# Factors Affecting Multiple Chipseal Layer Instability

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# Contents

# Executive summary

The accumulation of chipseal layers following repeated road resurfacing frequently results in an unstable surface that can flush quickly, sometimes within twelve months. Many pavements in New Zealand that have multiple chipseal layers have not developed instability problems, and the reasons why some multiple layers develop the problem and others do not was the focus of this investigation, carried out between August 2002 and August 2004. The following conclusions have been reached:

1. Sites with multiple chipseals, both with no indications of shortened seal life and with apparent surface instability, were cored in and between the wheelpaths. For all sites, measurements of the surface hardness were carried out with the falling weight ball penetrometer. No relationship was found between ball penetrometer readings and the tendency of seals to flush.

2. The shear strength of a selection of surfaces was measured by a newly developed laboratory test that dynamically loaded (constant stress) core sample surfaces with a circular ram (50 mm diameter). The embedment of the ram as the sample sheared was recorded as a function of the number of impacts. A standard test temperature of 45°C was adopted. The change in compaction level (in mm) between 300 and 3000 impact pulses was used to compare rates of compaction.

3. For sites where premature flushing has occurred, the rate of compaction outside the wheelpath is significantly greater than that occurring within the wheelpath. For non-flushed sites the wheelpath and outside-wheelpath rates are similar.

4. This indicates that the structure (aggregate packing) and binder content of seals that flush prematurely are different from those of seals that perform well.

5. The laboratory test method could be used to provide an early indication of whether a seal treatment for flushing was likely to be effective.

6. No relationship between binder content alone and seal ‘instability’ was found.

7. Seals with higher percentages passing the 4.75 mm sieve appear to be more stable. However no relationship between aggregate grading and chip sequence was obvious.

8. Analysis of the seal histories indicated that the start of a series of shorter-than-expected seal lives appeared to be associated with a ‘catastrophic’ seal failure. Often the seal would last less than two years. Subsequent seals did not achieve the expected design life.

9. It is proposed that high bitumen content in itself is not the principal cause of flushing. Rather, the ratio of bitumen volume to the available volume in an optimum packed multiple seal layer is the determinant. The quantity of bitumen

that could be accommodated will depend on the grade of chip and the sequence of seals.

# Abstract

A laboratory investigation of multiple chipseal cores was carried out between August 2002 and August 2004, with a view to clarifying the causes of premature flushing in these seals. Generally, such flushing becomes an ongoing problem after resealing has been carried out unduly early and only once (as specified by RAMM expected lifetimes for seals). The testing indicated early flushing was associated with inadequate void content within the seal matrix, possibly as a result of sealing on to an uncompacted relatively high textured surface. (Spraying on to high textured surfaces currently requires an increased binder spray rate.) There was no evidence that a large number of sequential seals are unduly likely to flush, provided suitable seal design practice has been followed.

# 1. Introduction

## 1.1 Purpose of research

The predominant road surfacing treatment used on New Zealand state highways is chipseal over a flexible pavement. At the end of the chipseal life another chipseal is constructed over the top, forming multiple layers of chipseals. The accumulation of chipseal layers frequently leads to an unstable surface. Flushing and bleeding (binder rise to the surface) are major problems on New Zealand highways. Almost 50% of State Highway reseals are now carried out because of reported flushing or bleeding (Ball 2004).

It has been proposed that flushing and bleeding are especially likely where pavement surfacings have multiple chipseals, one on top of the other (which is the case for most of the network). Once the surfacing becomes unstable a new seal will flush quickly, sometimes within twelve months. Flushing results in slippery, unsafe roads and binder pickup on vehicles. The flushing/bleeding problem has become more pronounced in recent years, and in an extreme case even led to a closure on State Highway 1N in 1999. To quantify the problem a brief analysis of chipseals on the State Highway RAMM database (as at 25 September, 2001) was undertaken. Only sections of highway consisting solely of chipseal surfacings were included. The mean seal life as a function of the number of reseal layers is shown below:

| Number of Reseal Layers | Length (km) | Mean Age of Top Seal (years) |
|---|---|---|
| 1 | 1862.50 | 8.2 |
| 2 | 3076.45 | 5.3 |
| 3 | 1814.05 | 3.7 |
| 4 | 610.10 | 2.9 |
| 5 | 150.05 | 2.8 |

The weighted average mean life for the top layer in seals with 2 or more layers is 4.5 years, a reduction of 3.7 years compared to one layer. For seals with 4 or more layers failure of the road base or cracking may be contributing to the reduced lifetimes (due to the cumulative age of the road), but for seals with only 2 or 3 layers flushing is clearly the major factor.

Research in Hawke's Bay by Transit New Zealand and Opus International consultants Gray & Hart (2003) has identified a range of factors that characterise unstable multiple chipseals. The symptoms to look for in a pavement are:

- Flushed seal surface on an ageing pavement with a top surface layer consisting of many layers of seal.
- Relatively high bitumen binder:stone ratio in the top surface. Typically effective binder quantities were >10%. This contrasts with the effective bitumen content of 2% to 7% present in 'stable' asphaltic concrete layers.

- Evidence of shallow shear which indicates a near-surface layer instability problem as the main cause of the observed pavement distress.
- Evidence that the sealing life cycle on the pavement is reducing to below expected seal life.

There are many pavements in New Zealand that have multiple chipseal layers which have not developed instability problems and do not fit the above criteria. The reason why some multiple-seal layers develop the problem and others do not is unclear. With higher traffic stresses more use is being made of two-coat seals and there is concern that these treatments may be resulting in an acceleration of the instability problem. If the mechanisms leading to instability are not understood, then current surfacing treatments may be leading to a major surfacing problem and associated cost.

This project was designed to investigate the combination of seal types that can lead to surface instability and to determine how multiple seals can be constructed with reduced risk of the problem developing.

## 1.2 Research methodology

Sites with multiple chipseals, both with no indications of shortened seal life and with apparent surface instability, were located by a combination of Transit New Zealand RAMM database searching and communication with local highway administration personnel. When shortened lifetimes had occurred in the seals chosen there was a history of several early reseals, so that unduly high cutter content leading to flushing/bleeding is not considered to be a basic cause of the short lifetime problem, except possibly in the case of the first short-life seal in the sequence. A selection of these seals was cored in and between the wheelpaths. Simultaneous measurements of the surface hardness were carried out with a falling weight ball penetrometer (see Appendices A and B).

A method was developed for assessing the shear strength of the seal surfaces, and applied to a selection of flushed and unflushed core samples. In addition bitumen contents and gradings were performed on the samples.

# 2. Sampling

## 2.1 Choice of sites

Multiple chipseal sites were sought from a range of regions, both for instances of short lifetimes (as defined by the expected RAMM lifetime for the seal type and traffic level) where flushing is a chronic problem, and for cases where there was no evidence of reduced lifetimes. Particular instances of shallow shear or high binder content (hard to assess before sampling in any case) were not specifically looked for.

Appendix A lists details of the seals chosen for further investigation.

Premature flushing sites sampled, with number of sites in brackets, were:

- Bay of Plenty (6)
- Hawke's Bay (6)

Standard lifetimes were:

- Mid Canterbury (5)

The sealing histories listed in the tables of Appendix A were obtained from a combination of RAMM and old National Roads Board Highway Information Sheets. In the latter case complete data on the seals was not always available.

## 2.2 Sampling procedures

At each site sampled eight 150 mm (nominal) diameter cores were obtained, four for an outer wheelpath on one side of the road and four between the wheelpaths on the same side. At each core position five ball penetrometer readings were taken. Surface temperatures were noted to adjust the penetrometer readings. Penetrometer results are listed in Appendix B.

# 3. Assessing surface shear strength

An apparatus was designed and constructed to produce a shear force on the seal surface of cores using pressures similar to those applied by a typical truck tyre. Seal core samples (corer diameter 150 mm) were supported on mortar plaster in a cylindrical steel holder, with the seal surface as near as practicable to one end of the holder. Epoxy (Fosroc Nitoprime 35) was then poured into any gap between the cylinder wall and the core, so the sides and bottom of the core sample were confined (mimicking actual field conditions).

Equipment was built to hold the sample at a constant temperature during testing and the top surface dynamically loaded (constant stress) with a circular ram (50 mm diameter) with the embedment of the ram as the sample sheared being recorded as a function of time. Details follow.

## 3.1 Temperature control

The temperature was maintained by placing the sample core mounted in its steel holder into a double-walled vessel with water from a controlled temperature bath circulating between the walls. The vessel was insulated by mounting on a circular insulating material centring pad above the steel base of the testing apparatus, by rubber foam insulation about the circular walls, and by polystyrene sheet over the seal surface.

## 3.2 Testing apparatus

Dynamic loads were applied to the seal surfaces using a UTM-5 testing frame (Industrial Process Control Limited, Australia) with a pneumatically driven actuator. To ensure full contact with the (irregular) seal surface a plain/spherical bearing (SKF GX 20 F) was placed immediately above the 50 mm-diameter circular ram that was in contact with the seal surface. (It is noteworthy that in some cases for seals with large chip the ram moved several millimetres sideways from its original position during the test.)

Test parameters were as follows:

| | |
|---|---|
| Pulse Type | Haversine |
| Pulse Width | 50 ms |
| Pulse Frequency | 2 $s^{-1}$ |
| Pulse Height | 2.04 kN |
| Preload | 0.2 kN |

A photograph of the test apparatus is shown in Figure 3.1.

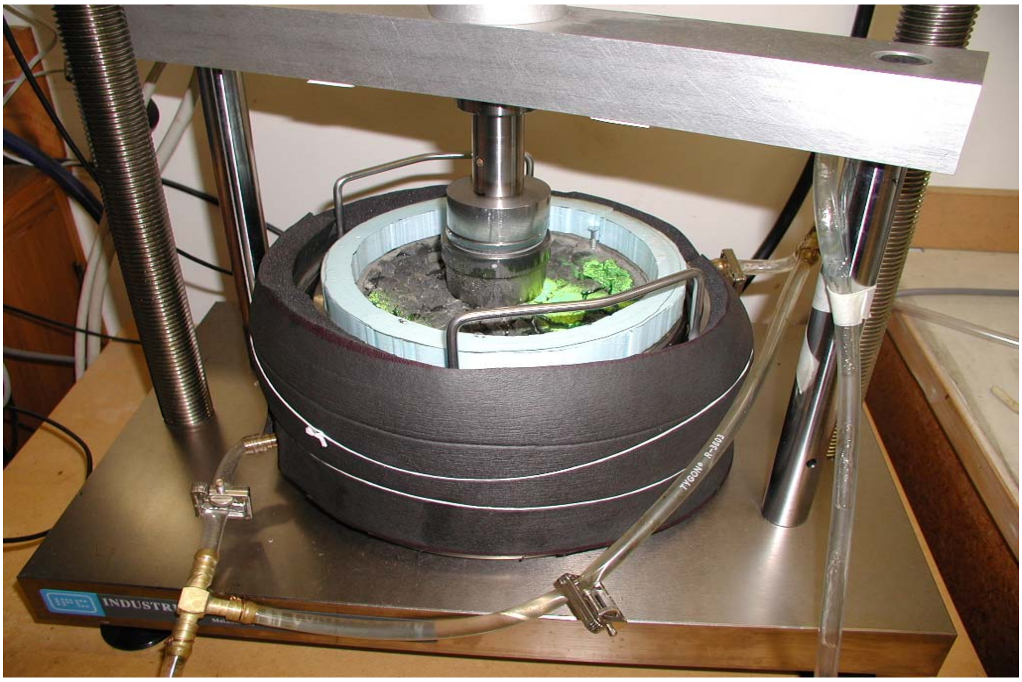

**Figure 3.1 Sample mounted for testing, with insulating polystyrene sheet removed to show the seal surface.**

## 3.3 Testing procedure

The prepared cores in their steel holders were placed in an oven at 45°C for at least 18 hours before testing. The double walled vessel interior was stabilised within 1°C of the test temperature, and the core in its holder was transferred from oven to vessel immediately before testing.

Actuator displacements were recorded continuously in ASCII format by the Industrial Process Control Limited supplied software. At completion of the run the data was transferred to a Microsoft EXCEL® file and edited to retain only readings taken at rest (i.e. not during the stress pulses), before plotting for inspection.

Plots of displacement against the number of impact pulses are displayed in Appendix C. For purposes of ready comparison the change in compaction level (in mm) between 300 and 3000 impact pulses are listed in the tables of Appendix B. The reasons for this choice of pulse range are discussed in Section 4.3.

# 4. Seal core properties and test results

## 4.1 Bitumen contents and gradings

The bitumen contents and gradings are given in Appendix B. The bitumen contents varied from 7.2% to 15.9% by weight.

As would be expected all material passes a 19 mm sieve. However, a range from 14% to 28% passed the 4.75 mm sieve. This unexpectedly high content of fines is discussed in Section 5.4.

## 4.2 Ball penetrometer results

The ball penetration test consists of measuring the indentation of a 19 mm ball bearing into the surface when hit with one blow of a Marshall Hammer.

The test was a modification of the one originally developed in South Africa, similar to that used to assess surface hardness in the Transit New Zealand P/17 Performance Based Specification for Sealing. Details are given in Appendix D.

The test results are given in Appendix B and show a range of values from 1.85 mm to 3.7 mm.

## 4.3 Shear test results

Results from the shear tests are plotted in Appendix C.

For all tested samples the rate of impaction gradually decreases, as would be normally expected. There is an occasional increase of impaction rate at unpredictable points, presumably associated with the observed partial release and re-orientation of sealing chips at the edge of the ram face. The seal surfaces after testing exhibit this re-orientation.

The inherent rates of compaction for the different surfaces have been compared by using the change of ram displacement between 300 and 3000 impact pulses. The lower level is chosen to ensure that the measurements are past any possible initial rapid compaction that might be associated with early slippage of the ram face during bedding in. The 3000-pulse level was chosen to be below the occurrence of any significant chip re-orientation. Values of compaction change (in mm) are listed in Table 4.1 in decreasing order of compaction rate for the between-wheelpath samples, and in the more detailed tables of Appendix B. A check of rates of compaction at a higher pulse level gave the same ordering of samples.

**Table 4.1 Seal compaction results in decreasing order of compaction rate for the between-wheelpath samples.**

| Site No. | Site Condition | Site Route Position | Compaction 300 - 3000 pulses (mm) | | |
|---|---|---|---|---|---|
| | | | Between Wheelpath | Wheelpath | Ratio |
| 5 | Premature Flushing | SH 2 RP 304/5.25 | -0.823 | -0.297 | 2.77 |
| 11 | Premature Flushing | SH 2 RP 691/0.407 | -0.566 | -0.278 | 2.04 |
| 1 | Premature Flushing | SH 2 RP 294/6.2 | -0.499 | -0.221 | 2.26 |
| 9 | Premature Flushing | SH 2 RP 592/12.15 | -0.388 | -0.207 | 1.87 |
| 3 | Premature Flushing | SH 2 RP 304/4.0 | -0.381 | -0.284 | 1.34 |
| 17 | Normal Life | SH 1S RP 447/11.77 | -0.256 | -0.221 | 1.16 |
| 16 | Normal Life | SH 1S RP 447/7.30 | -0.238 | -0.288 | 0.83 |
| 13 | Normal Life | SH 1S RP 416/11.00 | -0.238 | -0.266 | 0.90 |

# 5. Discussion

## 5.1 Shear test

From the results in Table 4.1 the following trends are apparent:

1. The compaction rate in the wheelpaths is the same order of magnitude for all sites, whether or not premature wheelpath flushing has occurred.

2. Where the surfaces have not shown a tendency to flush, compaction rates for wheelpath and between-wheelpath samples are similar.

3. For sites where premature flushing has occurred, laboratory compaction for between-wheelpath samples is significantly higher than for the corresponding wheelpath samples.

The laboratory impact test apparatus results provide a good diagnosis for liability of a seal to flush. The indications are that surfaces which are not liable to flush early would have 300-3000 pulse compactions of magnitude less than 0.3; for sites liable to flush early the magnitude would be greater than 0.35, or possibly even 0.38. The test could provide an early indication of whether a seal treatment for flushing was likely to be effective.

## 5.2 Ball penetration test

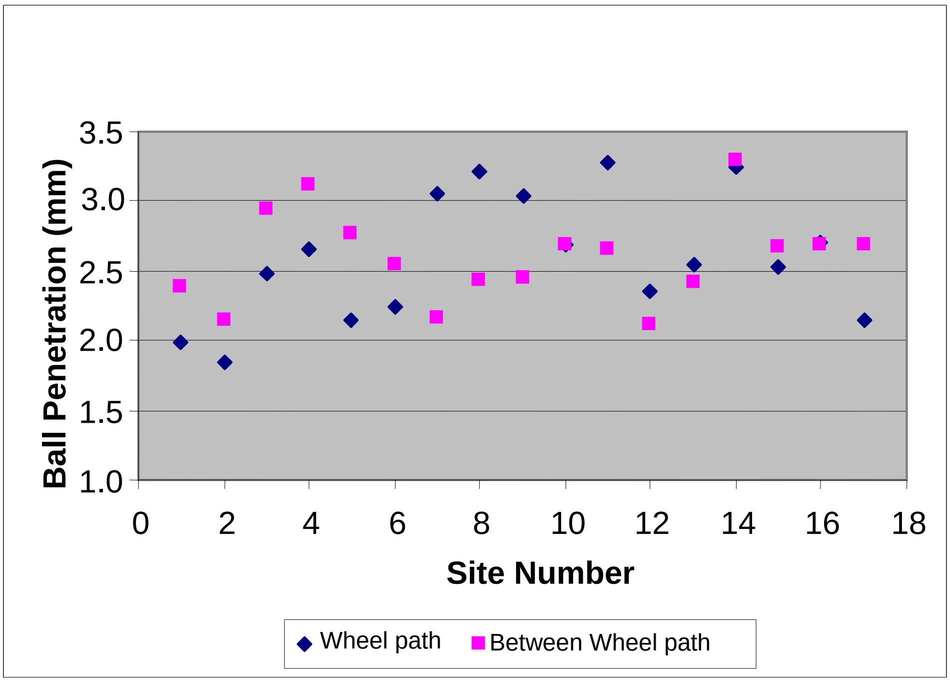

**Figure 5.1 Ball penetration results for between wheelpaths and for wheelpaths for Bay of Plenty sites 1-6, Hawke's Bay sites 7-12, & Mid Canterbury sites 13-17.**

The ball penetration test does not show any relationship with a site's potential for early flushing as is shown in Figure 5.1, where sites 1-6 are Bay of Plenty sites, 7-12 Hawke's Bay, and 13–17 are the Mid Canterbury non-flushed sites.

In contrast to the compaction test, the ratio of the in-wheelpath ball penetration to the between-wheelpath penetration does not correlate with flushing potential, as shown in Figure 5.2. There is an apparent regional effect, with the ratios for Bay of Plenty sites (1–6) being generally lower than those for the Mid Canterbury sites (13–17), which in turn tend to be lower than Hawke's Bay sites (7–12). The reason for this is not immediately apparent and further research would be needed to find the cause of this trend.

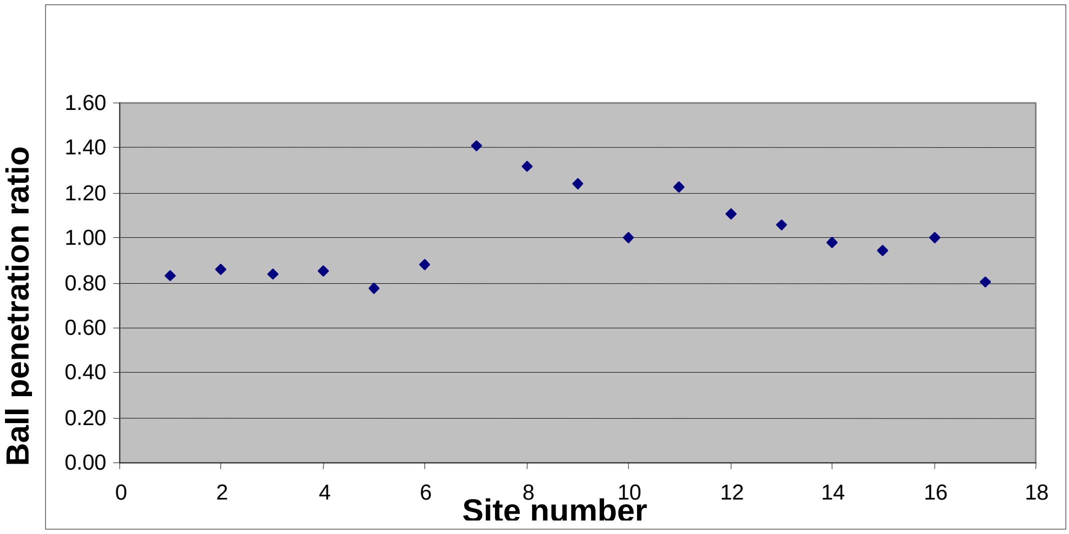

**Figure 5.2 Ball penetration ratio for Bay of Plenty sites 1-6, Hawke's Bay sites 7-12, & Mid Canterbury sites 13-17.**

## 5.3 Effect of binder quantities

Figure 5.3 shows the distribution of bitumen contents with site number. Sites 14–17 are the Mid Canterbury sites that do not show premature flushing yet sites 16 and 17 have comparatively high bitumen contents.

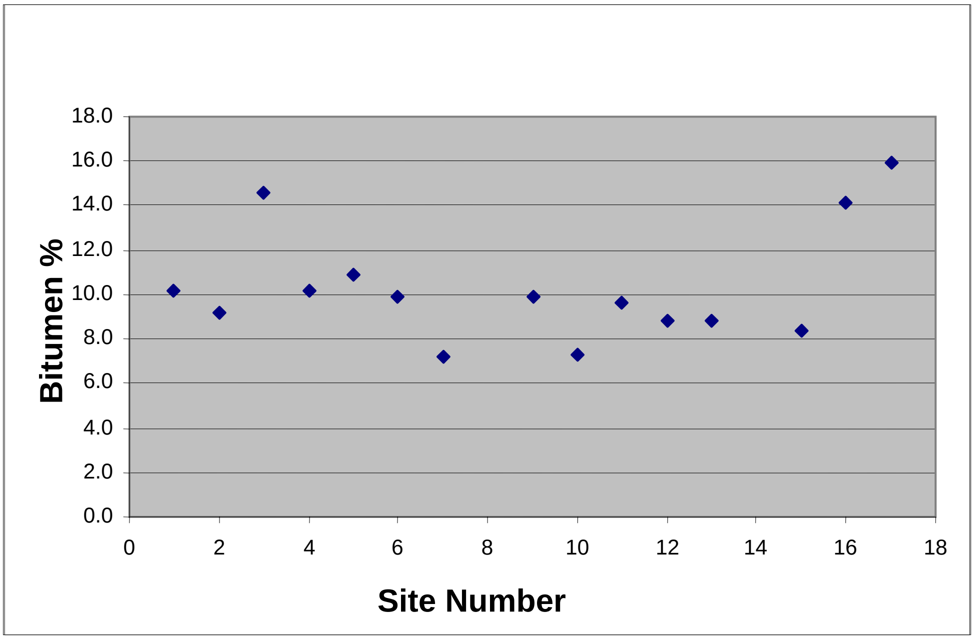

**Figure 5.3 Bitumen contents (%) for Bay of Plenty sites 1-6, Hawke's Bay sites 7-12, & Mid Canterbury sites 13-17.**

## 5.4 Aggregate grading

Figure 5.4 gives the percentage passing the 4.75 mm sieve versus site number. Sites 1, 2, 13, 16 and 17 have more than 20% passing the 4.75 mm, while the other sites are more coarse graded.

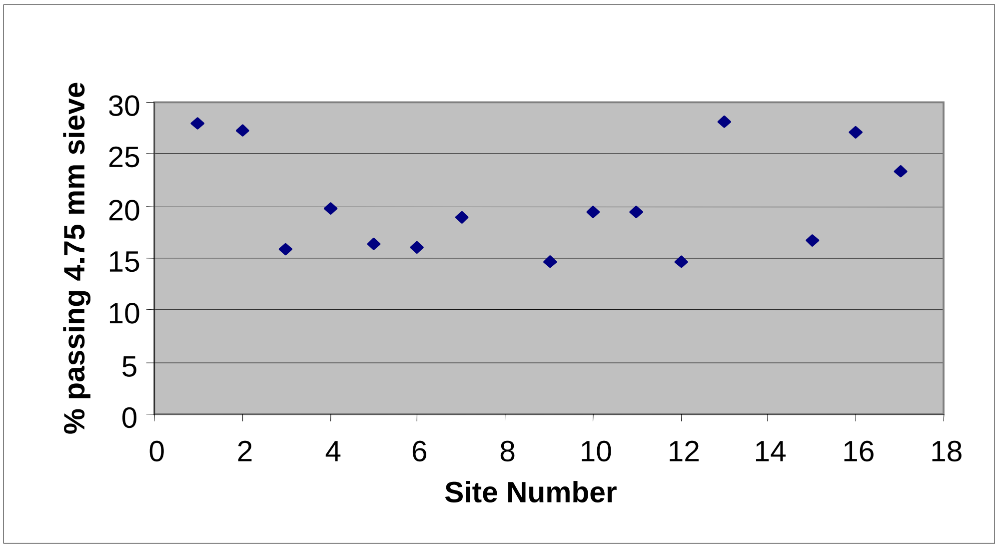

**Figure 5.4 Aggregate fines (as % passing 4.75 mm sieve) for Bay of Plenty sites 1-6, Hawke's Bay sites 7-12, & Mid Canterbury sites 13-17**

At first sight there is no relationship between fines content and liability to flush. However sites 1 and 2 in the Bay of Plenty are special cases. They have high percentages passing the 4.75 mm sieve and have flushed early. On both sites a two coat grade 2/5 seal was constructed in 1998, and it was resealed within one year. This suggests that a construction fault in the sealing operation has lead to the reduced subsequent life.

If we then ignore sites 1 and 2, the trend may be for high fines content to correlate with low susceptibility to flushing.

If the shear test can be considered a method of ranking a seal's 'risk' of instability (high compaction ratio), then Figure 5.5 indicates that a relationship exists between the percentage passing the 4.75 mm sieve and shear properties.

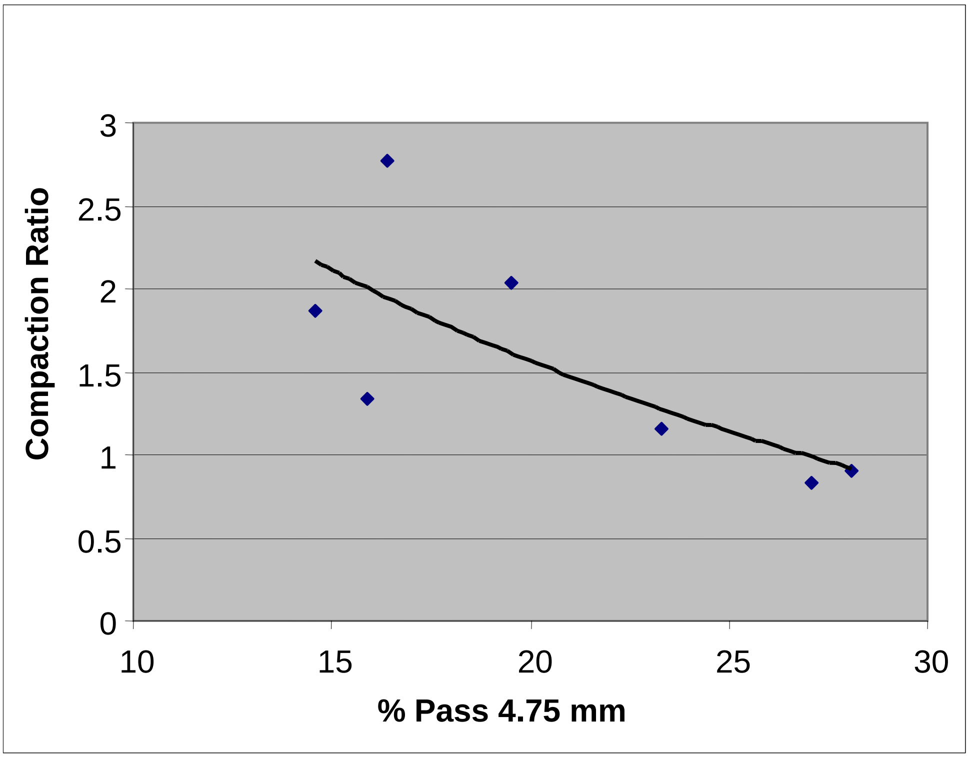

**Figure 5.5 Effect of fines (as % passing 4.75 mm sieve) on compaction ratio.**

The relatively high percentage passing the 4.75 mm sieve is surprising in that the grading of the materials used do not have a significant percentage passing this sieve size. Thus, considering the grading limits for the Grade 5 and 6 chips as specified in Transit New Zealand M/6 specification (see Table 5.1), it can be seen that only Grade 6 chip has significant material passing the 4.75 mm sieve.

**Table 5.1 TNZ M/6 requirements for Grade 5 and 6 chip.**

| Sieve Size (mm) | Cumulative % Passing | |
|---|---|---|
| | Grade 5 | Grade 6 |
| 13.2 | 100 | — |
| 9.5 | 95-100 | 100 |
| 6.7 | — | 95-100 |
| 4.75 | 8 max | — |
| 2.36 | 2 max | 15 max |
| 0.3 | 0 | 8 max |

Using a typical chip application rate of 900/ALD $m^2/m^3$ (ALD is average least dimension of chips in mm) and a typical aggregate specific gravity of 2.65, a theoretical grading can be calculated for various chip sequences.

For a chip sequence of Grades 3,5,4,6, the percentage passing the 4.75 mm = 16%

For a chip sequence of Grades 2,4,3,5, the percentage passing the 4.75 mm is less than 5%.

As all the samples had approximately 15% or more passing the 4.75 mm sieve, in theory they should contain Grade 6 chip. However there appears to be no relationship between the seal sequence given in RAMM and the gradings obtained. For example sites 13 and 17 have high percentages passing the 4.75 mm sieve but RAMM does not record the use of a Grade 6 chip.

The reason for the unexpectedly high fines contents remains an open question. In situ disintegration of chip surfaces under the combined effects of traffic and weather is one possibility that could be investigated.

A close examination of some seals, e.g. site 17, indicates that a bituminous mix may have been used in the past although there is no record. This highlights the danger of relying on the RAMM records for construction history when deciding how to reseal.

## 5.5 Seal sequence

Examination of the sealing histories of the sites listed in Appendix A show that chip sizes ranged from Grade 2 to Grade 6.

A close examination of the sealing sequences and achieved lives suggests the possibility that decrease in seal lives follows a catastrophic seal failure, rather than being a gradual decrease in expected life from seal to seal.

For example, in site 5 in the Bay of Plenty a second coat seal achieving 10 years life was followed by a voidfill, but then in 1996 a Grade 2 seal was applied that only lasted two out of the expected 12 years.

Similarly, in site 2 a 2/5 seal only lasted only one out of the expected 13 years.

A similar trend is found in the Hawke's Bay seals. In Site 9 a second coat seal that performed well was followed by a texturising seal, but then the following Grade 2 seal only lasted 2 years where a 10-year life was expected.

Seals applied after 'failure' tend to continue giving the shorter than expected life but not necessarily to the same extent.

As most of the 'catastrophic' failures occurred in the early 1990s it is difficult to now trace the reasons. A study of reasons given for resealing where 'catastrophic' failure has only recently occurred might give improved understanding of at least some of the causes of reduced seal lifetimes.

If the start of rapid flushing is associated with a seal construction failure, then this should not affect the use of two coat seals. There is no reason to suspect that a two coat seal would contribute to seal instability. In fact, a two coat seal uses less binder than two single coats, and it would decrease the total binder percentage content of a multiple seal coat layer.

Early resealing after a catastrophic failure will tend to lead to high binder contents in the multiple seal structure. Chips in a multiple seal layer will have a theoretical optimum packing arrangement. The chips will attempt to rearrange and compact under the action of traffic to reach this state until chip to chip contact prevents further movement. The effect of this is to minimise the bulk volume of the total seal layer. The energy input from a passing vehicle is not sufficient to cause significant disruption to the layers or large displacements of individual chips, so that this packing will be a metastable state, not the absolute theoretical maximum for the particular grading of chip in the layer. Immediately after construction the top layer of chip will begin to re-orientate and pack into the underlying layer of chip. If this process is not complete before the next layer is applied, excess volume (filled with bitumen) will be 'built into' the seal, since the standard spray rate algorithm requires more bitumen the higher the surface texture. Such a situation could arise if a seal failure such as partial stripping occurred soon after construction and necessitated another seal coat. As discussed above, catastrophic failure appears to have occurred at those sites later showing premature flushing.

The shear test data showed that compaction rates outside the wheelpaths were much greater for the flushed sites, 0.38-0.82 compared to 0.2-0.3 for non-flushed samples, suggesting the presence of 'excess volume' that is lost as the chips pack together under traffic. As the bitumen is incompressible, it is exuded to the surface.

Compaction rates for the non-flushed sites were essentially the same for wheelpath and between-wheelpath areas. This indicates little ‘excess volume’ was present and packing in the layers was near some stable state. (Some slow rate of compaction will always be present as the vertical load applied to the samples in the test, and through tyres in the field, acts on and through irregularly shaped chips. Thus turning moments and hence shearing forces are unavoidable, even in a theoretical minimum volume packing arrangement.)

At the flushed sites wheelpath compaction rates were much lower than the equivalent between-wheelpath rates, and were similar to those of the non-flushed sites. This is consistent with the excess volume hypothesis allowing that considerable trafficking had taken place by the time the samples were taken, i.e. excess volume in the system had already been lost by the time compaction measurements were made, as evidenced by the observed flushing.

If the above hypothesis is correct then a high bitumen content in itself would not be a cause of flushing (as observed). Rather the ratio of bitumen to the available volume in an optimum packed multilayer seal is the important criterion. The quantity of bitumen that could be accommodated would depend on the grade of chip and sequence of seals.

## 5.6 Other causes

Premature flushing can be caused through reasons other than the build up of seal layers. Ball et al. (1999) have shown that it is possible for bitumen to be forced to the surface through vapour pressure of water. The occurrence of small bubbles of bitumen on a seal surface is relatively common and when these bubbles are opened there is visible water present.

# 6. Summary and conclusions

The accumulation of chipseal layers with repeated road resurfacing frequently results in an unstable surface that can flush quickly, sometimes within twelve months.

Many pavements in New Zealand have multiple chipseal layers that have not developed instability problems, and the reasons why some multiple seal coat layers develop the problem and others do not were the focus of this investigation.

- Sites with multiple chipseals, both areas with no indications of shortened seal life and others with apparent surface instability, were cored in and between the wheelpaths. For all sites measurements of the surface hardness were carried out with the ball penetrometer. No relationship was found between ball penetrometer readings and the tendency of seals to flush.
- The shear strength of a selection of surfaces was measured by a newly developed laboratory test that dynamically loaded (constant stress) core sample surfaces with a circular ram (50 mm diameter). The embedment of the ram as the sample sheared was recorded as a function of the number of impacts. A standard test temperature of 45°C was adopted. The change in compaction level (in mm) between 300 and 3000 impact pulses was used to compare rates of compaction.
- For sites where premature flushing has occurred the rate of compaction outside the wheelpath is significantly greater than that occurring within the wheelpath. For non-flushed sites the wheelpath and between-wheelpath rates are similar.
- This indicates that the structure (aggregate packing) and binder content of seals that flush prematurely are different from seals that perform well.
- The laboratory test method could be used to provide an early indication of whether a seal treatment for flushing was likely to be effective.
- No relationship between binder content alone and seal ‘instability’ was found.
- Seals with higher percentages passing the 4.75 mm sieve appear to be more stable. However no relationship between aggregate grading and chip sequence was obvious.
- Analysis of the seal histories indicated that the start of a series of shorter than expected seal lives appeared to be associated with a ‘catastrophic’ seal failure. Often the seal would last less than two years. Subsequent seals did not achieve the expected design life.
- All sites tended to use a succession of chip sizes; generally a large chip (Grade 2 or 3) was followed by a voidfill or texturising seal before a large chip was used again.
- It is proposed that high bitumen content in itself is not the principal cause of flushing. Rather, the ratio of bitumen volume to the available volume in an optimum packed multilayer seal is the determinant. The quantity of bitumen that could be accommodated will depend on the grade of chip and the sequence of seals.

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# Appendix A Seals Chosen for Investigation

## A1 Bay of Plenty

| Site No | Site Route Position | AADT (%HCV) | Chip Grade/s | Surface Type | Sealing Date | Expected Life (years) | Age Achieved (years) | Percent Achieved | Surface Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Wheel-path | Between Wheelpath |
| 1 | SH 2 RP 294/6.2 | 3500 (10%) | 5 | R/S | 16/12/1998 | 5 | 2 | 40% | Fully Flushed | Unflushed |
| | | | 2/5 | R/S | 26/01/1998 | 13 | 1 | 8% | | |
| | | | 6 | Text | 16/01/1996 | 3 | 1 | 39% | | |
| | | | 3 | R/S | 25/12/1989 | 9 | 7 | 78% | | |
| 2 | SH 2 RP 294/7.0 | 3500 (10%) | 2/4 | R/S | 2/03/1999 | 13 | >3 | >23% | Heavy Spot Flushing | Unflushed |
| | | | 5 | R/S | 16/12/1998 | 5 | 0.1 | 2% | | |
| | | | 2/5 | R/S | 26/01/1998 | 13 | 1 | 8% | | |
| | | | 6 | Text | 11/09/1996 | 3 | 1 | 33% | | |
| | | | 3 | R/S | 25/12/1986 | 9 | 10 | 111% | | |
| 3 | SH 2 RP 304/4.0 | 1350 (14%) | 2/4 | R/S | 1/03/1999 | 14 | 4 | 29% | Heavy Spot Flushing About 50% cover | Unflushed |
| | | | 2 | R/S | 12/12/1996 | 12 | 2 | 17% | | |
| | | | 6 | V/F | 3/02/1994 | 6 | 3 | 50% | | |
| | | | 2 | 2nd | 25/01/1983 | 12 | 10 | 83% | | |
| 4 | SH 2 RP 304/4.65 | 1350 (13%) | 2/4 | R/S | 13/12/2000 | 14 | >2 | >14% | Unflushed | Unflushed |
| | | | 2 | R/S | 12/12/1996 | 12 | 4 | 33% | | |
| | | | 6 | V/F | 3/02/1994 | 6 | 3 | 50% | | |
| | | | 2 | 2nd | 25/12/1983 | 12 | 10 | 83% | | |
| 5 | SH 2 RP 304/5.25 | 1350 (13%) | 2/4 | R/S | 22/01/2002 | 14 | 1 | 7% | Fully Flushed | Unflushed |
| | | | 2/4 | R/S | 1/03/1999 | 14 | 3 | 21% | | |
| | | | 2 | R/S | 12/12/1996 | 12 | 2 | 17% | | |
| | | | 6 | V/F | 3/02/1994 | 6 | 3 | 50% | | |
| | | | 2 | 2nd | 25/12/1983 | 12 | 10 | 83% | | |
| 6 | SH 2 RP 304/5.7 | 1350 (13%) | 2/4 | R/S | 2/12/1999 | 14 | >3 | >21% | Spot Flushing | Unflushed |
| | | | 2 | R/S | 12/12/1996 | 12 | 3 | 25% | | |
| | | | 6 | V/F | 3/02/1994 | 6 | 3 | 50% | | |
| | | | 2 | 2nd | 25/12/1983 | 12 | 10 | 83% | | |

Notation:

| | |
|---|---|
| 2nd | Second Coat Seal |
| B/C | Bicouche/Sandwich Seal |
| E180 R/S | Reseal with 180/200 bitumen emulsion binder |
| Locking | Locking Coat |
| PMB R/S | Reseal with polymer modified bitumen binder |
| R/S | Reseal |
| Text | Texturising seal |
| V/F | Voidfill |

## A2 Hawke's Bay

| Site No | Site Route Position | AADT (%HCV ) | Chip Grade/s | Surface Type | Sealing Date | Expected Life (years) | Age Achieved (years) | Percent Achieved | Surface Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Wheel-path | Between Wheelpath |
| 7 | SH 50 RP17/1.80 Mere Road | 2164 (7%) | 2/4 | B/C | 1/11/1999 | 13* | 4 | 31% | Fully Flushed | Unflushed |
| | | | 2 | R/S | 9/02/1995 | 10 | 5 | 40% | | |
| | | | 5 | Text | 2/04/1992 | 5 | 3 | 60% | | |
| | | | 3 | R/S | 28/11/1987 | 12 | 5 | 42% | | |
| 8 | SH2 RP577/15.62 Waikare Top/ Putorino | 1800 (18%) | 2/4 | B/C | 28/01/1999 | 14* | 4 | 29% | Fully Flushed | Unflushed |
| | | | 3 | R/S | 24/02/1994 | 10 | 5 | 50% | | |
| | | | 5 | Text | 20/03/1992 | 5 | 2 | 40% | | |
| | | | 2 | R/S | 6/03/1991 | 9 | 1 | 11% | | |
| | | | 3 | R/S | 25/12/1982 | 8 | 8 | 100% | | |
| 9 | SH 2 RP 592/12.15 Kaihiwi II | 1800 (18%) | 2/4 | B/C | 3/03/2000 | 14* | 3 | 21% | Fully Flushed | Spot Flushed ~1/5 of surface |
| | | | 2 | R/S | 20/02/1996 | 10 | 4 | 40% | | |
| | | | 3 | R/S | 25/02/1994 | 10 | 2 | 20% | | |
| | | | 5 | Text | 10/10/1989 | 4 | 4 | 100% | | |
| | | | 2 | 2nd | 25/12/1978 | 10 | 11 | 110% | | |
| 10 | SH 2 RP 638/3.19 Bay View | 10300 (12%) | 3/5 | B/C | 10/12/1999 | 8* | 3 | 38% | Fully Flushed | Unflushed |
| | | | 3 | R/S | 16/02/1994 | 9 | 6 | 63% | | |
| | | | 5 | R/S | 13/03/1991 | 5 | 3 | 60% | | |
| | | | 2 | 2nd | 25/12/1978 | 9 | 12 | 130% | | |
| 11 | SH 2 RP 691/0.407 Burma Road | 6400 (11%) | 2/4 | B/C | 26/02/1999 | 12* | 4 | 33% | Fully Flushed | Flushed ~1/10 of surface |
| | | | 5 | R/S | 17/04/1996 | 5 | 3 | 60% | | |
| | | | 3 | R/S | 30/01/1992 | 8 | 4 | 50% | | |
| | | | 5 | Text | 16/03/1990 | 5 | 2 | 40% | | |
| | | | 3 | R/S | 25/12/1980 | 9 | 8 | 110% | | |
| 12 | SH 2 RP 592/9.50 | 1800 (18%) | 2 | R/S | 19/02/1996 | 10 | >7 | >70% | Spot Flushing | Spot Flushing |
| | | | 5 | Text | 20/03/1992 | 5 | 5 | 80% | | |
| | | | 3 | R/S | 25/12/1985 | 9 | 6 | 67% | | |
| | | | 6 | V/F | 25/12/1983 | 3 | 2 | 67% | | |
| | | | 3 | R/S | 25/12/1979 | 9 | 4 | 44% | | |

* Local consultants have assigned short expected lives in view of the performance of previous seals and expected reconstruction.

## A3 Mid Canterbury

| Site No | Site Route Position | AADT (%HCV) | Chip Grade/s | Surface Type | Sealing Date | Expected Life (years) | Age Achieved (years) | Percent Achieved | Surface Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Wheel-path | Between Wheelpath |
| 13 | SH 1S<br>RP 416/11.00 | 9570<br>(14%) | 3 | R/S | 27/01/1997 | 9 | >7 | >78% | Unflushed | Unflushed |
| | | | 5 | V/F | 1/02/1988 | 5 | 9 | 180% | | |
| | | | 3 | R/S | 02/1977 | | 11 | | | |
| | | | 1 | R/S | 01/1961 | | 16 | | | |
| 14 | SH 1S<br>RP 430/3.20 | 8400<br>(5%) | 3/5 | R/S | 22/01/1996 | 10 | >6 | >60% | Slight<br>Spotting | Slight<br>Spotting |
| | | | 5 | V/F | 1/02/1989 | 5 | 7 | 140% | | |
| | | | 3 | R/S | 03/1981 | | 8 | | | |
| | | | ? | R/S | 11/1960 | | 20 | | | |
| 15 | SH 1S<br>RP 430/4.30 | 8500<br>(5%) | 3 | R/S | 25/01/1996 | 9 | >6 | >67% | Unflushed | Unflushed |
| | | | 5 | V/F | 27/11/1989 | 5 | 7 | 140% | | |
| | | | 3 | R/S | 1/03/1978 | 10 | 12 | 120% | | |
| | | | ? | R/S | 02/1959 | | 19 | | | |
| 16 | SH 1S<br>RP 447/7.30 | 6480<br>(15%) | 5 | V/F | 31/10/2001 | 5 | >1 | >20% | Unflushed | Unflushed |
| | | | 3 | R/S | 2/11/1990 | 10 | 11 | 110% | | |
| | | | 5 | V/F | 1/02/1984 | 5 | 7 | 140% | | |
| | | | 3 | R/S | 11/1966 | | 17 | | | |
| | | | ? | R/S | 11/1954 | | 12 | | | |
| 17 | SH 1S<br>RP 447/11.77 | 6480<br>(15%) | 3 | R/S | 22/11/1994 | 9 | >7 | >70% | Unflushed | Unflushed |
| | | | 6 | V/F | 30/10/1990 | 3 | 4 | 133% | | |
| | | | 5 | V/F | 1/02/1984 | 5 | 7 | 140% | | |
| | | | 3 | R/S | 12/1967 | | 16 | | | |
| | | | ? | R/S | 11/1953 | | 14 | | | |

# Appendix B Test Results

Compactions and ball penetrations are measured in millimetres.

## B1 Bay of Plenty

| Site<br>Route Position | Compaction 300 - 3000 pulses | | | Ball Penetration (40°C) | | Bitumen % by Mass (Volume) |
|---|---|---|---|---|---|---|
| | Wheelpath | Between Wheelpath | Ratio | Wheelpath | Between Wheelpath | |
| SH 2 RP 294/6.2 | -0.221 | -0.499 | 2.26 | 1.98 | 2.39 | 10.2(22.2) |
| SH 2 RP 294/7.0 | | | | 1.85 | 2.15 | 9.2(19.9) |
| SH 2 RP 304/4.0 | -0.284 | -0.381 | 1.34 | 2.48 | 2.95 | 14.6(31.5) |
| SH 2 RP 304/4.65 | | | | 2.66 | 3.11 | 10.2(22.0) |
| SH 2 RP 304/5.25 | -0.297 | -0.823 | 2.77 | 2.14 | 2.76 | 10.9(23.1) |
| SH 2 RP 304/5.7 | | | | 2.24 | 2.54 | 9.9(21.4) |

| Sieve Size mm | Percent Passing | | | | | |
|---|---|---|---|---|---|---|
| | SH 2 RP 294/6.2 | SH 2 RP 294/7.0 | SH 2 RP 304/4.0 | SH 2 RP 304/4.65 | SH 2 RP 304/5.25 | SH 2 RP 304/5.7 |
| 19.0 | 100.0 | 99.3 | 100.0 | 100.0 | 100.0 | 100.0 |
| 13.2 | 84.4 | 83.0 | 65.8 | 84.7 | 73.0 | 74.0 |
| 9.5 | 53.7 | 46.5 | 34.0 | 53.6 | 45.2 | 36.2 |
| 6.7 | 35.8 | - | - | - | 24.1 | - |
| 4.75 | 27.3 | 23.7 | 15.9 | 19.8 | 16.4 | 16.1 |
| 2.36 | 15.3 | 14.6 | 12.1 | 12.7 | 12.8 | 12.4 |
| 1.18 | 11.0 | 11.2 | 9.8 | 9.2 | 10.9 | 10.6 |
| 0.600 | 9.2 | 9.8 | 8.4 | 6.9 | 9.8 | 9.5 |
| 0.300 | 7.7 | 8.9 | 6.8 | 5.2 | 8.7 | 8.6 |
| 0.150 | 6.1 | 8.0 | 5.1 | 4.0 | 7.4 | 7.5 |
| 0.075 | 4.8 | 7.4 | 3.7 | 2.5 | 6.3 | 6.5 |

## B2 Hawke's Bay

| Site Route Position | Site Name | Compaction 300 - 3000 pulses | | | Ball Penetration (40°C) | | Bitumen % by Mass (Volume) |
|---|---|---|---|---|---|---|---|
| | | Wheelpath | Between Wheelpath | Ratio | Wheelpath | Between Wheelpath | |
| SH 50 RP 17/1.80 | Mere Road | | | | 3.05 | 2.16 | 7.2(15.6) |
| SH2 RP 577/15.62 | Waikare Top/Putorino | | | | 3.21 | 2.44 | |
| SH 2 RP 592/12.15 | Kaihiwi II | -0.207 | -0.388 | 1.87 | 3.04 | 2.45 | 9.9(21.5) |
| SH 2 RP 638/3.19 | Bay View | | | | 2.68 | 2.68 | 7.3(15.8) |
| SH 2 RP 691/0.407 | Burma Road | -0.278 | -0.566 | 2.04 | 3.27 | 2.66 | 9.6(20.5) |
| SH 2 RP 592/9.50 | - | | | | 2.35 | 2.12 | 8.8(19.0) |

| Sieve Size mm | Percent Passing | | | | |
|---|---|---|---|---|---|
| | SH 2 RP 577/15.62 | SH 2 RP 592/12.15 | SH2 RP 638/3.19 | SH2 RP 691/0.407 | SH 2 RP 592/9.50 |
| 19.0 | 100.0 | 100.0 | 100.0 | 99.3 | 100.0 |
| 13.2 | 84.0 | 82.3 | 92.9 | 81.8 | 71.7 |
| 9.5 | 45.2 | 43.5 | 55.9 | 41.2 | 31.7 |
| 4.75 | 19.0 | 14.6 | 19.5 | 19.5 | 14.7 |
| 2.36 | 13.5 | 10.2 | 12.9 | 12.4 | 11.2 |
| 1.18 | 11.3 | 8.2 | 10.7 | 9.4 | 9.1 |
| 0.600 | 10.1 | 7.0 | 9.4 | 7.8 | 7.9 |
| 0.300 | 9.1 | 6.1 | 8.5 | 6.7 | 6.8 |
| 0.150 | 8.2 | 5.2 | 7.8 | 4.5 | 5.7 |
| 0.075 | 7.2 | 4.0 | 7.0 | 4.4 | 5.0 |

## B 3 Mid Canterbury

| Site<br>Route Position | Compaction 300 - 3000 pulses | | | Ball Penetration (40°C) | | Bitumen % by Mass (Volume) |
|---|---|---|---|---|---|---|
| | Wheelpath | Between Wheelpaths | Ratio | Wheelpath | Between Wheelpath | |
| SH 1S RP 416/11.00 | -0.266 | -0.238 | 0.90 | 2.55 | 2.41 | 8.8(19.7) |
| SH 1S RP 430/3.20 | | | | 3.24 | 3.30 | |
| SH 1S RP 430/4.30 | | | | 2.53 | 2.67 | 8.4(18.7) |
| SH 1S RP 447/7.30 | -0.288 | -0.238 | 0.83 | 2.70 | 2.69 | 14.1(32.4) |
| SH 1S RP 447/11.77 | -0.221 | -0.256 | 1.16 | 2.15 | 2.68 | 15.9(37.0) |

| Sieve Size mm | Percent Passing | | | |
|---|---|---|---|---|
| | SH 1S RP416/11.0 | SH 1S RP 430/4.30 | SH 1S RP 447/7.30 | SH 1S RP 447/11.77 |
| 19.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| 13.2 | 86.2 | 90.9 | 97.1 | 91.4 |
| 9.5 | 48.9 | 44.8 | 58.6 | 48.0 |
| 4.75 | 28.1 | 16.7 | 27.1 | 23.3 |
| 2.36 | 22.0 | 11.0 | 18.4 | 15.0 |
| 1.18 | 17.8 | 7.3 | 14.0 | 11.9 |
| 0.600 | 15.1 | 6.4 | 11.6 | 10.0 |
| 0.300 | 12.4 | 5.1 | 9.1 | 8.2 |
| 0.150 | 9.2 | 4.2 | 6.2 | 6.2 |
| 0.075 | 6.7 | 3.3 | 4.4 | 5.0 |

Site SH 1S RP 430/3.2 proved unexpectedly, on sampling, to have a 50 mm thick layer of an asphalt mix immediately below the top seal. This would explain why the ball penetration is greater than for the other Mid Canterbury samples. Binder and gradings were not obtained for this site, since the samples do not fit the multiple seal criterion.

# Appendix C Impact shear test plots

Displacement of the testing apparatus actuator is plotted against the number of impact pulses experienced by the seal surface. Plots for the wheelpaths and between-wheelpaths are plotted together for each sample. For each site a second plot of displacement versus the logarithm of the number of impact pulses accentuates positions where the rate of compaction changes suddenly.

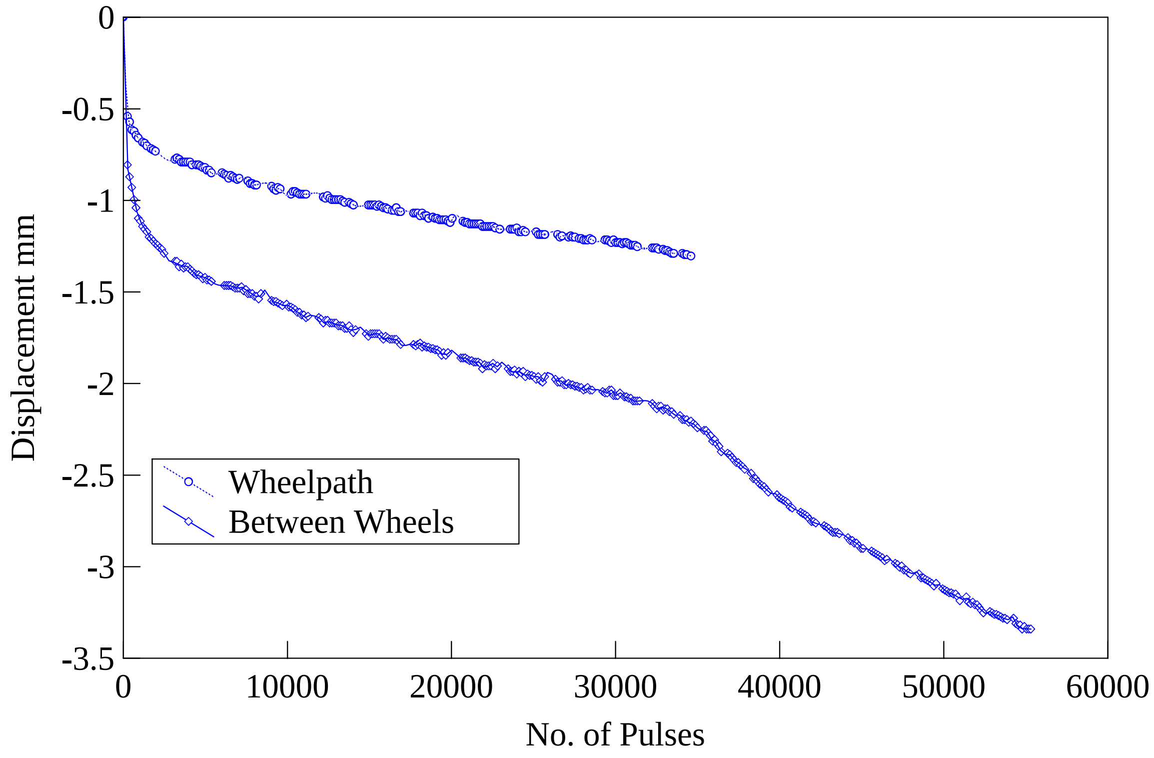

**Figure C1 State Highway 2 Route Position 294/6.2**

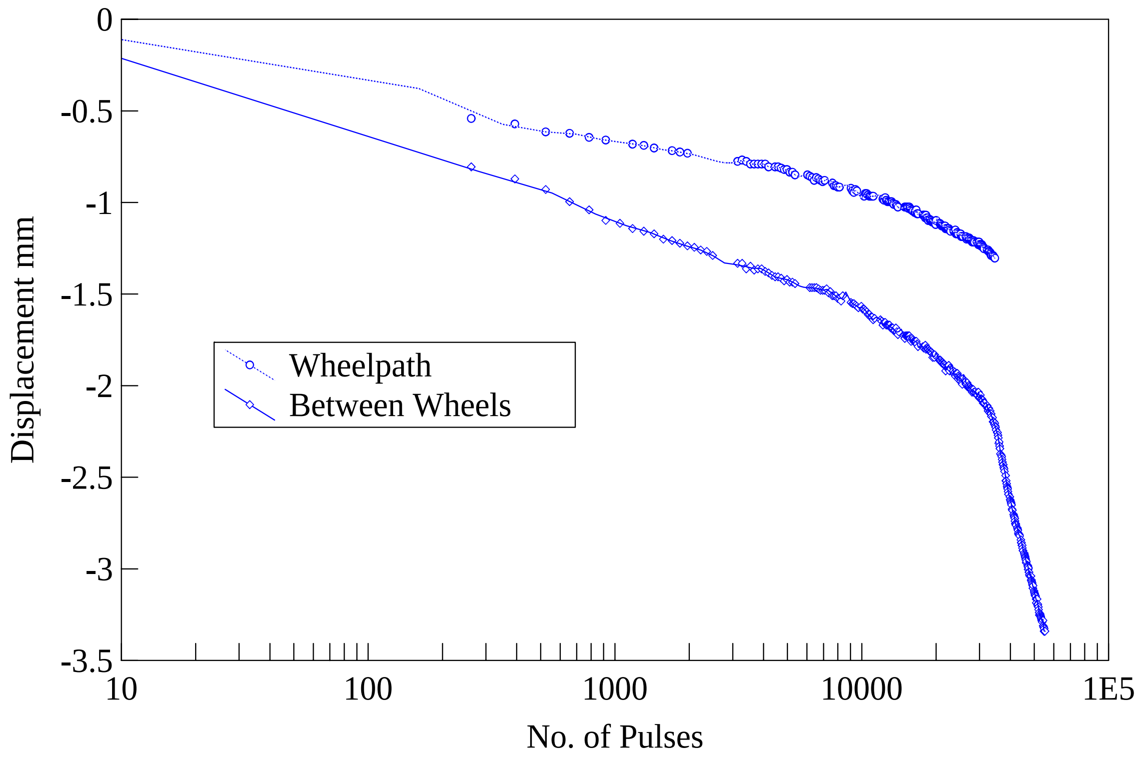

**Figure C2 State Highway 2 Route Position 294/6.2 Logarithmic Plot**

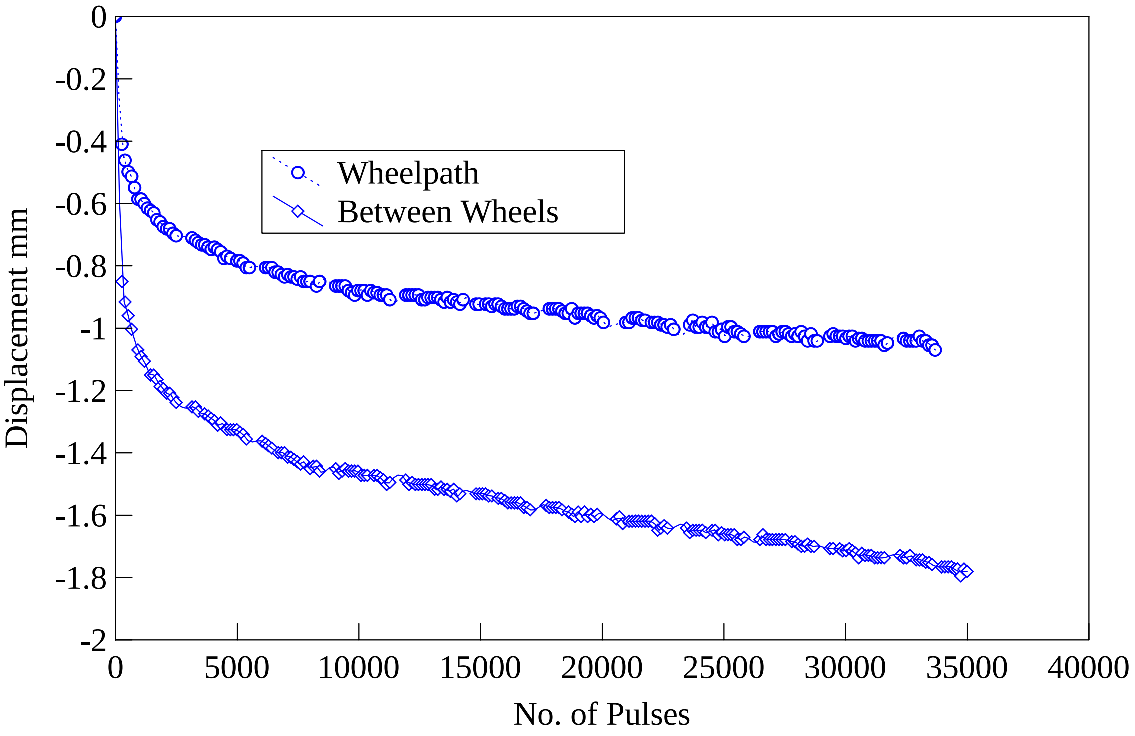

**Figure C3  State Highway 2 Route Position 304/4.0**

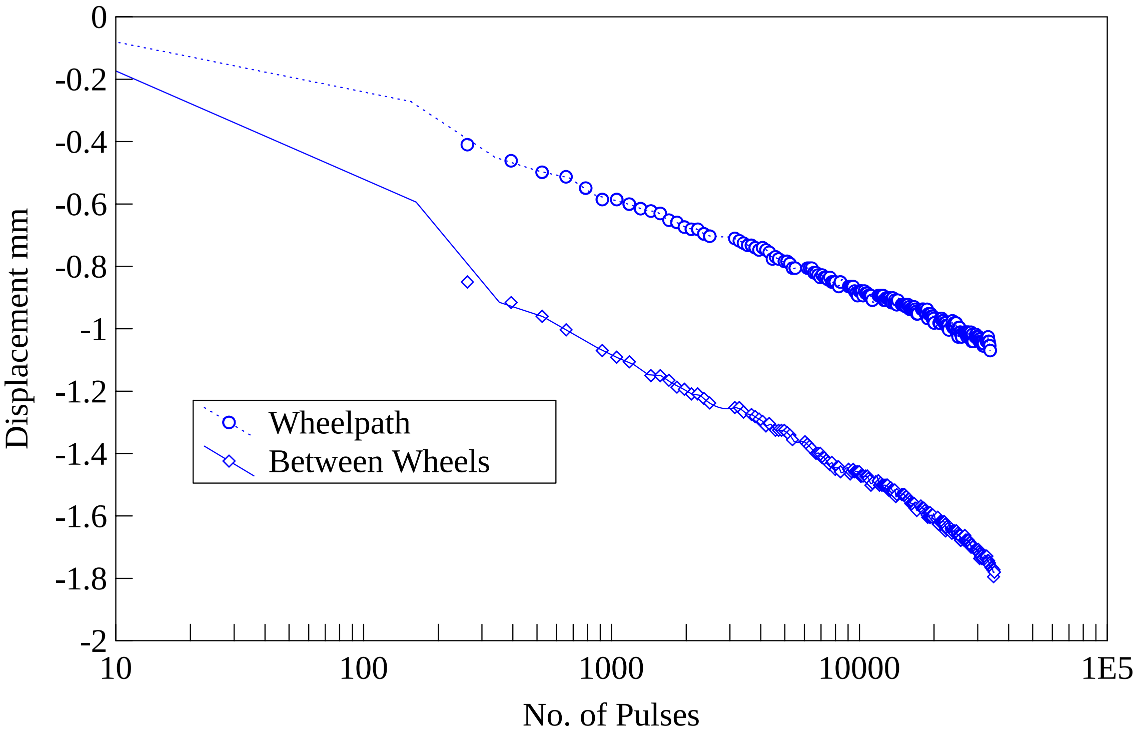

**Figure C4  State Highway 2 Route Position 304/4.0 Logarithmic Plot**

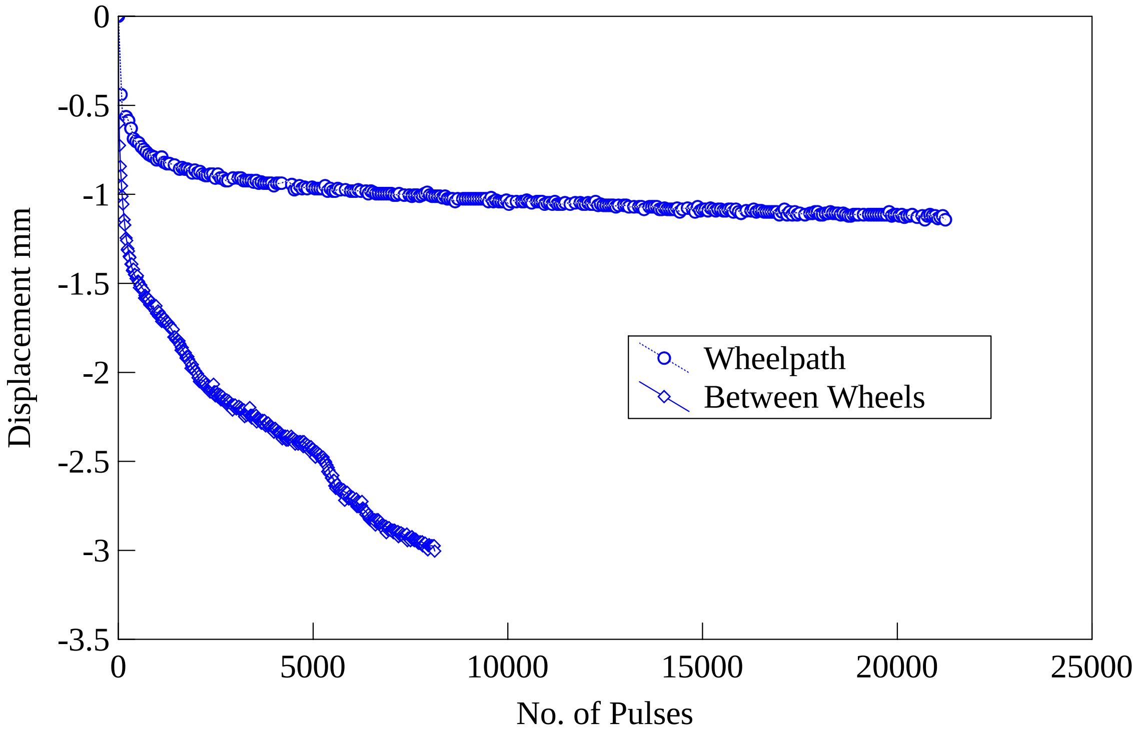

**Figure C5** **State Highway 2 Route Position 304/5.25**

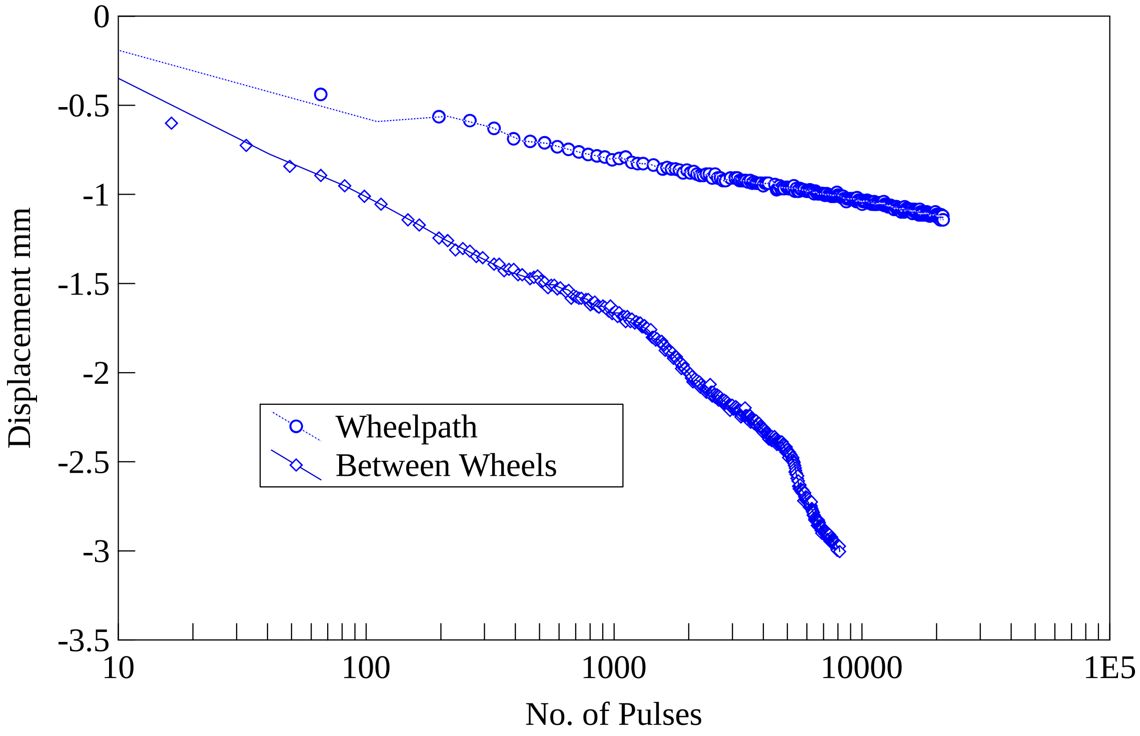

**Figure C6** **State Highway 2 Route Position 304/5.25 Logarithmic Plot**

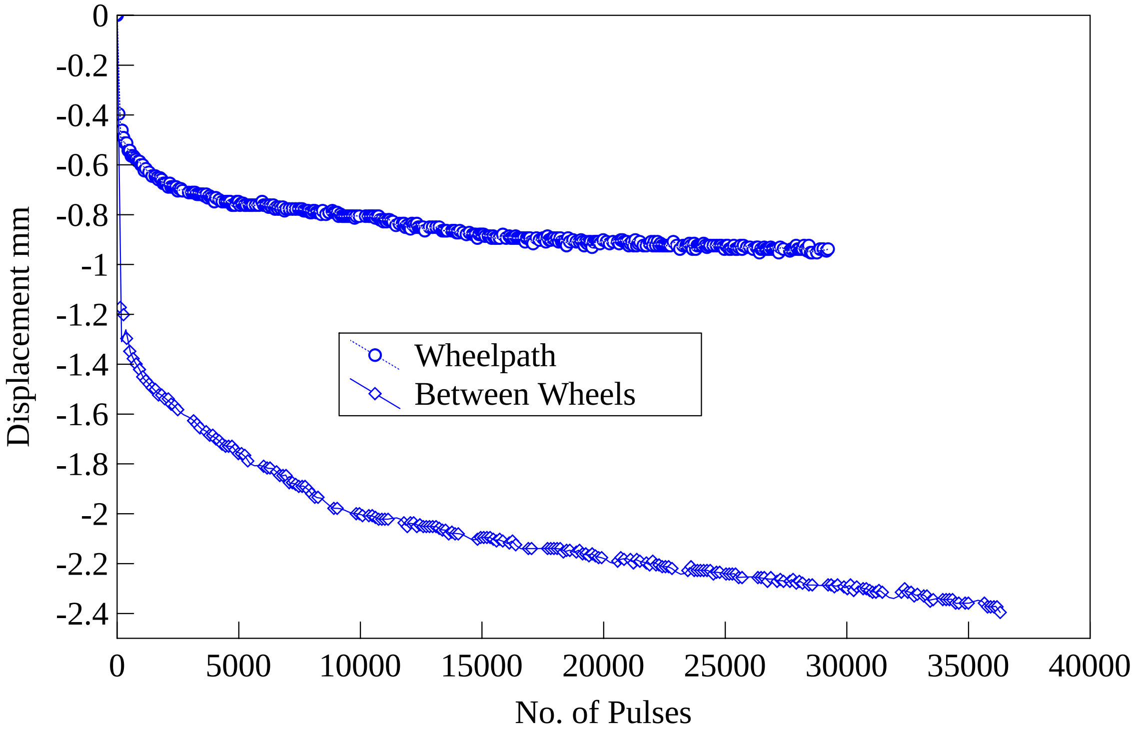

**Figure C7 State Highway 2 Route Position 592/12.15 (Kaihiwi II)**

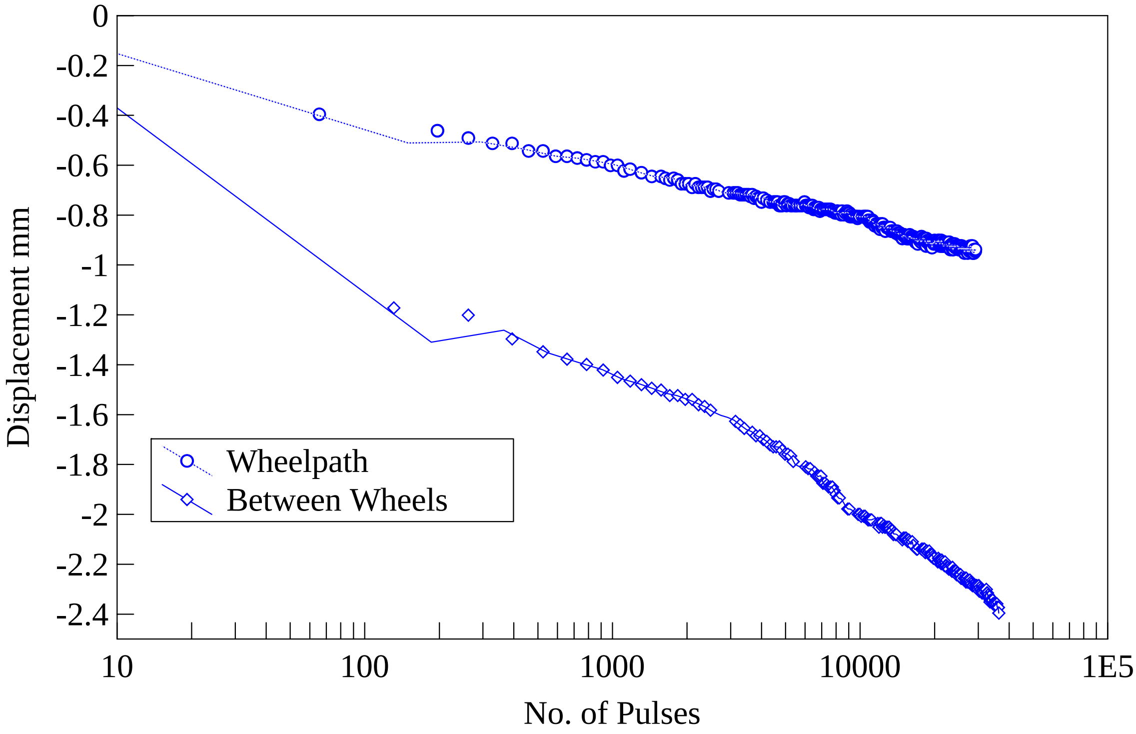

**Figure C8 State Highway 2 Route Position 592/12.15 (Kaihiwi II) Logarithmic Plot**

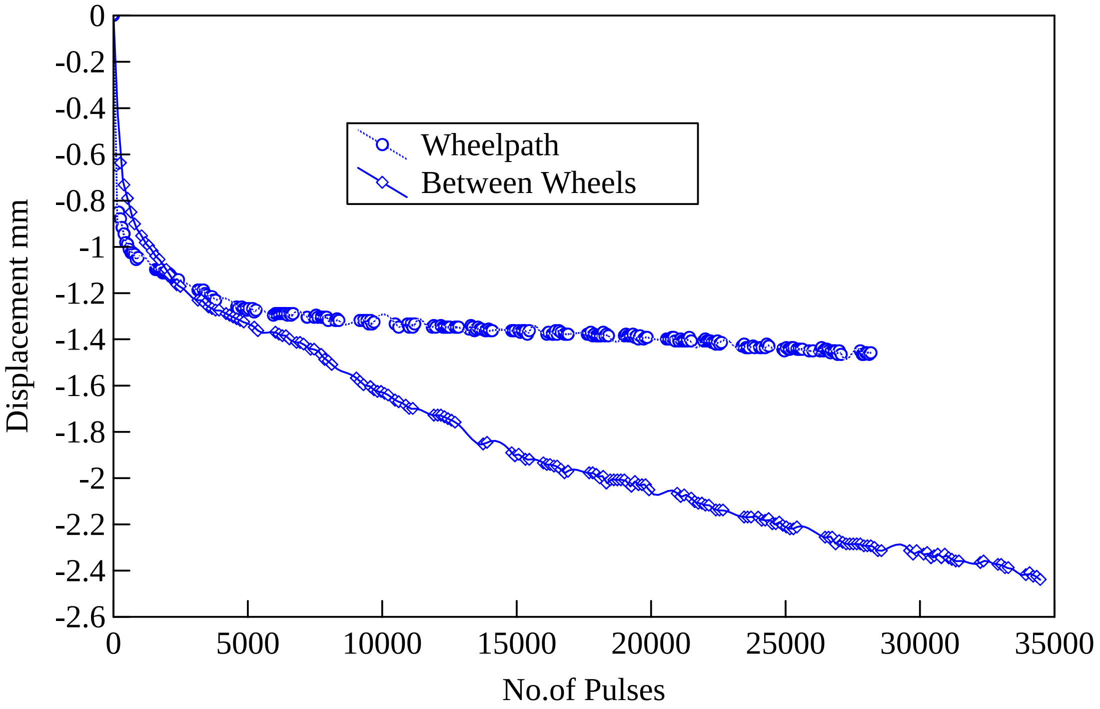

**Figure C9 State Highway 2 Route Position 691/0.407 (Burma Road)**

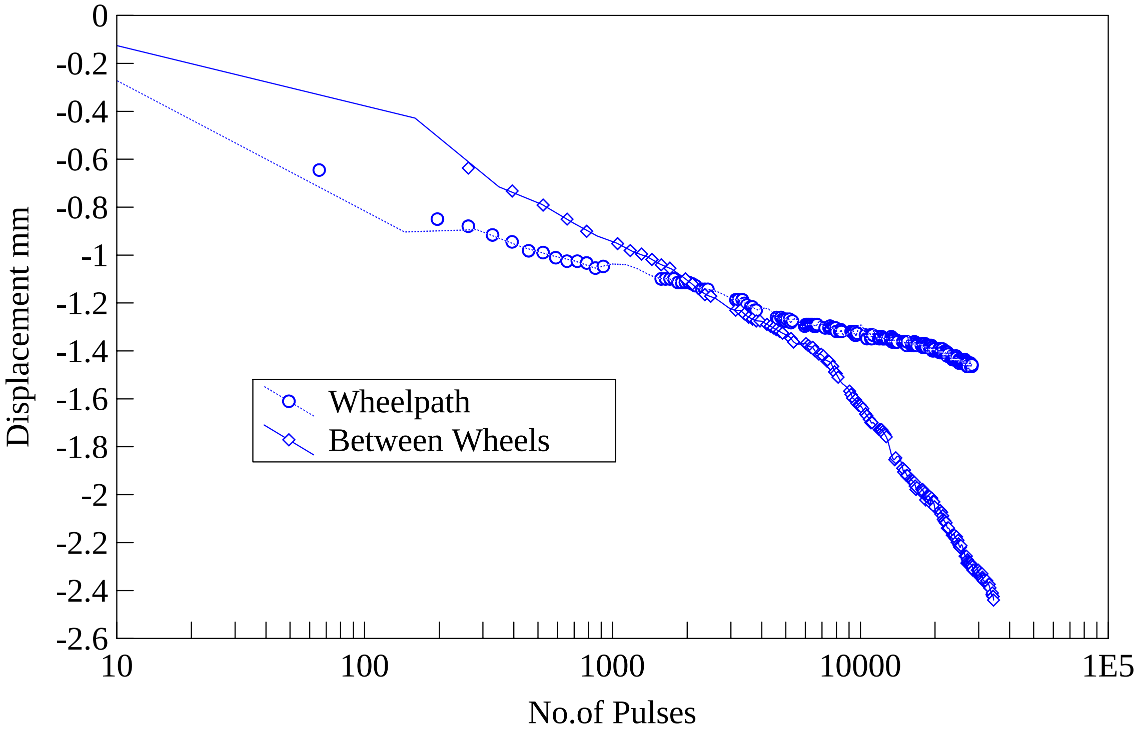

**Figure C10 State Highway 2 Route Position 691/0.407 (Burma Road) Logarithmic Plot**

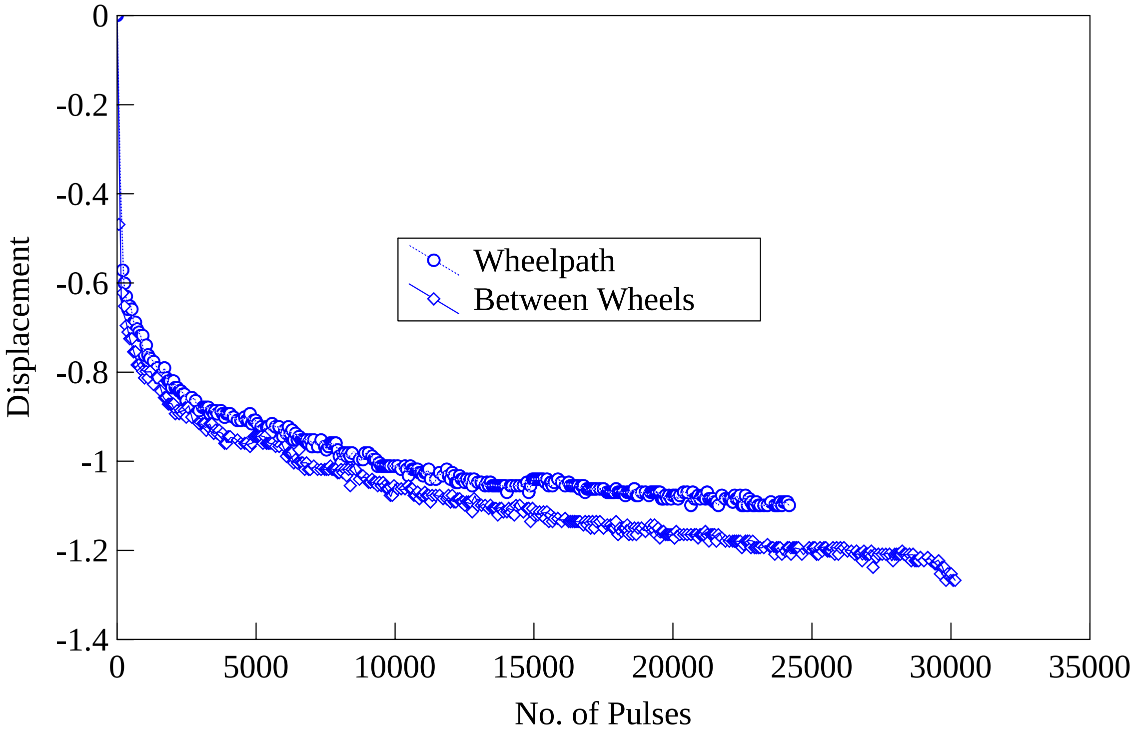

**Figure C11 State Highway 1S Route Position 416/11.00**

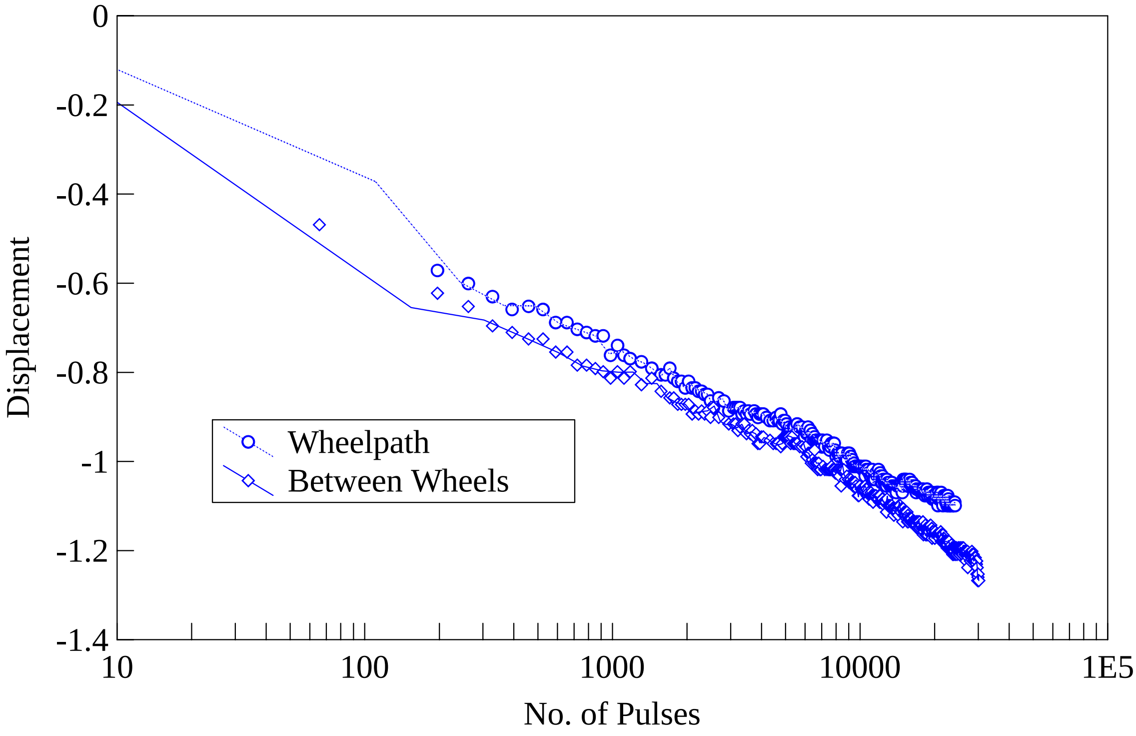

**Figure C12 State Highway 1S Route Position 416/11.00 Logarithmic Plot**

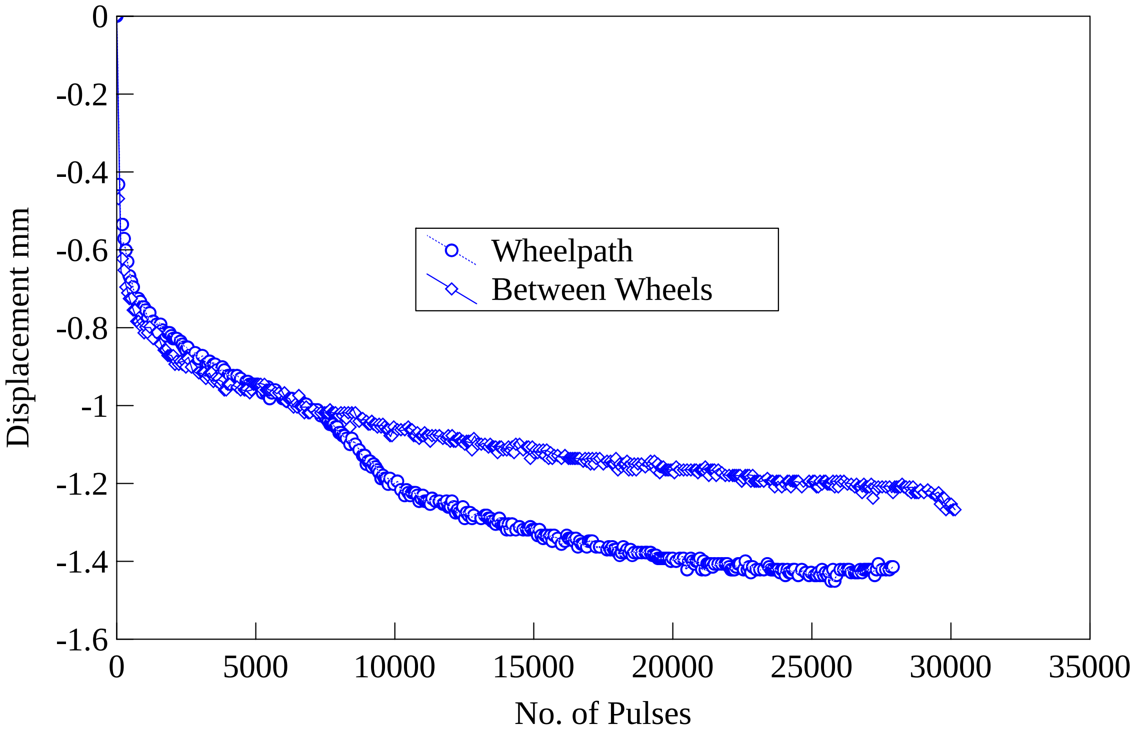

**Figure C13 State Highway 1S Route Position 447/7.30**

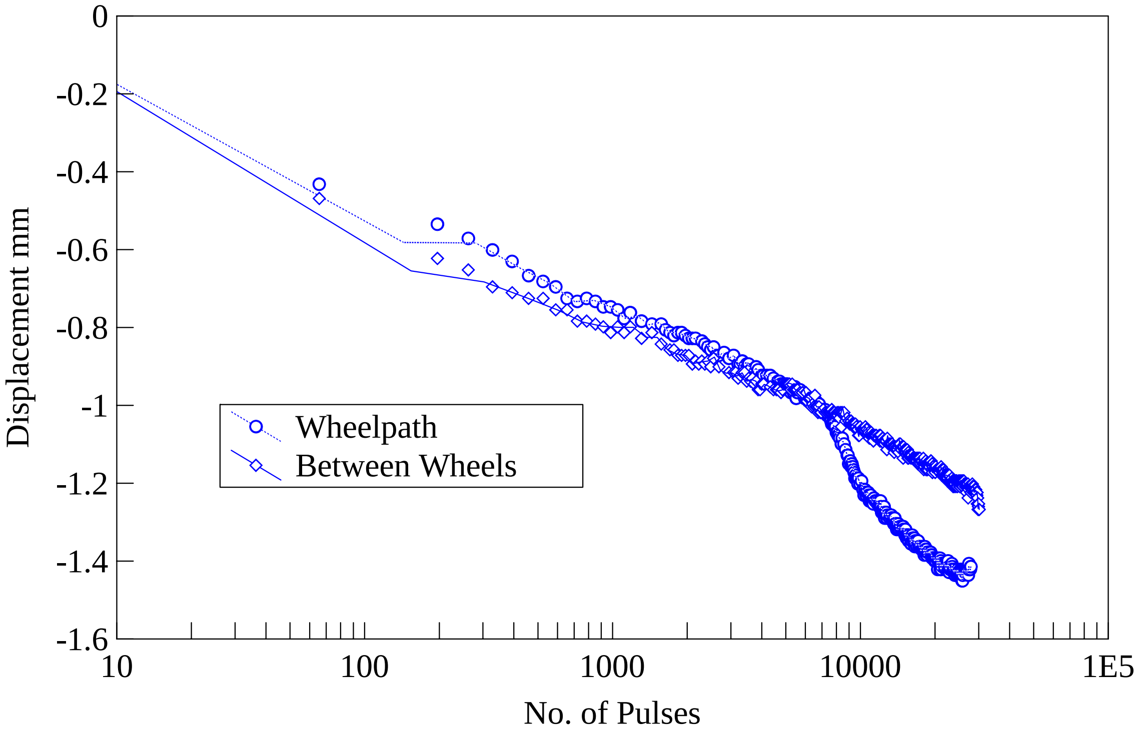

**Figure C14 State Highway 1S Route Position 447/7.30 Logarithmic Plot**

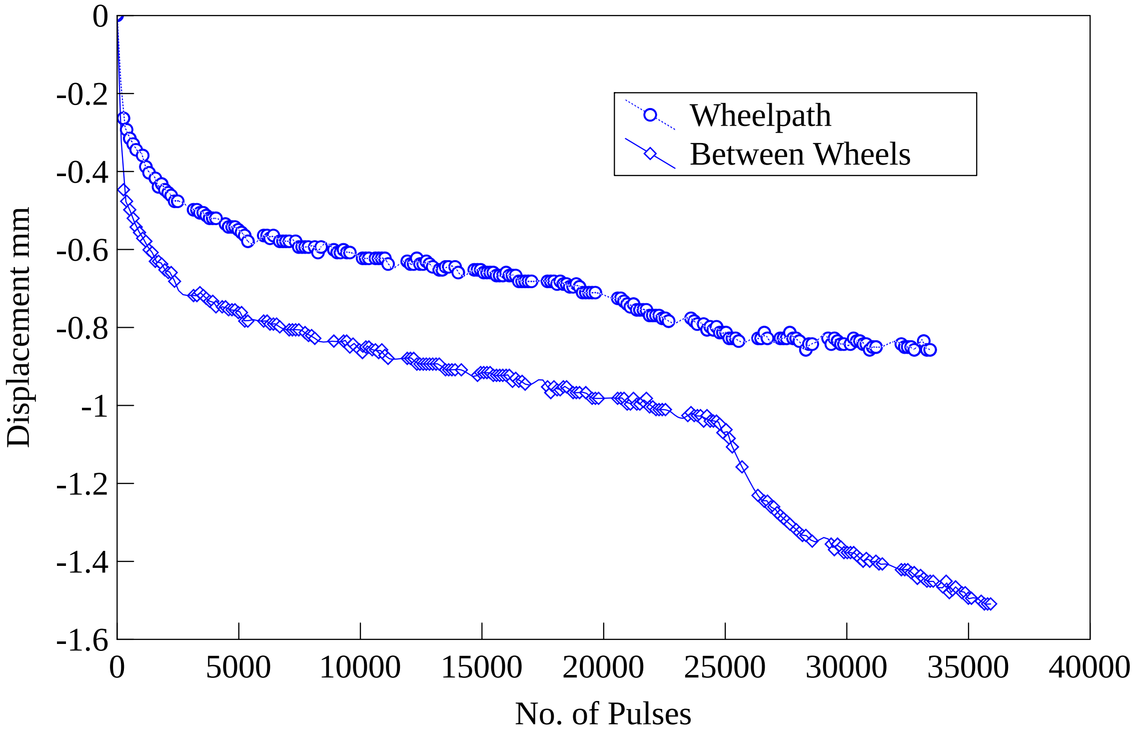

**Figure C15 State Highway 1S Route Position 447/11.77**

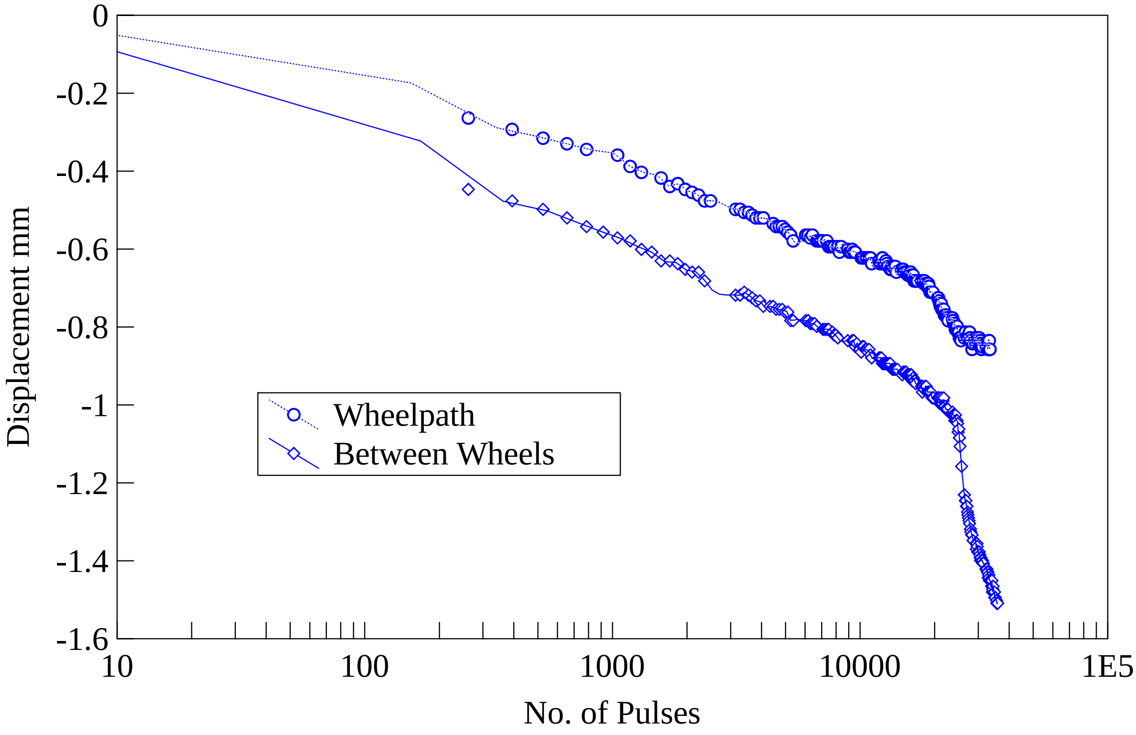

**Figure C16 State Highway 1S Route Position 447/11.77 Logarithmic Plot**

# Appendix D Ball Penetrometer Test

The penetrometer test has not been standardised for New Zealand. In order to ensure uniformity of practice at the various test sites a method was drafted as follows. It was based on the original South African test, with modifications to allow the use of the available penetrometer which was a redesign of the South African instrument.

## D1 Scope

The ball penetration test assesses the penetration resistance of a road surface by measuring the amount a standard steel ball penetrates the surface under a standard single impact from a Marshall hammer. The test is designed to provide an indication of the expected embedment by traffic of the surface stone into the underlying surface.

## D2 Apparatus

- Hand operated Marshall hammer.
- Frame to hold Marshall hammer. This frame should be able to stand freely on the road surface, enable the centring of the hammer on the part of the road surface to be tested, have a means of levelling the frame and a levelling gauge to ensure that the hammer falls vertically.
- 19 mm hardened spherical steel ball or equivalent surface impactor.
- Equipment to measure the degree the impactor travels into the surface under the Marshall hammer blow. The equipment shall be able to resolve the position of the impactor to within 0.01 mm.
- Means of measuring road surface temperature to within 1°C.
- Soft brush or hand broom.

An alternative surface impactor may be used to transfer the Marshall hammer energy into the road surface, provided the section in contact with the road is of hardened steel and has a 19 mm diameter spherical surface. An example would be a flat plate (contacting the hammer face) with an underlying hemispherical section in contact with the road surface.

## D3 Procedure

- Remove any detritus from the road area to be tested.
- Place the Marshall hammer in the frame over the test site, with the surface impactor on the road surface. Level the frame so the hammer will fall vertically.
- Take a measurement to establish the initial position of the surface impactor within 0.01 mm.
- Apply one blow from the Marshall hammer to the surface impactor.
- Take a measurement to establish the final position of the surface impactor within 0.01 mm.
- Measure the surface temperature, *T* (°C), at the time the test is carried out.

# D4 Calculations

- Determine the depth of penetration, $P_T$ in mm, as the difference between the initial and final measurements of the position of the surface impactor.
- Convert to a normalised penetration, $P_0$, at a standard temperature $T_0$, using the following formula:

$$P_0 = P_T - K(T - T_0)$$

where K varies according to the type of surface as follows.

| Surface Type | K (mm/°C) |
|---|---|
| Single and multiple unflushed chipseals | 0.04 |
| Slurry seals (unflushed) | 0.05 |
| Cape seals (unflushed) | 0.07 |
| Asphaltic concretes and flushed surfaces | 0.08 |

This relationship is valid for all road surfaces and temperatures, $T$, lying between 25°C and 55°C.

# D5 Reporting

Report
Date and time of testing
Site Location
Surface Type
$P_T$, T, $T_0$ and $P_0$.

# D6 Notes

- The road surface should be at least 25°C when penetration measurements are taken.
- Use a value of 40°C for $T_0$ unless a compelling reason exists to choose otherwise.
- For assessment of a road site the full test procedure should be carried out on at least ten positions on the site, and the mean and standard deviation of $P_0$ reported.

**Figure D1 Measuring position of surface impactor with micrometer.**

**Figure D2 Hammer raised for impacting. Micrometer has been wound back to prevent damage.**