads. The ultimate aim is to determine ways of minimising the effect of flushing and so extend the life of chipseals.

The tasks to be determined in the research and described in this report are as follows:

1. Seal Compaction Apparatus Development
   A laboratory rolling tyre apparatus developed at Opus Central Laboratories, Lower Hutt, was modified to allow compaction on seal samples over a range of temperatures (–15°C to 60°C). Methodology was developed to enable closely repeatable measurements of the sample texture depths.

2. Site Selection and Sampling
   Chipseal sites on which flushing had occurred were located, having a range of traffic levels and areas. Core samples from flushed and unflushed areas at each site were obtained, as well as data on traffic levels and sealing history.

3. Laboratory Analysis
   Field samples were inspected, and samples with the binder removed were characterised rheologically at several temperatures.

4. Compaction Testing
   The rate of change of seal texture under rolling in the laboratory rolling tyre apparatus was measured for unflushed samples (recovered immediately adjacent to flushed wheelpaths) at a range of temperatures (40°C, 50°C and 60°C), and during 100,000 passes of the rolling tyre.

5. Data Analysis
   Data collected during the project were analysed to determine any relationships between the rate at which flushing develops, and the composition of seals and the seal environment.

3. SEAL COMPACTION APPARATUS DEVELOPMENT

3.1 Original Design

The original seal compaction apparatus was built for Transit New Zealand Research Project PR3-0104 "Changes to New Zealand Bitumen Production". It was designed to produce realistic compaction, similar to that of traffic, of artificial chipseals on metal plates. These seals were used for laboratory investigations of the effects of different types of binder on chipseal resistance to chip loss from trafficking.

The basic apparatus consists of a pneumatic tyred wheel, weighted to simulate the effect of a car tyre, driven backward and forward over the test seal plates by a pneumatic cylinder. The pneumatic cylinder is preferred to a crank attached to an electric motor because it is significantly compact given the large stroke (1 m) involved, and because it gives a more uniform motion. The test seal plates themselves are driven slowly back and forth at right angles to the wheel motion. Thus the full plate is rolled, and a slight twisting action on the sealing chip assists compaction. Rates of traverse are approximately 0.4 m/s (1.44 km/h) for the wheel and 0.5 mm/s for the transverse motion.

3.2 Compaction Apparatus Modifications

3.2.1 Sample Mounting

The decision was made to take samples for the flushing investigation using a 250 mm-diameter corer made specifically for this work. This diameter was the largest that could be used on the coring machine. The samples were large enough for tracking, given the size of the tyre and the need to have adequate area to make texture depth estimations. Also they were of a standard size so that a frame could be constructed for mounting the samples for tracking.

The frames to hold the samples were constructed of 12 mm-thick steel plate with three cylindrical pipes welded, in line, to the plate surface. Thus three samples could be tracked simultaneously. The pipes were 80 mm high, this dimension being dictated by the dimensions of the existing rolling apparatus.

Field samples taken for the flushing investigation were secured in the pipes with a plaster of Paris mix, with the top of each seal surface clear of the end of its pipe to ensure that it remained in contact with the tyre throughout the rolling process. The remainder of the space in the pipes was filled with a mixture of aggregate and plaster of Paris.

Samples that were thicker than 30 mm were cut to that thickness with a saw before insertion in the pipes. It was assumed for this project that most of the flushing process takes part in the upper surface of the road, since surface temperature falls away rapidly with increasing depth (Ball 1987), leading to greater binder viscosities in the sub-seals and hence greater resistance to extrusion of binder. Retaining greater seal sample thicknesses for the laboratory tracking could lead to misleading results since, during the laboratory tracking, the samples are at approximately the same temperature throughout.

Wooden inserts were placed between the pipes before rolling to ensure that the tracking tyre remained at the same height throughout the rolling procedure.

Initially the sample frame did not traverse back and forth during the rolling system owing to difficulties in conceiving a way to accomplish this without expensive alterations to the rolling equipment. As well the initial indications were that flushing would occur rapidly without transverse motion of the samples (see Section 4 of this report). However, when flushing could not be obtained with seals retrieved from state highways, the equipment was re-examined and modifications were devised to re-introduce the transverse motion.

3.2.2 Temperature Control System

A refrigeration and heating system to control sample temperature to a specified ±1 °C within the range −15 °C to 60 °C was designed and built by Refcold Refrigeration (NZ) Ltd of Lower Hutt. The temperature range is larger than required for the present project because the system is designed for, and financed from, other research projects as well. Air heated or cooled to the target temperature is blown into a cabinet placed over the modified compaction apparatus. Polystyrene packing is used to minimise heat transfer to the surrounds and to the mounting of the compaction apparatus.

3.2.3 Tyre Characteristics

The amount of air in the tyre was adjusted for different test temperatures, so that the pressure was constant at 207 kPa (30 psi) for all test runs.

The tyre footprint at 207 kPa is approximately 100 mm long and a maximum of 71 mm wide. The 71 mm-wide section is approximately 43 mm long; the footprint tapers gradually at each end and is approximately 20 mm wide at about 20 mm from each end. Given the approximate tyre speed of 0.4 m/s, the centre line and edge line sections of the tyre are in contact with the seal surface for approximately 0.25 and 0.11 seconds per wheel pass (equivalent to frequencies of 4 and 9.3 Hz respectively).

Because of the transverse oscillation of the test seal, the actual number of tyre passes experienced by any point on the seal is less than the total number of passes over the seal. The rolling apparatus is adjusted so that the tyre moves gradually sideways during rolling until its outer edge is at the edge of the sample, and then reverses back into a new oscillation. From tyre and sample dimensions it follows that if a number, say N, passes of the wheel have taken place over the sample, the number of passes that have been experienced by a section of the seal near the sample centre is:

$$\frac{N}{\left(\frac{250}{71} - 1\right)} \approx 0.3966\ N \qquad (1)$$

Areas of the seal within 71 mm of either of the seal edges in a transverse direction receive fewer passes than this.

Seal texture depth is plotted against the total number of passes (i.e. N).

3.3 Texture Depth Measurement

In order to follow the texture depth changes of the samples during rolling, the texture depth measurements need to be repeatable to within ±0.1 mm. A laser profilometer modelled on that developed by the Swedish Road and Traffic Research Institute (VTI), and built at Opus Central Laboratories, for study of New Zealand road surface textures (Cenek et al. 1997) was used for this application, with the software being adapted for the relatively short scan length. A jig was built to hold the sample frame in position beneath the profilometer so that the same section of seal would always be tracked and changes in field texture would be followed accurately.

A "mean profile depth" (MPD) is usually estimated from a profilometer surface profile following ISO Standard 13473-1 (ISO 1996). The standard provides a conversion to an "estimated texture depth" (ETD) using the equation:

$$ETD = 0.8\ MPD + 0.2 \qquad (2)$$

The ETD is an estimate of the texture depth that would be obtained using the standard sand circle method, although the latter method gives less reproducible results.

Measurements of sample texture depth using equation (2) turned out to have poor repeatability. This was tracked to the prescribed method of calculating the MPD, which establishes the average of the highest points in each half of the texture profile as the baseline to estimate profile texture depths. For the relatively short profiles that are being examined in this work, a single uncharacteristic high chip can effect the estimation of texture depth significantly.

The root mean square (RMS) of the deviation from the average profile depth proved to be a far more repeatable value. A series of measurements carried out in a survey of seals around Napier, New Zealand, had provided the following relationship between RMS and MPD values:

$$RMS = 0.701\ MPD - 0.276 \qquad (3)$$

Combining equations (2) and (3) we obtain:

$$ETD = 1.1412\ RMS + 0.5150 \qquad (4)$$

Equation (4) was used throughout this project to estimate texture depth. For the laboratory test measurements, the test frame containing three core samples was removed from the temperature control cabinet and placed in the jig beneath the profilometer. Texture depths are measured along the line of centres of the three samples and along parallel tracks 10, 20 and 30 mm either side of the centre line. The average of the seven results (which may typically vary over a range of ±0.2 mm for a given sample) is taken as the texture depth.

4. SITE SELECTION AND SAMPLING

The Wellington City Council Streetworks Division provided a list of several sealed sites at which flushing occurred. After inspection of the sites, five were selected for sampling. In accordance with the requirements of the brief, three flushed samples and at least three adjacent unflushed ones and three unflushed ones further down the road were sampled. Site data are listed in Appendix 1.

Laboratory rolling of three unflushed roadside samples at 60°C, without transverse motion of the rolling wheel, resulted in rapid flushing. At this point all the core samples were inspected, and all seals were found to have been constructed over finely graded asphalt. It was apparent that the presence of this asphalt was the likely cause of the flushing, probably through chip embedment under rolling, and that any further results would not apply to typical state highway seals.

Opus International Consultants Ltd in Masterton then provided a listing of flushed sites on state highways in the Wairarapa. After inspection of all sites, a total of six were found suitable for sampling. Site data, listed in Appendix 2, are labelled A, C, D, E, G and H, hereafter referred to by these labels. The sites consist of five Grade 3 and one Grade 2 single coat seals, but the details of the road structure beneath the surface are considerably different (Table A3 in Appendix 2).

5. LABORATORY ANALYSIS

The laboratory analysis work described here was carried out for all seal samples that were retrieved from sites in the Wairarapa.

Consideration was given to measuring air void content, but this course was rejected because:

- the structure of the seals is quite heterogeneous (see Table A3 in Appendix 2), and is different from seal to seal, and
- the changes in temperature with depth below the seal would affect the contribution of each layer of seal or smoothing mix to flushing (assuming that the viscosity of the seal binder is a significant factor in determining flushing performance).

Because of these factors, an average air void content would not be expected to correlate well with the compaction behaviour near the surface.

Liability to flush would be expected to be associated with binder flow properties. Accordingly, binder was removed from flushed surfaces at each site and, after larger aggregate was removed with a 250 micron mesh sieve (fine material was retained to obtain a binder having similar flow properties to that on the road), the rheological properties were measured from 1 to 10 Hz at 40°C, 50°C and 60°C, using a Carri-Med CSL^2 500 rheometer with an parallel plate fitting in the linear displacement range. Properties measured were the dynamic shear modulus, $|G^*|$ (in Pascals), and the phase angle δ. Since it is proposed that flushing is associated with binder flow, a dynamic viscosity, η, was also calculated:

$$\eta = \frac{|G*| \sin (\delta)}{2 \pi f} \tag{5}$$

with f being the frequency of oscillation in Hertz.

Table 1 shows the set of viscosity values at 10 Hertz, corresponding approximately to the impulse received by the laboratory compaction wheel.

Table 1. Viscosities (Pa s at 10 Hz) of flushed bitumen in seal samples from Wairarapa sites, in order of increasing age.

Sample site	D	H	G	E	A	C
40°C	4847	5001	4879	4322	5185	10032
50°C	1302	1418	1293	1251	1698	2844
60°C	383	420	384	381	495	762
Seal age (years)	3.46	3.46	4.39	5.06	5.20	10.27

The tendency for binder viscosity to increase with seal age is present but not consistent. This may be partly because mixing with differently hardened binder in layers below the top seal occurs with flushing. In addition, different types of underlying material will affect the access of oxygen to the surface layer differently, and hence affect the reactions which harden the bitumen.

6. COMPACTION TESTING RESULTS

Detailed results are given in Appendix 3. Because the initial texture depths of the specimens were different, the results were normalised by expressing changes as a percentage of the original depth.

Figure 1 illustrates the linear relationship between the percentage change in texture depth and the number of wheel passes for sites A, C, D, E, H and G tested at 60°C.

Figure 1. Percentage change in texture depth v number of wheel passes for sites A, C, D, E, H and G, tested at 60°C.

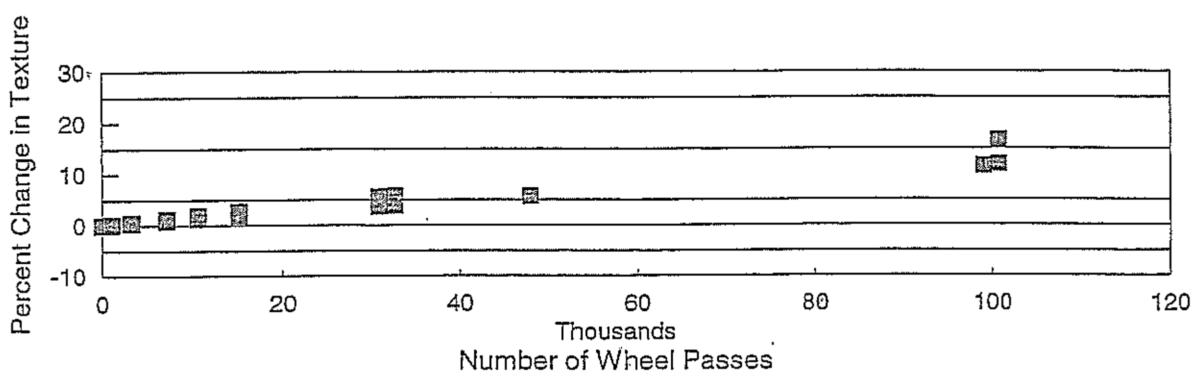
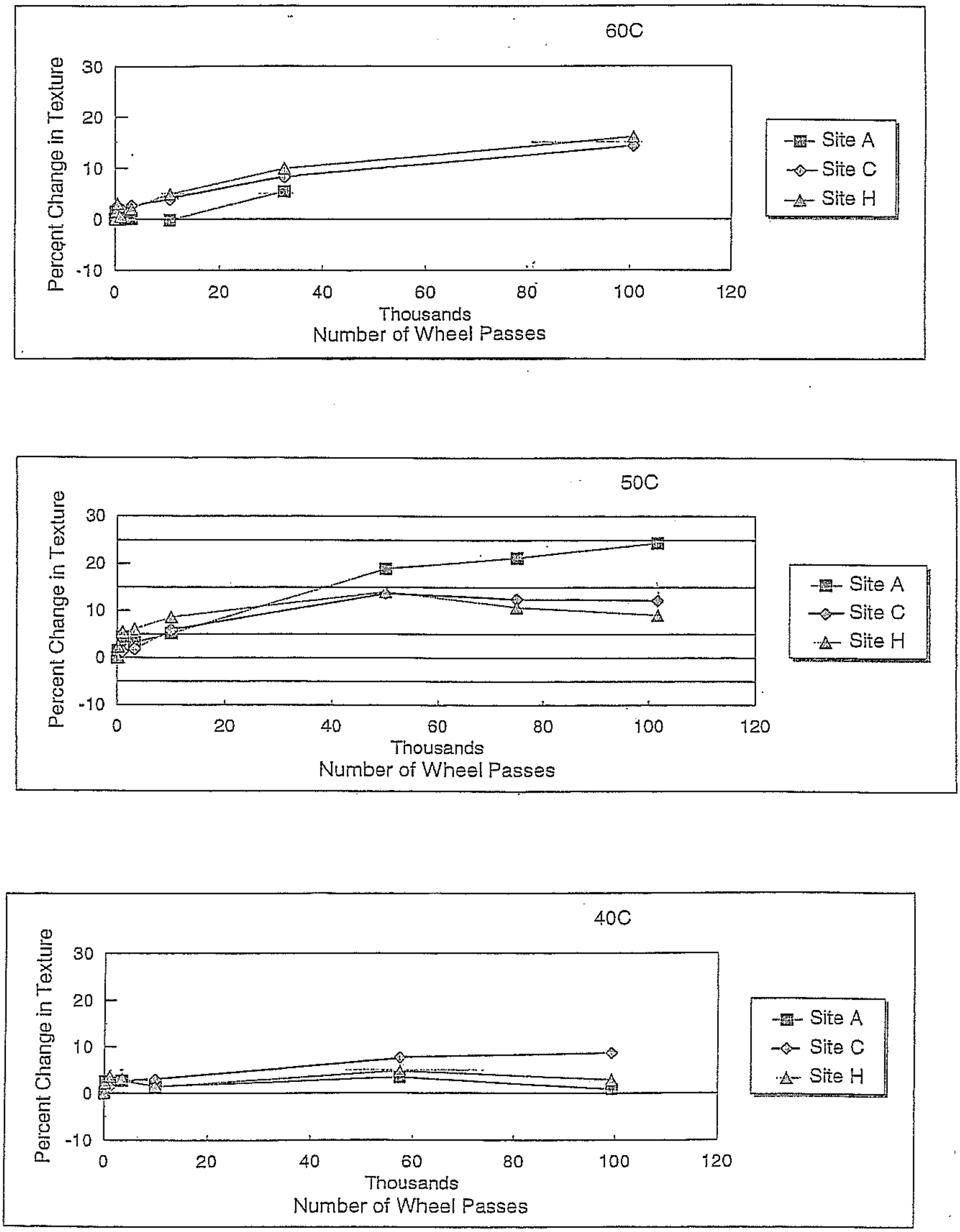


Figure 2 compares the results for sites A, C and H tested at 60°C, 50°C, and 40°C. The complete sets of results available for each of the three test temperatures were regressed against number of wheel passes. The results of this analysis are in Table 2.

Table 2. Linear regression of percentage change in texture depth on number of wheel passes.

Temperature (°C)	40	50	60
Constant	1.84	3.12	0.11
Slope	3.2×10^{-5}	1.5×10^{-4}	1.3×10^{-4}
r^2	0.29	0.66	0.96

Figure 2. Percentage change in texture depth at sites A, C and H, at 60°C, 50°C, and 40°C.

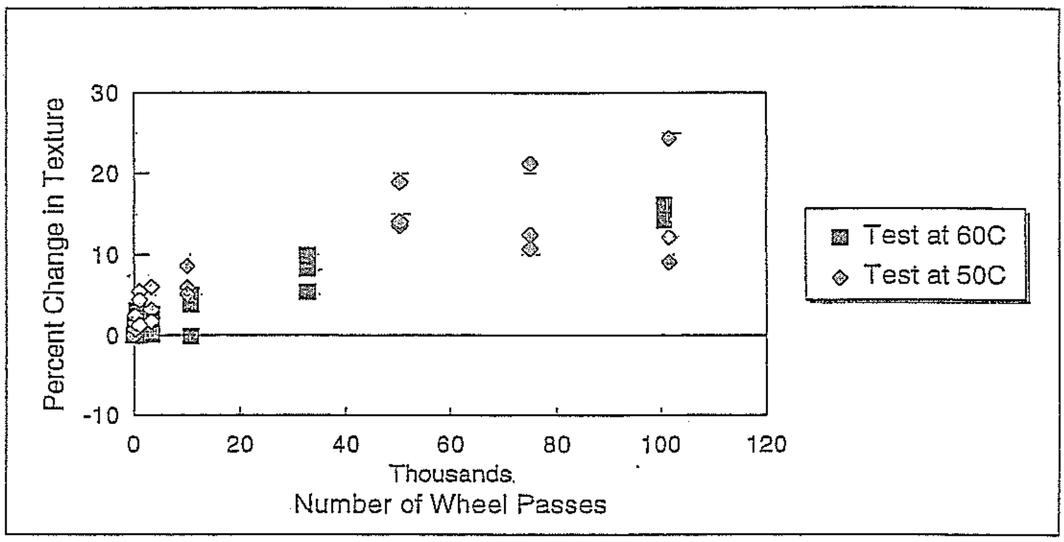


The analysis indicates that the slopes of the relationships for 50°C and 60°C are similar, while at 40°C the rate of change is approximately one-fifth of that at the higher temperatures.

The correlation coefficient (r^2) improves as the temperature increases. This is attributable to the smaller texture depth changes occurring at lower temperatures. The texture change over the testing period at 60°C was of the order of 0.50 mm, while the corresponding change at 40°C was 0.13 mm. The scatter in results is therefore associated with the accuracy to which these small changes can be measured.

In Figure 3, the 50°C and 60°C data for sites A, C and H have been combined. The rates of change of texture depth are seen to be similar for the two temperatures, confirming the regression results.

Figure 3. Comparison of rates of change of texture depth at 50°C and 60°C.

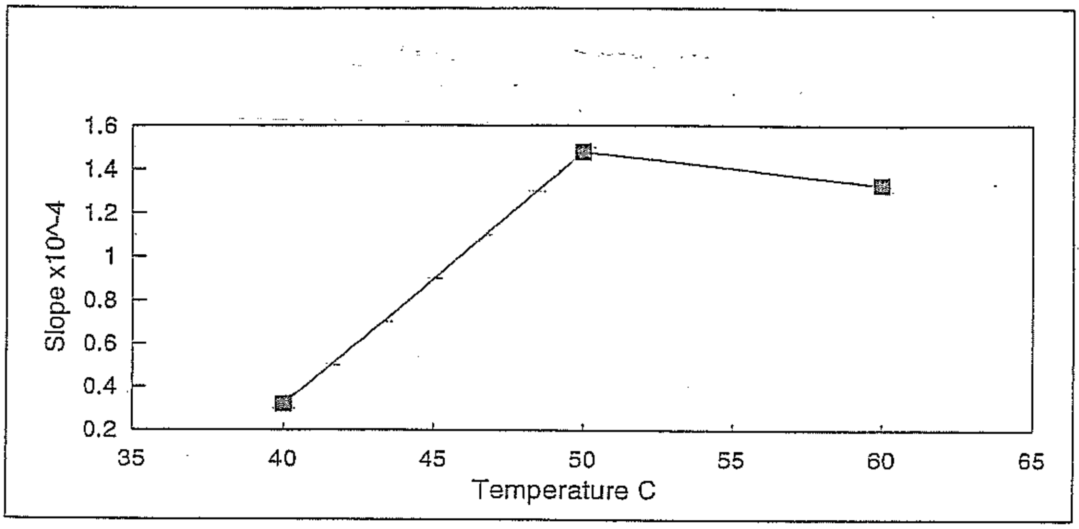


7. ANALYSIS OF RESULTS

A comparison of the rate of change of texture depth with the rheological data shows no obvious relationship between the site bitumen viscosity and the laboratory rolling results at any specific temperature. Site C had the highest viscosity and site H the lowest, yet, as can be seen in Figure 2, the rates of texture depth change were very similar.

On the other hand, there is a significant difference in the rates of texture depth change with temperature (Figure 4).

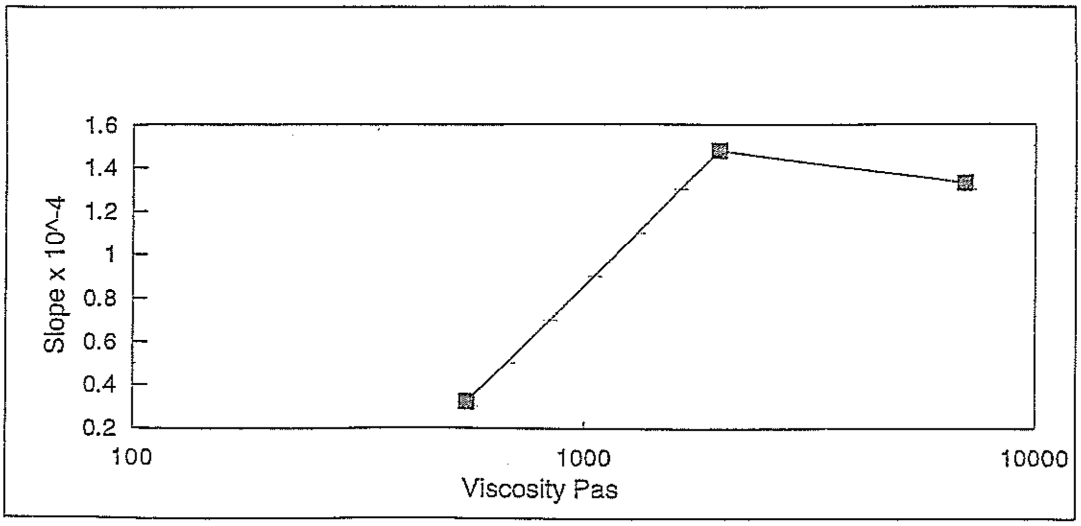
Figure 4. Rate of change in texture depth as a function of temperature.



Using the average of the bitumen viscosities for sites A, C and H, the rate of texture depth change as a function of the logarithm of the viscosity can be found (Figure 5).

The results indicate that, below a "critical viscosity" level (i.e. above a particular temperature for a particular binder), the rate of change of texture depth is effectively constant. As the viscosity increases above the critical level the rate of texture depth change decreases rapidly.

Figure 5. Rate of change in texture depth v the logarithm of the bitumen viscosity.



8. DISCUSSION

1. The test results indicate a linear relationship between the number of wheel passes and changes in texture depth. This is in contrast to the logarithmic relationship found in the field (Patrick & Donbavand 1996):

$$\text{Texture depth} = k - (B \times ALD \times \log_{10} T) \qquad (6)$$

where:

k	=	a constant related to the sealing chip average least dimension (ALD) and the volume (L) of bitumen sprayed;
T	=	total traffic at time of texture depth measurement, in equivalent light vehicles (elv) (one heavy vehicle is equivalent to 10 light vehicles);
ALD	=	average least dimension (mm) of the sealing chip;
B	=	a constant equal to 0.074.

The reasons for this difference are not known. Possibly this difference reflects the relatively small amount of laboratory trafficking compared to what the seals had already experienced on the road.

The specimens tested in this investigation had been in service a number of years, and the approximately 100,000 passes in the test would be equivalent to less than one month's field exposure in the wheeltracks (see traffic level values in Table A2, Appendix 2). Specimens had been taken outside the wheeltracks, and the number of vehicle passes that they have actually experienced is unknown.

2. The test results show that there is a critical viscosity of the binder, below which the rate of change of texture is essentially constant. In the laboratory tests carried out this critical viscosity was approximately 1400 Pa s.

The testing apparatus applies a force of the same order of magnitude as a car tyre. Therefore 1400 Pa s would be expected to be of the right order for cars but a different critical viscosity would be expected for heavy vehicles.

3. The difference of the slope of the linear plot of percentage change in texture depth against number of test wheel passes at 40°C, from those at 50°C and 60°C, indicates that at the higher temperatures the rate of texture change is approximately five times that at 40°C.

4. In order to apply the results of these tests to the field, an estimation was made of the effect of the change in slope for site A.

5. The basic equation relating change in texture to the number of traffic passes (Patrick & Donbavand 1996), is:

$$\frac{V_V}{ALD} = 0.838 - 0.074 \log_{10} T \qquad (7)$$

where:

V_V	=	volume of voids = $T_d + V_b$;
T	=	total traffic at time of texture depth measurement in equivalent light vehicles (elv, as defined for equation (6));
T_d	=	texture depth (mm);
V_b	=	volume of bitumen sprayed (L/m^2);
ALD	=	average least dimension of the sealing chip (mm).

On site A the bitumen application rate used was 1.70 L/m^2 (subtracting 0.1 L/m^2 from the RAMM value to allow for texture depth of the underlying surface).

The average daily traffic was 2400 vehicles/day which translates to 2172 elv/lane/day, assuming 9% of vehicles are classified as heavy.

For argument's sake, a typical Grade 3 ALD value of 8.75 mm is used.

At the time of sampling the seal was flushed in the trafficked area (assumed texture depth, typical of flushing, is 0.9 mm) and 1898 days old.

The sample taken from outside the wheeltrack had a V_V/ALD ratio of 0.461. Substituting this value into equation (7) and solving the equation for T, results in a total traffic level value of 124,300 elv. This is an estimate of the traffic at time of texture depth measurement over the unflushed area of seal.

For the higher temperature trials, the texture depth changed by ~15% over 100,000 passes of the compaction apparatus. Based on an original texture depth of 2.4 mm, the slope of the relationship of equation (7) that would occur was calculated for this change in the number of traffic passes, from 124,300 to 224,300. The calculated slope factor was 0.16 (as against 0.074 in equation (7)).

6. The analysis of step 5 was repeated for the 40°C data, where the texture changed 5% over 100,000 passes. The slope factor reduced to 0.055.

7. These calculations indicate that, for site A, a change in the field temperature from 40°C to over 50°C would result in a tripling of the slope of texture versus log(traffic) plot.

8. This analysis results in slope factors that are either side of the value derived from a large number of sites by Patrick & Donbavand (1996), thus confirming the validity of the analysis.

9. Equation (7) can also be used to demonstrate the sensitivity to small changes in the slope factor of the time that a seal takes to flush.

10. Using the site A data given above, the slope factor was calculated based on the age and traffic volumes. A value of 0.082 was obtained, which compares well with the 0.074 of equation (7). The time to flushing (defined as the point where surface texture depth is reduced to 0.9 mm) is very sensitive to the value of the constant. If, through using a harder grade of binder, the slope was reduced from 0.082 to 0.080, the life of the seal before flushing would be increased by approximately two years.

    In the 40°C to 60°C range, over which the most texture change occurs, the effect of changing from 180/200 to 80/100 penetration grade bitumen would be equivalent to a drop of pavement temperature of approximately 8°C. This would be expected to increase considerably the seal life, in terms of time to flushing.

11. These results also demonstrate that an increase in the temperature susceptibility of bitumen used on New Zealand roads, allowing the use of a bitumen with a lower viscosity at higher seal temperatures, could significantly reduce seal life.

9. CONCLUSIONS

1. The seal compaction apparatus used with chipseal samples produces a realistic reproduction of the seal texture loss process that is associated with trafficking in the field. However, a large number of passes of the tracking wheel (possibly several million) would be needed to confirm with confidence that the texture loss versus traffic level relationship followed that found for trafficking in the field by Patrick & Donbavand (1996) and used in TNZ P/17:1995.

2. Seals sprayed over asphaltic concrete (including one over a smoothing mix) were confirmed to be very susceptible to early flushing, presumably from the embedment of the chip in the asphalt mix. The emphasis of the current study has been on the more common situation on state highways, which is of reseals and second coat seals sprayed over other seal layers.

3. The viscosity of the hardened binder in the oldest chipseal tested was approximately twice that of seals of around one-third that age. On the other hand, the viscosities changed over the temperature range studied (40°C to 60°C) by a factor of approximately 13 (see Table 1). In New Zealand chipseals are expected to reach field temperatures around 55°C (Ball 1987).

Temperature change is therefore expected dominate any effect due to binder ageing in determining flushing behaviour in the long term for a given penetration grade of bitumen.

The compaction test results confirmed that the variation in bitumen viscosity related to field ageing had no significant effect on the rates of texture change.

4. Traffic compaction behaviour of the tested seal samples did not change much between 50°C and 60°C, but the rate of texture depth change at 50°C was approximately five times greater than that at 40°C. Below a "critical" bitumen viscosity level of approximately 1400 Pa s, the rate of change of texture depth was effectively constant.

5. Given the design of the testing apparatus, there is probably a critical bitumen viscosity level of approximately 1400 Pa s for cars on the open road. However, the critical viscosity level for heavy vehicles may be significantly different.

6. The use of 80/100 or 130/150 penetration grade bitumens, rather than 180/200, could be expected to delay the time to flushing of a seal considerably, and contribute to lengthening seal life.

7. Using bitumens that are more temperature-susceptible than those used on New Zealand roads in the past, results in a significant risk of reducing seal life through early flushing.

10. RECOMMENDATION

The laboratory study of seal flushing has highlighted the importance of binder properties on the loss of seal texture. At present the Transit New Zealand performance-based specification for bituminous reseals (TNZ P/17) assumes a single relationship (equation 6), based on sealing chip size and binder spray rate, for rate of texture depth loss. As noted in the discussion (Section 8 of this report), the susceptibility to texture loss and the resulting projected seal lifetime is very sensitive to the slope constant (B) in that equation. The slope constant B, in turn, may be significantly affected by the seal bitumen penetration grade and by the viscosity-temperature relationship of the bitumen. If the scope of TNZ P/17:1955 is to be extended, the effects of these bitumen properties on B need to be quantified.

However the laboratory rolling test apparatus used to investigate these effects requires a very large amount of testing time to give results that can be compared with the predictions obtained from the standard TNZ P/17:1995 equation. Consequently, the recommendation is that a field sealing trial be established to obtain the required information.

The trial as proposed would consist of a set of reseals or second coat seals of different types (e.g. chip size, single and two coat seals) constructed with bitumens of different penetration grades and temperature sensitivities. The test seals would be constructed on a single section of road over a uniform seal surface, that would not have any shape correcting asphalt beneath the existing seal.

Texture depth of the different seals would be measured initially, and then monitored to a prescribed timetable, using a laser profilometer, at accurately fixed positions. This procedure will ensure precise results that will show texture depth changes accurately.

Recommendation
A field sealing trial should be constructed, using a range of seal and bitumen types, to investigate further the factors affecting rates of seal texture depth loss and the flushing that eventually results.

11. REFERENCES

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APPENDICES

APPENDIX 1 SAMPLES FROM WELLINGTON CITY SITES

Table A1. Chipseal data supplied by Wellington City Council, Streetworks Division.

In all cases the bitumen used is 180/200 penetration grade

Site	Chip grade	Binder spray rate (L/m^2)	Sealing date	Sampling date	Age (days)	Average daily traffic (ADT)
Mitchell Street, Brooklyn	4	1.41	16/12/93	4/4/97	1205	792
Cashmere Ave, Khandallah	4	1.18	18/2/92	4/4/97	1872	5240
Nicholson Road, Khandallah	4	1.51	12/12/89	4/4/97	2670	2620
Duthie Street, Karori	3	1.73	19/2/93	7/4/97	1508	1210
Padrell Cres., Paparangi	3	1.94	17/12/92	7/4/97	1572	182

APPENDIX 2 SAMPLES FROM WAIRARAPA STATE HIGHWAY SITES

Table A2. Chipseal data supplied by Opus International Consultants, Masterton, Wairarapa.

All bitumen is 180/200 penetration grade
All sites are on State Highway 2

Site label	Route position	Chip grade	Binder spray rate (L/m^2)	Sealing date	Sampling date	Age (days)	Average daily traffic (ADT)
A	873/0.35	3	1.80	12/2/92	24/4/97	1898	2400
C	858/9.2	2	1.68	15/1/87	24/4/97	3752	2370
D	858/3.5	3	1.70	19/11/93	6/5/97	1264	2370
E	905/5.3	3	1.65	1/4/92	24/4/97	1849	4470
G	905/10.0	3	1.78	16/12/92	6/5/97	1602	4470
H	905/13.0	3	1.45	19/11/93	7/5/97	1265	4470

Table A3. Seal structure from RAMM database and highway information sheets (two top layers) and observed from core samples.

Highest layers are at the top of column
The layers are listed as far as they are discernible
Smoothing coat thicknesses are indicative, as they vary from sample to sample from the same site

Site Label	**A**	**C**	**D**	**E**	**G**	**H**
Top surface	Grade 3 Reseal	Grade 2 Reseal	Grade 3 2nd Coat	Grade 3 Reseal	Grade 3 Reseal	Grade 3 Reseal
Underlying (Previous Wearing) Surfaces	Grade 5	Grade 6 Void Fill	Grade 4 First Coat	Grade 5	Grade 5 Void Fill	Grade 5
	Smoothing Coat ~ 18 mm	Grade 2		Smoothing Coat ~ 30 mm	Grade 3	?
	Grade 3	Grade 6		Grade 2	?	
	Grade 3			Grade 2		
	Paint Layer			Smoothing Coat ~ 5 mm		
	Grade 5			Grade 2		
	Smoothing Coat ~ 15 mm					
	Grade 5?					

Question marks indicate the probable but uncertain presence of further seal layers, as judged from the appearance of the core samples.

APPENDIX 3 RESULTS OF ROLLING UNFLUSHED WAIRARAPA SEAL SITE SAMPLES

Texture depths, determined as described in Section 3.2 of this report, are in millimetres

Table A4. Results from Site A samples at three temperatures.

60°C		50°C		40°C	
Wheel passes	**Texture depth**	**Wheel passes**	**Texture depth**	**Wheel passes**	**Texture depth**
0	2.439	0	2.570	0	2.274
158	2.404	152	2.532	152	2.218
502	2.401	1000	2.459	1104	2.222
1002	2.441	3222	2.490	3500	2.213
3202	2.438	10002	2.440	10002	2.240
10555	2.443	50298	2.084	57518	2.196
32591	2.309	75000	2.025	99291	2.255
–	–	101682	1.945	–	–

Table A5. Results from Site C samples at three temperatures.

60°C		50°C		40°C	
Wheel passes	**Texture depth**	**Wheel passes**	**Texture depth**	**Wheel passes**	**Texture depth**
0	2.544	0	2.588	0	2.595
158	2.528	152	2.571	152	2.578
502	2.474	1000	2.555	1104	2.559
1002	2.491	3222	2.544	3500	2.527
3202	2.477	10002	2.436	10002	2.520
10555	2.448	50298	2.237	57518	2.398
32591	2.335	75000	2.266	99291	2.371
100704	2.182	101682	2.274	–	–

Table A6. Results from Site H samples at three temperatures.

60°C		50°C		40°C	
Wheel passes	Texture depth	Wheel passes	Texture depth	Wheel passes	Texture depth
0	2.311	0	2.474	0	2.165
158	2.277	152	2.417	152	2.118
502	2.241	1000	2.341	1104	2.086
1002	2.299	3222	2.326	3500	2.098
3202	2.264	10002	2.263	10002	2.132
10555	2.198	50298	2.128	57518	2.063
32591	2.083	75000	2.209	99291	2.102
100704	1.940	101682	2.251	–	–

Table A7. Results from Sites D, E and G samples, at 60°C.

D		E		G	
Wheel passes	Texture depth	Wheel passes	Texture depth	Wheel passes	Texture depth
0	2.425	0	1.421	0	2.632
1000	2.203	1000	1.438	1000	2.547
3200	2.171	3200	1.400	3200	2.522
7122	2.196	7122	1.381	7122	2.524
15173	2.152	15173	1.246	15173	2.484
30833	2.176	30833	1.039	30833	2.408
47957	2.424	–	–	47957	2.399
98983	–	–	–	98983	2.358