Effect on Pavement Wear of Increased Mass Limits for Heavy Vehicles – Stage 4

G. Arnold, B. Steven, D. Alabaster & A. Fussell

Land Transport New Zealand Research Report 280

ISBN 0-478-25391-5
ISSN 1177-0600

PO Box 2840, Waterloo Quay, Wellington, New Zealand
Telephone 64 4 931 8700; Facsimile 64 4 931 8701
Email: *research@landtransport.govt.nz*
Website: *www.landtransport.govt.nz*

Arnold, G.[1], Steven, B.[2], Alabaster, D.[3], Fussell, A.[3] 2005. Effect on pavement wear of increased mass limits for heavy vehicles – Stage 4. *Land Transport New Zealand Research Report 280.* 30 pp.

[1] Formerly PaveSpec Ltd, 30 Balfour St, Mornington, Wellington, now Transit New Zealand, PO Box 5084, Lambton Quay, Wellington
[2] University of Canterbury, Private Bag 4800, Christchurch, New Zealand
[3] Transit New Zealand, PO Box 1479, Christchurch

Keywords: accelerated pavement testing, CAPTIF, heavy vehicles, loads, loading, mass limits, New Zealand, pavement, pavement loading, pavement performance, pavement wear, roads, road user charges, surface texture, thin-surfaced pavements, traffic, vehicles

An important note for the reader

This report is the final stage of a project commissioned by Transfund New Zealand before 2004, and is published by Land Transport New Zealand.

Land Transport New Zealand is a Crown entity established under the Land Transport New Zealand Amendment Act 2004. The objective of Land Transport New Zealand is to allocate resources in a way that contributes to an integrated, safe, responsive and sustainable land transport system. Each year, Land Transport New Zealand invests a portion of its funds on research that contributes to this objective.

While this report is believed to be correct at the time of its preparation, Land Transport New Zealand, and its employees and agents involved in its preparation and publication, cannot accept any liability for its contents or for any consequences arising from its use. People using the contents of the document, whether directly or indirectly, should apply and rely on their own skill and judgement. They should not rely on its contents in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice in relation to their own circumstances, and to the use of this report.

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

Contents

List of figures

List of tables

Executive summary

Introduction

Accelerated pavement testing at CAPTIF (Canterbury Accelerated Pavement Testing Indoor Facility, Christchurch, New Zealand) was conducted between 2000 and 2004 on a standard two-coat chipseal that is typically used on New Zealand roads. This report is of Stage 4 of a 4-year accelerated pavement testing programme to assess the effects on pavement and surfacing life, should an increase in mass limits for heavy vehicles be allowed. In this test on a chipseal surface, two single-tyred loads trafficked different circumferential paths of the CAPTIF track. One of the wheels was loaded to 20 kN to simulate the current legal single-axle dual-tyred load limit of 8 tonnes, and the other was loaded to 30 kN which is equivalent to a 12-tonne axle load. During testing the mean profile depth (MPD), which is the international standard for surface texture measurement, was measured with a laser profiler at regular intervals.

Increases in mass limits are likely to have a significant impact on the life of New Zealand chipseal surfaces. In Europe and North America higher mass limits are allowed and are one of the reasons why chipseal surfacings are rarely used there. On private forestry roads in the central North Island of New Zealand, where the axle loads are in excess of 12 tonnes, chipseal surfaces have shown a high incidence of flushing and reduced seal life. Research in South Africa using a Heavy Vehicle Simulator (HVS) has shown that an increase in tyre contact pressure from 520 kPa to 720 kPa results in a 6-fold increase in the rate of flushing.

Conclusions

Conclusions found for this accelerated pavement test on a chipseal surfacing are summarised as follows:

- Texture depth has a great deal of variability and the averages of a large number of readings are needed to get stable results. Thus trends in texture depth loss could not be obtained by plotting texture depth against loading cycles at individual measurement stations. The averages had to be taken around a complete circuit of the track.
- The 'Patrick model' for texture loss under loading, which is used for performance prediction in New Zealand, match the measured data well although with coefficients that differ significantly from those given by the originators of the model.
- Assuming one pass of the 8-tonne axle is equal to 10 passes of light vehicles, as used in current chipseal design and performance modelling, then one pass of a 12-tonne axle is equal to 23 passes. However this figure cannot be used directly as not all heavy commercial vehicles will be affected by this particular increase in mass limits.
- The relative surface texture change between the 8-tonne and 12-tonne axle loads can also be considered as a damage law exponent of 2.0.

- A modification of the form of model used by researchers in Australia to model the rutting of a chipseal surface was fitted to the texture data and resulted in a reasonable fit. The best-fit exponent of the power law for the effect of mass was 2.8. Although this model explicitly accounts for the effect of mass with a power law relationship, it does not fit with the current method of chipseal design and therefore the results were not considered at this stage in recommendations for chipseal design.
- When calculating chipseal design traffic loading in terms of number of light vehicles, the suggestion is that 1 HCV (Heavy Commercial Vehicle) is replaced by 1 ESA (Equivalent Standard Axle), and that this equivalent is made equal to 10 light vehicle passes. This allows for the consideration that only part of the HCV fleet will be affected by any increases in mass limits, and is based on the current assumption in design that 1 HCV equates to 1 ESA.
- To calculate the number of ESAs for chipseal design for roads on which axle loads are higher than the current legal load, then a damage law exponent of 2.0 is recommended.

Should an increase in mass limits be allowed, and as 1 HCV equates to 1 ESA which is equal to 10 light vehicles, then the design number of light vehicles would increase. This in turn would result in reduced chipseal binder application rates being required which would help prevent premature flushing. However it would also increase the risk of a stripping failure.

Abstract

The relative change in chipseal surface texture depth between 8- and 12-tonne single-axle dual-tyred load limits was assessed using accelerated pavement testing at CAPTIF (Canterbury Accelerated Pavement Testing Indoor Facility, Christchurch, New Zealand) in a 4-year research programme carried out between 2000 and 2004. Results showed the 'Patrick model', which is used in the current method of chipseal design, could be applied to the measured data. The relative difference in chipseal life between 8- and 12-tonne loads should be calculated using a damage law exponent of 2.0.

1. Introduction

1.1 Background

The study reported here is the final stage of a 4-year research programme (carried out over the years 2000-2004, as part of the Transfund New Zealand research programme) using accelerated pavement testing on typical New Zealand pavement designs. It has investigated the relative effect on pavement and chipseal surface life of an increase in axle load from the current legal limit of 8.2 tonnes. This report is one of a series of Transfund New Zealand and Land Transport New Zealand Research Reports in which the effect on pavement life in terms of vertical surface deformation (rutting) for increases in axle loads to 10 and 12 tonnes is reported. The other reports recording the research carried out for this 4-year study so far are as follows:

- *Transfund New Zealand Research Report No. 214*, by Arnold et al., 2001: Prediction of pavement performance from repeat load tri-axial tests on granular materials, and preliminary background research.
- *Transfund New Zealand Research Report No. 207*, by de Pont et al., 2001: Effect on pavement wear of an increase in mass limits for heavy vehicles [Stage 1].
- *Transfund New Zealand Research Report No. 231*, by de Pont et al., 2002: Effect on pavement wear of an increase in mass limits for heavy vehicles – Stage 2.
- *Land Transport New Zealand Research Report 279*, by Arnold et al., 2005a: Effect on pavement wear of increased mass limits for heavy vehicles – Stage 3.

Increases in mass limits are likely to have a significant impact on the life of New Zealand chipseal surfaces. In Europe and North America higher mass limits are allowed and are one of the reasons why chipseal surfacings are rarely used there. On private forestry roads in the central North Island of New Zealand, where the axle loads are in excess of 12 tonnes, chipseal surfaces have shown a high incidence of flushing and reduced seal life (Arnold & Pidwerbesky 1994).

Research in South Africa using the CSIR Heavy Vehicle Simulator (HVS) has shown that an increase in tyre contact pressure from 520 kPa to 720 kPa results in a 6-fold increase in the rate of flushing (de Beer et al. 1997).

When calculating the design of chipseals, traffic loading is a key input and expressed in terms of number of light vehicles. The assumption is that one heavy vehicle is equivalent to ten light vehicles and is based on the current New Zealand range of vehicles on the road, for which the legal axle load limit is 8.2 tonnes. Any increases in this legal load are likely to change this relationship.

In New Zealand pavement maintenance and rehabilitation is driven primarily by measures of functional condition and, thus, the mean texture depth (MPD) is used as an indicator of chipseal deterioration.

1.2 The Canterbury Accelerated Pavement Testing Indoor Facility (CAPTIF)

CAPTIF is located in Christchurch, New Zealand. It consists of a circular track, 58 m long (on the centreline) contained within a 1.5 m deep x 4 m wide concrete tank so that the moisture content of the pavement materials can be controlled and the boundary conditions are known. A centre platform carries the machinery and electronics needed to drive the system. Mounted on this platform is a sliding frame that can move horizontally by 1 m. This radial movement enables the wheelpaths to be varied laterally and can be used to have the two 'vehicles' operating in independent wheelpaths. An elevation view is shown in Figure 1.1.

At the ends of this frame, two radial arms connect to the Simulated Loading and Vehicle Emulator (SLAVE) units shown in Figure 1.2. These arms are hinged in the vertical plane so that the SLAVEs can be removed from the track during pavement construction, profile measurement, etc., and in the horizontal plane to allow for vehicle bounce.

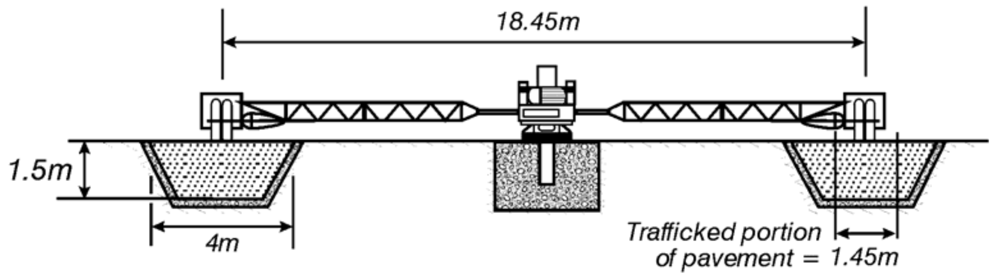

Figure 1.1 Elevation view of CAPTIF.

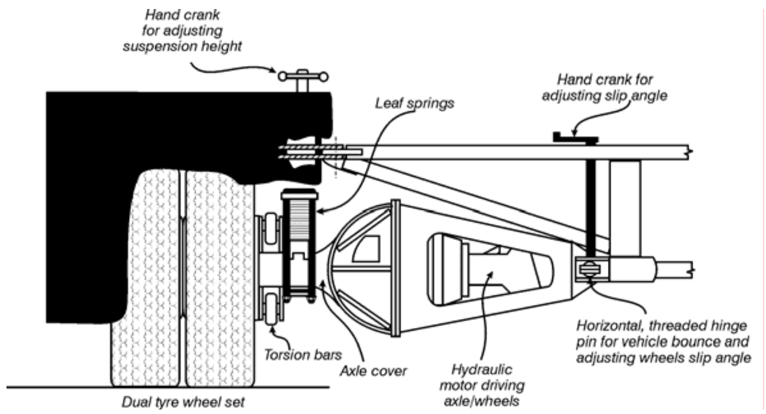

Figure 1.2 The CAPTIF SLAVE unit.

CAPTIF is unique among accelerated pavement test facilities in that it was specifically designed to generate realistic dynamic wheel forces. A more detailed description of CAPTIF is detailed in other Transfund NZ Research Reports on mass limits and by Pidwerbesky (1995).

1.3 The Test Programme

This report follows from the 2002/2003 Stage 3 research reported by Arnold et al. (2005a). The pavement constructed for this 2002/2003 test was utilised to construct the chipseal surface required for this project. The track was rehabilitated, resurfaced with a chipseal and tested using both the 12-tonne and 8.2-tonne simulations. The loads were in separate wheelpaths to provide a direct comparison of loss of surface texture.

2. Objectives

For this study on chipseal surfaces the specific objectives are:

- To determine the relative damaging effect on pavement wear and chipseal life compared to the standard load (8.2-tonne dual-tyred single-axle) for increases in vehicle loads and tyre pressures using accelerated testing, load response data, existing accelerated pavement test results, and for developing an appropriate pavement model.
- To determine appropriate Road User Charges (RUCs) for new increased heavy vehicle load limits that take into account their effect on both pavement and chipseal life.
- To provide a methodology and pavement model to predict the potential impact on the New Zealand road network in relation to chipseal surfaces caused by increases in heavy vehicle load limits.

These objectives and the overall objectives of this multi-stage project that assesses the impact of increases in mass limits on pavement and surfacing life is more fully addressed in the concluding report (Arnold et al. 2005b).

3. Method

3.1 Chipseal design

A chipseal surface was constructed successfully for the first time for the Stage 2 (2002) mass limits test at CAPTIF (de Pont et al. 2002). A robust two-coat seal with a locking coat was used to withstand the high turning stresses expected at CAPTIF. Cutters were needed to ensure the binder adhered adequately as construction was late in the sealing season. This seal performed well although to minimise bleeding water had to be sprayed continuously on the track.

In an attempt to minimise the tyre pick-up of bitumen and bleeding observed in the first chipseal trial, the decision was made to use a racked-in Grade 3/5 seal. The design chosen was:

- Basecourse surface to be lightly prime sealed (approx. 0.2 ℓ/m^2) with a 50/50 blend of 80/100 bitumen and a turpentine cutter.
- A racked-in Grade 3/5 two-coat seal using 80/100 bitumen, with adhesion agent and a minimum of cutters.
- On completion of the construction rolling, the surface was conditioned by SLAVE with a single-tyre single axle, minimum loading, and a uniform loading pattern at low speed.
- Final pavement loading was with a single-tyre single axle, with wander in the wheelpath. The rate of loading was monitored to ensure that unnecessary damage to the seal was not done during the early load cycles.

This racked-in seal stripped within the first 1000 wheel passes so the test was abandoned and a new chipseal surface was constructed that was similar to the two-coat seal constructed in the Stage 2 project (de Pont et al. 2002). It was accepted that frequent tyre cleaning and changes would be needed, and that a bleeding failure would be likely when the texture approached 1.1 mm MPD.

3.2 Chipseal construction

As discussed in Section 3.1, two attempts at constructing a chipseal were made. This section describes construction of the second chipseal design as this lasted a sufficient number of passes to form comparisons of surface texture changes between the two wheel loads.

Before construction of the first chipseal which subsequently failed, the asphalt surfacing of the original pavement was removed and the post-mortem trenches were backfilled and compacted. The failed first chipseal was removed and the surface ripped and levelled. A 50-mm overlay of AP20 M/4 was added to the pavement. A tractor with a laser-controlled blade cut the surface back to the target level and a 3-tonne steel/rubber combination roller was used for compaction. The surface was left to dry and was primed when the moisture content readings showed that the degree of saturation of the basecourse was below 60%.

The first coat seal consisted of 1.4 ℓ/m^2 of a 180/200 grade bitumen with a Grade 4 chip. After spreading the chips a Sakai combo roller followed by a larger Dynapac combo roller was used. However, initially the chips were not sticking to the binder and the rolling was stopped. Diesel and heaters were used to soften the bitumen and rolling recommenced.

The second coat two-coat seal used Grade 3 chip followed by more binder and a Grade 5 chip was applied. The surface was swept and vacuumed with a suction truck.

The final construction reflects that the seal was applied late in the sealing season:

- Prime Coat 50/50 Bitumen/Turpentine cutback, hand sprayed at approx. 0.3 ℓ/m^2 to leave approx. 0.15 ℓ//m^2 residual binder;
- First Coat Seal (Single Coat Seal), 180/200 pen grade, 3pph Kerosene, 0.7pph Adhesion Agent, Grade 4 SC12 chip ALD 7.08 mm, Application Rate 1.40 ℓ//m^2 hot;
- Second Coat Seal (Two Coat Seal), 180/200 pen grade, 1pph AGO, 6pph Kerosene, 0.7pph Adhesion Agent, Grade 3 SC16 chip ALD 9.2 mm, Grade 5 SC10 chip ALD 4.96 mm, Application Rates 1.0 ℓ//m^2 first spray, 0.8 ℓ/m^2 second spray (both hot application rates).

3.3 Pavement testing

Two single-tyred SLAVE units were run in offset wheelpaths. The inside wheelpath has a single wheel load of 20 kN (to simulate the 8.2-tonne dual-tyred axle) while the outside wheel had a load of 30 kN (to simulate the 12-tonne dual-tyred axle). A conditioning 5,000 loads were applied at a single wheel load of 20 kN over the whole pavement. A Stationary Laser Profilometer was used to measure the surface texture. Temperature sensors were placed on the chipseal surface and in the air at each of the three measurement stations.

At 37,000 wheel passes the heavier outer wheelpath was bleeding to such an extent the test was terminated. In order to continue testing on the lighter inner wheelpath, the tyre in the outer wheelpath was shifted across to the other dual tyre position. In addition the load was reduced to 20 kN. It was decided not to apply water to the new wheelpath being trafficked. Surface texture measurements were also taken for this new wheelpath.

To minimise bleeding and bitumen sticking to the tyres, a sprinkler system mounted to the rear of the vehicles was used (as had been developed in the previous chipseal surface test by de Pont et al. in 2002). Water was applied continuously although towards the end of the project bleeding still occurred. During the project the tyres had to be cleaned 3 times and replaced 3 times because of a thin build-up of bitumen on the tyres.

3.4 Surface texture measurements

The traditional method for measuring surface texture is the volumetric patch technique using sand or glass spheres (the Sand Circle test). This technique, although very simple, is quite labour intensive and time consuming. There is also a degree of technician-dependent variation in the results. As an alternative the International Standards Organisation (ISO 1997) has developed an alternative procedure using the surface profile which gives comparable results. This enables laser and other profilometers to be used for the measurements, with mathematical processing of the results to obtain texture depth measurements. By specifying the performance requirements of the profilometer and the measurement procedure in detail, this approach ensures standards of accuracy and repeatability. The profilometer measurement process can be automated and undertaken at relatively high speeds so that texture measurements can be done quite rapidly and at frequent intervals along the pavement.

With the ISO method the profile is measured along a baseline which is 100 mm ±10 mm long. The baseline is divided in half and the peak level of the profile in each half is determined. These two values are then averaged to give the profile peak, and the Mean Profile Depth (MPD) is defined as the profile peak minus the average profile level. From the MPD a parameter known as the Estimated Texture Depth (ETD) can be calculated using Equation 3.1:

$$ETD = 0.2 + 0.8 \cdot MPD \qquad \text{Equation 3.1}$$

ETD is an estimate of the Mean Texture Depth (MTD) which is the measure generated by the volumetric method. It is calculated by dividing the volume of sand used by the area of the circle created. Details of the specific measurement and processing requirements for determining MPD are given in the ISO standard (ISO 1997).

The laser profilometer at CAPTIF was used to determine MPD in each of the two wheelpaths around the track. Readings were averaged over a length of 1600 mm centred at every second measurement station. At the start of the test, 1,000 load cycles were applied between measurements but this was gradually increased as the test proceeded so that, by the end of the test, 25,000 load cycles were being applied between measurements.

4. Results and analysis

4.1 Introduction

The main concern of this study is pavement wear as represented by a loss of functional condition in terms of surface texture. Loss of surface texture will reduce the skid resistance and increase the risk of aquaplaning in wet conditions.

4.2 Surface texture changes

Plotting the progression of MPD (Mean Profile Depth, Section 3.4) against load cycles for each station showed a high degree of variation and clear trends were difficult to see. However, averaging the MPD for the whole circuit in each wheelpath and plotting against load cycles did show a clear trend and clearly shows that the two wheelpaths are different as illustrated in Figure 4.1.

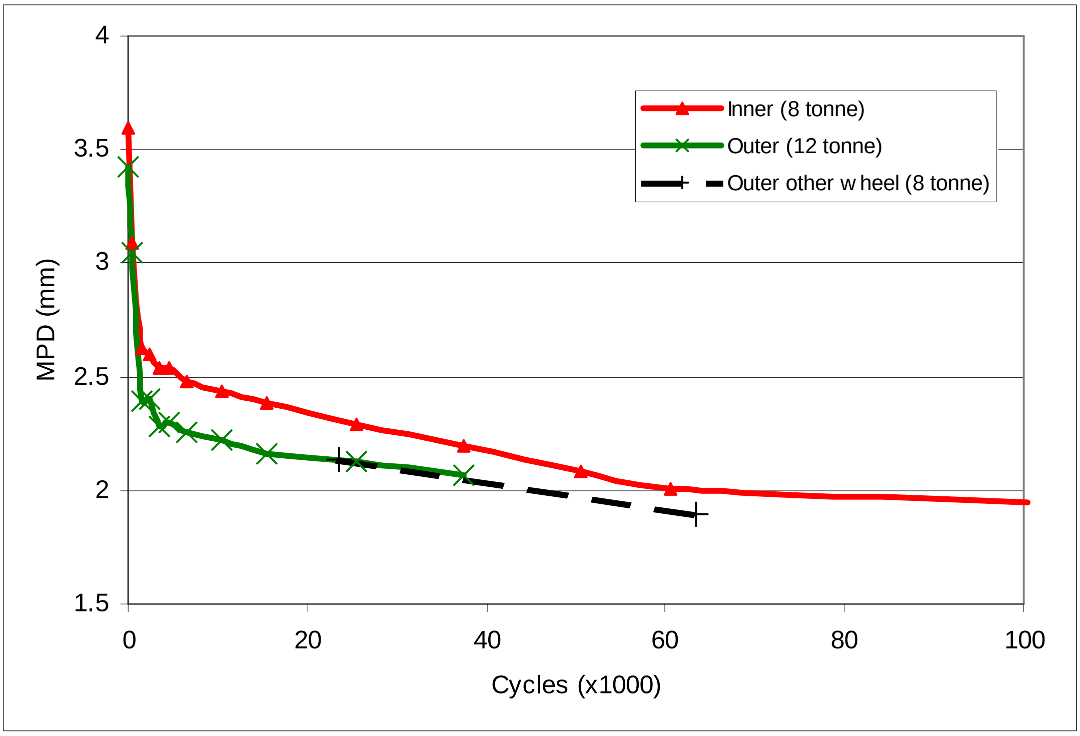

Figure 4.1 Average MPD for each wheelpath against applied load cycles.

There are some interesting features to note in Figure 4.1:

- The plot does not include the 5,000 conditioning laps that were applied after the chipseal was placed. These loads were applied by having both vehicles traversing the full trafficable width of the track evenly. Thus, both wheelpaths should have received the same applied loads. The initial average MPD immediately after the 5,000 conditioning laps at zero cycles shown in Figure 4.1 is nearly the same for the two wheelpaths.

- After the conditioning and when the two different wheel loads were applied, an immediate drop in surface texture occurred.
- The initial reduction in surface texture was greater for the heavier wheelpath as would be expected. However after 5,000 load cycles, the rate of change between the two wheel loads was similar and possibly greater for the lighter wheelpath.
- The test on the new wheelpath, which was started after the heavier 30 kN (i.e. 12-tonne load) had failed at 37,500 cycles, had the same rate of change in surface texture as the lighter 20 kN (i.e. 20-tonne load) wheelpath. Interestingly though the starting texture was low for a supposedly untrafficked wheelpath.

Transit New Zealand presents the following model for texture depth, which was developed by Patrick et al. (1998), based on the work by Houghton & Hallett (1987).

$$TD = k - ALD \cdot B \cdot \log T \qquad \text{Equation 4.1}$$

where:

TD	is the texture depth
k	is a constant which depends on ALD and the bitumen spray rate
ALD	is the average least dimension of the sealing chip
B	is a constant
T	is the total traffic to date in equivalent light vehicles where one heavy vehicle is equivalent to 10 light vehicles

Cenek (1999) derived the following incremental model for texture depth from the Patrick model. Equation 4.2

$$\Delta TD = k1 - TD - k1.k2.\log\left[10^{\left(\frac{1}{k2}-\frac{TD}{k1.k2}\right)} + \Delta NELV\right]$$

where
ΔTD is the change in texture depth
$\Delta NELV$ is the number of equivalent light vehicles over the time period
$k1$ is the initial texture depth after constructi on
$k2$ is the rate of change of texture depth with traffic

It is relatively straightforward to show that the two models are identical,

where $k_1 = k$ and $k_1 \cdot k_2 = ALD \cdot B$

This model is based on curve fitting to the measured data and does not represent a postulated wear mechanism. Both Patrick et al. (1998) and Cenek (1999) calculated estimates for the coefficient values based on observed data. Patrick obtains a value of $B = 0.07$. He does not present values for k because the model is used to look at changes in MTD and thus k can be eliminated from the equation. Cenek (1999) presents a table of values for k_1 and k_2, where k_1 depends on both the chip grade and the design traffic while k_2 depends only on the chip grade.

As the bitumen spray rate depends on the design traffic, the dependencies of k_1 in Cenek's model are the same as those of k in Patrick's model. For Grade 3 chip with ALD = 9.5 mm, the k_1 and k_2 values given by Cenek result in B values between 0.078 and 0.092 depending on the design traffic volume. For Grade 5 chip with ALD = 4.5 mm, the k_1 and

k_2 values given by Cenek result in *B* values between 0.091 and 0.107 depending on the design traffic volume. In all cases, a higher design traffic value implies a higher *B* coefficient, and in all cases, the *B* coefficient is greater than the value given by Patrick.

Although the Patrick–Cenek model represents a statistical fit to observed data rather than a mechanistic model, investigating the implications of the model is worthwhile before attempting to fit it to the current data. The Patrick form of the model is somewhat simpler and easier to work with, and basically the equation can be written as:

$$TD = c1 - c2 \,.\, \log T \qquad \text{Equation 4.3}$$

where:

c1 and *c2* are constants which depend on the pavement design.

Differentiating this equation gives:

$$\frac{dTD}{dT} = \frac{-c2}{2.302\ T} \qquad \text{Equation 4.4}$$

From these two equations, a number of properties of the model can be deduced. Because of the properties of the log function, the model does not behave well when *T* is less than one. The texture depth at construction (after passage of one equivalent light vehicle (elv)) is c_1 mm. Similarly the rate of change of texture depth with traffic at construction is $-c_2$ mm/elv. The rate of change of texture depth with traffic subsequently is inversely proportional to the total amount of traffic that has passed. Thus the rate of change reduces very quickly initially and asymptotes to zero.

Now consider how the model might be applied to the test data. The calculation of the traffic in elv assumes that each heavy vehicle is equal to ten light vehicles. However, it is not clear how many light vehicles a single pass of an 8-tonne or a 10-tonne axle is equal to. If each pass of an 8-tonne axle is assumed to be equal to α elv and each pass of a 10-tonne axle is equal to β elv, then if the ratio of β to α can be determined, we have determined the relative effect of mass on texture depth changes. Substituting in the simplified Patrick model above gives:

$$\begin{aligned} TD_{8t} &= c1 - c2 \,.\, \log \alpha N \\ &= c1 - c2 \,.\, \log \alpha - c2 \log N \end{aligned} \qquad \text{Equation 4.5}$$

Similarly

$$TD_{10t} = c1 - c2 \,.\, \log \beta - c2 \log N$$

where: N is the number of load cycles

The effect of the increase in mass is to change the initial texture after one pass of the axle by $c_2 \log \alpha$ for the 8-tonne axle and by $c_2 \log \beta$ for the 10-tonne axle. Otherwise there is no difference in the equations. As c_1 and c_2 are properties of the pavement only and should be identical in both wheelpaths, we can subtract one equation from the other to give:

$$TD_{10t} - TD_{8t} = c2 \,.\, \log\left(\frac{\alpha}{\beta}\right) \qquad \text{Equation 4.6}$$

This implies that the difference in texture depth between the wheelpaths will be constant as the number of load cycles changes. In the model the only effect of an increase in mass is a one-off reduction in texture depth. From then on the rate of change in texture depth is exactly the same as it was at the lower mass. Intuitively it seems unlikely that this would be the case in practice but this is what the model implies.

Substituting from Equation 3.1, Equations 4.5 and 4.6 can be re-written in terms of MPD as follows:

$$MPD_{8t} = 1.25.c1 - 0.25 - 1.25.c2 \log \alpha - 1.25.c2 \log N \qquad \text{Equation 4.7}$$

and

$$MPD_{12t} = 1.25.c1 - 0.25 - 1.25.c2. \log \beta - 1.25.c2 \log N$$

$$MPD_{12t} - MPD_{8t} = 1.25.c2 \log\left(\frac{\alpha}{\beta}\right) \qquad \text{Equation 4.8}$$

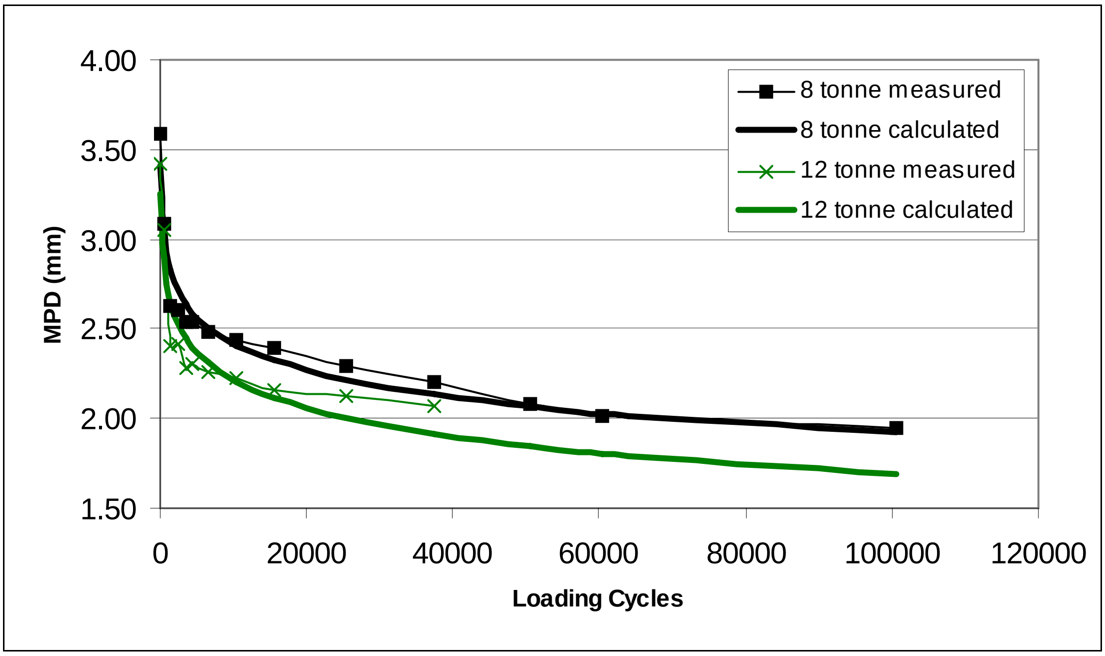

Figure 4.2 MPD v load cycles with Patrick-style model log function fit.

Applying log function fits of the modified form of the Patrick model, as shown in Equation 4.7, gives the graphs shown in Figure 4.2. The quality of the curve fit to the 8-tonne data was good with a R^2 of 0.95. However, for the 12-tonne data the fit was not quite as good with a R^2 of 0.88. Nevertheless the best-fit curves were nearly parallel as predicted by the model. The constants of Equation 4.8 for the best-fit curves are shown in Table 4.1. Consider now the difference in MPD for the two wheelpaths as shown in Figure 4.3.

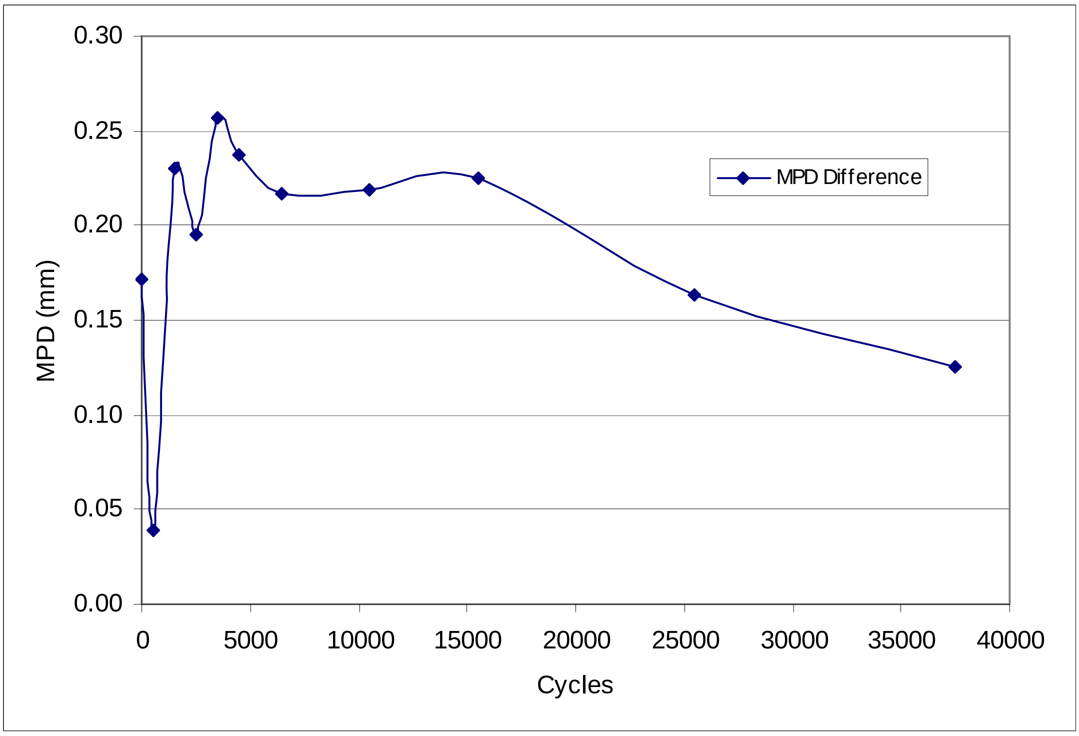

Figure 4.3 Difference in MPD for the two wheelpaths.

The model predicts that this curve should be a constant value (i.e. a horizontal straight line). Only the section of the curve between 1,000 load cycles and 16,000 load cycles fits this prediction well. Removing the two end data points from the calculation can be justified as clearly bleeding had occurred in the outer wheelpath under the heavier 12-tonne dual-tyred axle load. However this makes little difference to the analysis.

During the early stage of the testing the texture depth is changing very rapidly and the sample points are relatively closely spaced but they do not follow the model predictions well. This indicates that the model is not a good predictor of the performance of the pavement surface during this early stage of its life. Thus Equation 4.1 for the purpose of this study was considered to take the following form (Equation 4.9):

$$MPD = k_1 - k_2 \,.\, \log(N) \qquad \text{Equation 4.9}$$

where:

k_1 and k_2 are constants

N is number of wheel passes

The constants k_1 and k_2 in Equation 4.9 (the Patrick equation) were those that provided the best fit to each measured MPD curve, and the resulting calculated curves are plotted in Figure 4.2. Table 4.1 lists the constants determined for the two tests, and that the model fits the data well with R^2 values in excess of 0.81.

Table 4.1 Constants for the simplified Patrick model (all data) derived from regression analysis (from Equation 4.9).

Constants (Equation 4.9)	**k1**	**k2**	**R^2**
8 tonne *(in 8 v 12 tonne)*	4.397	0.495	0.95
12 tonne *(in 8 v 12 tonne)*	4.295	0.520	0.88

The Patrick equation can be re-arranged to calculate the number of passes to a given MPD value. This in turn allows the determination of an appropriate damage law exponent. If the slopes (k_2) of the Patrick equation fitted to the data where identical, it would be possible to directly determine an exponent for both datasets.

However this was not the case and thus an error function was developed to determine the best fit damage law exponent. The error function was the number of equivalent standard axles (ESAs) under the reference load to reach a level of MPD minus the number of ESA under the increased load to reach that same MPD. As the measurement intervals were based on a logarithmic scale, the logarithm of the error function at each interval was taken to prevent undue loading on the later stages of the testing.

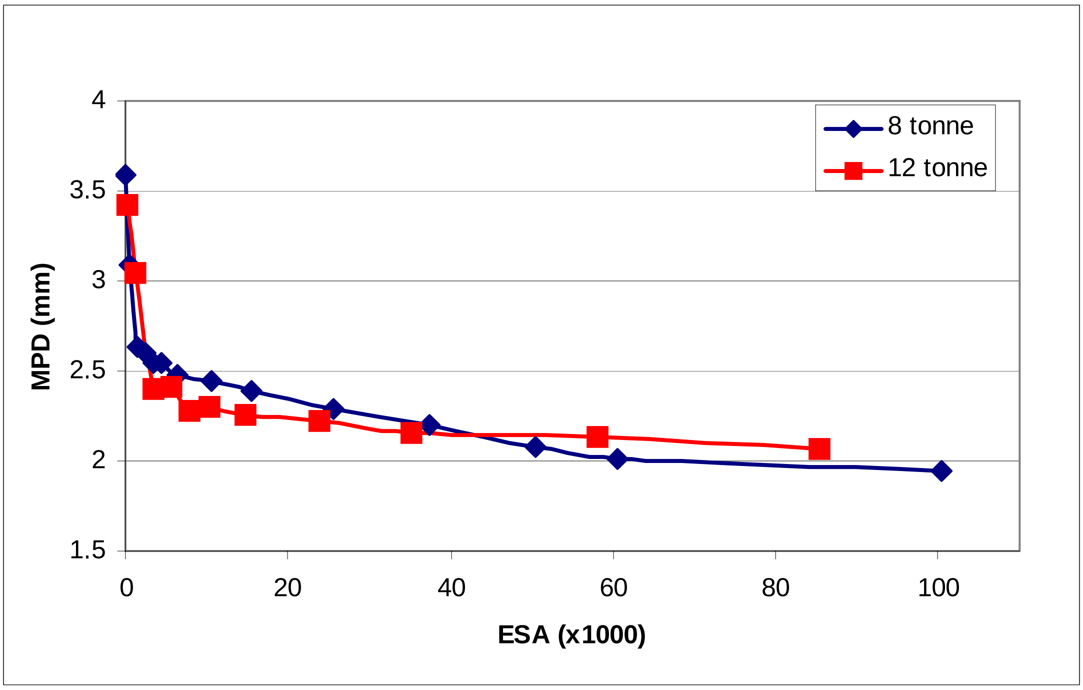

Figure 4.4 Measured MPD versus Equivalent Standard Axles (ESA) calculated using a damage exponent of 2.0.

Table 4.2 Constants using error function (from Equation 4.8) to obtain the Damage Law exponent *n*.

Constants (Equation 4.8)	α	β	**Damage law exponent, *n***
8 tonne v 12 tonne loads	10	23	2.0

The damage law exponent is calculated as 2.0, the effect of which is illustrated in Figure 4.4. Alternatively, assuming one pass of the 8-tonne axle is equivalent to 10 passes of light vehicles, then the 12-tonne axle is equivalent to 23 passes of light vehicles (Table 4.2).

4.3 Kinder–Lay model

Kinder and Lay (1988) developed a model to describe the progression of permanent deformation with loads. This model has the form:

$$VSD = KP^{m}N^{\frac{m}{\alpha}} \qquad \text{Equation 4.10}$$

where K, m and α are constants
P is the axle load in tonnes
N is the number of load cycles

and takes into account both a power law for the effect of mass and that the rate of change of Vertical Surface Deformation (VSD) changes as load cycles increase. This model form shows that α is the exponent of the power law. Allowing for surface deformation the model goes through the origin, i.e. at zero load cycles the deformation is zero. Applying a similar form of model to MPD requires a minor modification to the model to take into account that, at zero load cycles, the MPD is not zero. A suitable form of the model is:

Equation 4.11

$$MPD = MPD_0 - KP^{m}N^{\frac{m}{\alpha}}$$

where MPD_0 is the mean profile depth in mm at zero loads

From the test data for two different levels of load are obtained. Applying the model to each load magnitude and combining the two equations gives:

$$MPD_2 = MPD_0\left[1 - \left(\frac{P_2}{P_1}\right)^{m}\right] + MPD_1\left(\frac{P_2}{P_1}\right)^{m} \qquad \text{Equation 4.12}$$

where the subscripts 1 and 2 denote the two load cases

Applying linear regression to this equation best fit estimates can be obtained for MPD_0 and m. Alternatively Equation 4.11 can be rewritten as:

$$\frac{MPD_0 - MPD}{P^{m}} = K.N^{\frac{m}{\alpha}} \qquad \text{Equation 4.13}$$

Taking MPD_0 as the average start MPD for the two wheel loads and incrementally changing *m* we can take logarithms and use linear regression with the data from both loads to obtain best fit estimates of *K* and α. The combination of *m*, *K* and α that result in the lowest mean difference between measured and calculated MPDs are taken as the appropriate values. The best estimates of the parameters are detailed in Table 4.3 and these result in R^2 values of 0.96 for the 40 kN wheelpath and 0.88 for the 60 kN wheelpath.

Table 4.3 Best estimates of parameters in Kinder–Lay style model compared to the Patrick style model.

Mass	MPD_0	m	α	K	R^2
8 tonnes	3.51	0.38	2.8	0.077	0.96
12 tonnes	3.51	0.38	2.8	0.077	0.88

This model is only slightly better than the Patrick model (with a higher R^2 value) but it has the advantage for this study as it explicitly includes the effect of mass. As explained above, the parameter α is the exponent of the power law relationship for the effect of mass and this is 2.8, which is very similar to the 2.0 value derived by applying the Patrick model.

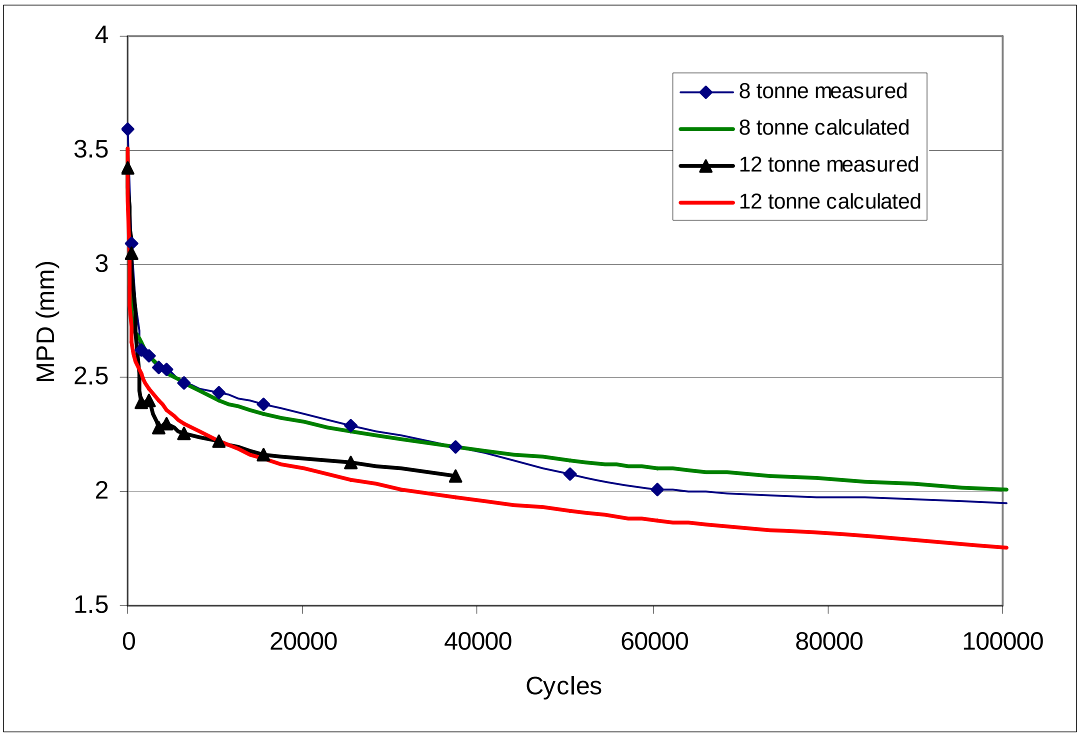

Figure 4.5 Comparison of MPD predicted by Kinder–Lay style model with the measured data.

Figure 4.5 shows a comparison of the Kinder–Lay style model with the measured data for each of the wheelpaths. The fit for the inner wheelpath with the 8-tonne axle loads is clearly better than that of the outer wheelpath where the match at the end of the test is not so good. The situation at the end of the test (last two measurements) is understandable as the surfacing had failed and the tyres were removing bitumen.

4.4 Statistical analysis

The difference in mean texture depths for the two wheel loads was tested for statistical significance, using an analysis of variance (ANOVA) to test for significant differences between means. For comparing two means, the ANOVA will give the same results as the t test for independent samples (if comparing two different groups of cases or observations), or as the t test for dependent samples (if comparing two variables in one set of cases or observations). For each loading cycle when texture measurements were undertaken a *p-value* was calculated in the ANOVA test. The statistical significance of a result is the probability that the observed relationship (e.g. between variables) or a difference (e.g. between means) in a sample which has occurred by pure chance ('luck of the draw'), and that in the population from which the sample was drawn, no such relationship or differences exist. In many areas of research, a maximum *p-value* of 0.05 is customarily treated as a 'border-line acceptable' error level. *p-values* of less than 0.05 were found for all load cycle measurements accept for the 500 load cycle case (Table 4.4). Thus for nearly all load cases the differences in the mean texture depths for the two wheel loads are significant.

Table 4.4 Statistical significance (*p-value*) in differences between mean texture depths. (NB: a lower *p-value* means a greater probability that they are different).

Loads	*p-value*
0	0.0003
500	0.4
1500	5.E-08
2500	1.E-06
3500	1.E-10
4500	2.E-09
6500	2.E-09
10500	3.E-08
15500	4.E-10
25500	4.E-06
37500	0.0004

Differences between the means were also shown graphically in the box plot (Figure 4.6) and jitter plot (Figure 4.7) as produced by the statistical programme. The box plots are made up of several parts: the box depicts the central half of the data roughly between the 25% and 75% points; the line across the box displays the median value; the 'whiskers' extend from the top and the bottom of the box to depict the extent of the main body of the data. Extreme values are plotted with a solid dot. Very extreme data values are plotted with a starburst. The shaded area superimposed on each box is a 95% confidence interval around the median. If two of the grey boxes fail to overlap, the corresponding medians are discernibly different at approximately the 5% significance level. Thus, the load case at 500 is shown not to be discernibly different between 8t to 12t using this system.

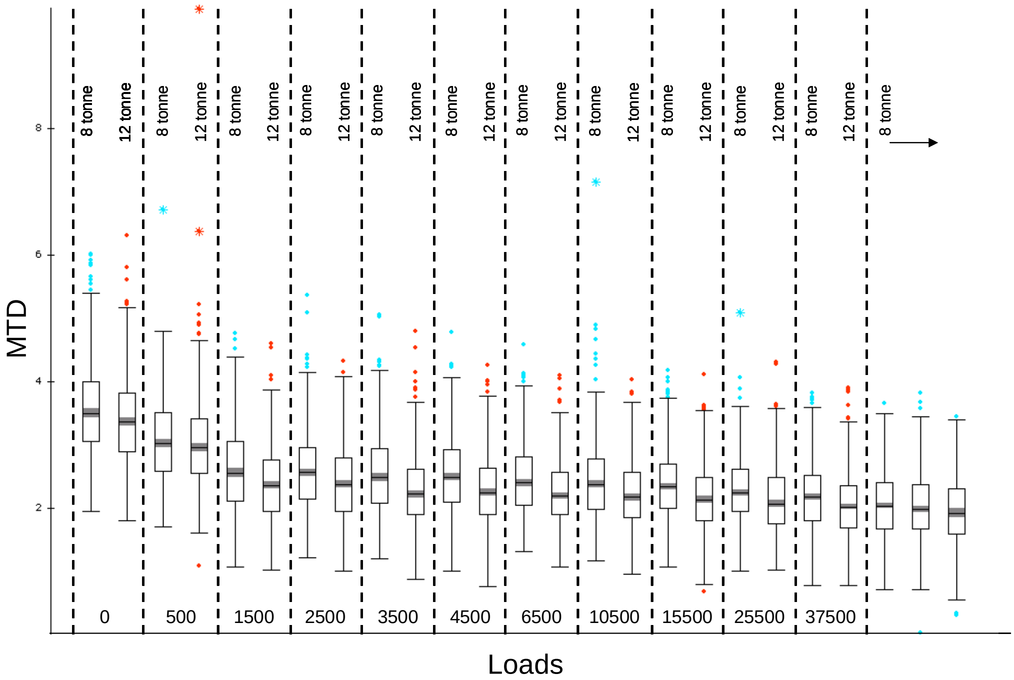

Figure 4.6 Box plot for differences in MPDs for the two wheel loads.

The jitter plot (Figure 4.7) plots all the measured textured depths for both wheelpaths side by side for comparison. Data shown in this fashion illustrates that the differences are not great between the two wheelpaths.

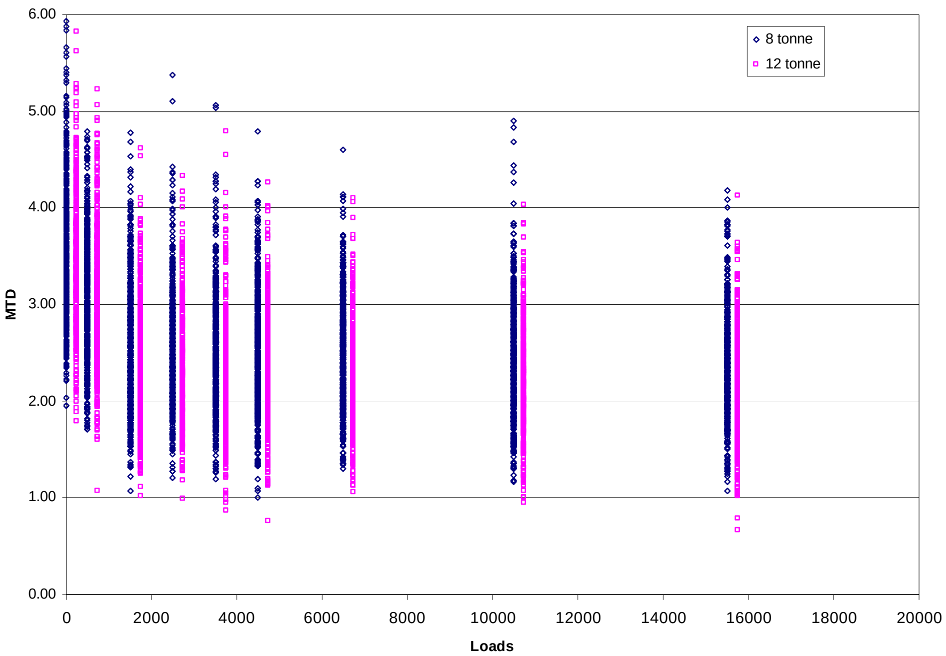

Figure 4.7 Jitter plot for MPDs for both wheelpaths.

5. Traffic loads used for chipseal design

Based on the Patrick model, but excluding two surface texture points obtained later caused by chipseal bleeding, one 12-tonne axle pass is estimated to be equivalent to 23 passes of light vehicles. However, this assumes that one pass of an 8-tonne axle is equivalent to 10 passes of light vehicles. Considering the relative damage of the two axle loads on the chipseal, a damage law exponent of 2.0 needs to be calculated.

The effect of a 12-tonne axle being equivalent to 23 passes of light vehicles cannot be used directly in the design of chipseals. This is because the current method of chipseal design assumes that 1 Heavy Commercial Vehicle (HCV) is equivalent to 10 passes of light vehicles. An HCV is any vehicle over 4 tonnes in gross weight and therefore a range of loads are all lumped into the one type. Should an increase in mass limits occur then not all HCVs will need to increase to the new axle load limits. It is therefore inappropriate to multiply all the HCVs by say 23 (assuming a 12-tonne axle load) to calculate the equivalent number of light vehicles.

Another method recommended for determining the number of equivalent light vehicles for chipseal design considers the use of ESAs (Equivalent Standard Axles). The current assumption made in pavement design is that 1 HCV is 1 ESA (New Zealand Supplement to the Austroads Pavement Design Guide, 2000). Therefore, 1 ESA can be considered equivalent to 10 light vehicle passes for use in chipseal design. To calculate the number of ESAs for any given traffic distribution the following equation is used, as given in the Austroads Pavement Design Guide (Austroads 1992):

$$ESAs = \left[\frac{Axle\_load}{Axle\_load\_reference}\right]^n \qquad \text{Equation 5.1}$$

where:

ESAs = number of standard axles needed to cause the same damage as one pass of the actual axle load (Axle_load, Equation 5.1)

Axle_load = actual axle load in kN

Axle_load_reference = reference load depending on the axle load group as defined in Table 5.1

N = damage law exponent (commonly = 4)

Table 5.1 Reference axle loads (Table 7.1 in Austroads 1992).

Axle: Tyres:	Single Single	Single Dual	Tandem Dual	Triaxle Dual
Load (kN)	53	80	135	181

The damage law exponent *n* (Equation 5.1) is usually assumed to be equal to 4. However, for axle loads greater than those listed in Table 5.1, the exponent used should be 2.0 as found in this study of chipseal deterioration. Finally, the number of ESAs are multiplied by 10 to determine the number of equivalent light vehicles for the purpose of chipseal design.

6. Discussion

This chipseal test at CAPTIF did show that an increase in loading would result in an increased deterioration of chipseal texture depth, and therefore in loss of skid resistance.

The current method of chipseal design in New Zealand is based on the Patrick (1998) model (Equation 4.1) and the limited study reported here shows no reason to depart from this model. Further, keeping with this model allows the direct use of results from this study in current design methods. To estimate the design number of light vehicles for a chipseal, the design should be based on the number of ESAs as described in Section 4.2 of this report.

Should an increase in mass limits for heavy vehicles be allowed, then when designing a new chipseal surface the design number of light vehicles would increase. This in turn would result in the calculation of reduced chipseal binder application rates. Chipseal studies on a private forestry road, where vehicles operate at axle loads in excess of 12 tonnes, support a reduction in binder application rates to prevent premature flushing (Arnold & Howard 1996). The reduced application rate assists in the preventing premature flushing failures. However it also increases the risk of a near instantaneous stripping failure.

7. Conclusions

The aim of this study was to compare the losses in chipseal texture depth generated by a 12-tonne axle with those of a standard 8.2-tonne axle. The aim was to consider the impacts on chipseal design and predict the implications on the road network caused by a change in the legal axle load limit in New Zealand. The procedure is described in Section 1.2 of this report.

- Texture depth has a great deal of variability and the average of a large number of readings is needed to get stable results. Thus trends in texture depth loss could not be obtained by plotting texture depth against loading cycles at individual measurement stations. The averages had to be taken around a complete circuit of the track.
- The 'Patrick model' for texture loss under loading, which is used for performance prediction in New Zealand, match the measured data well although with coefficients that differ significantly from those given by from those given by Patrick et al. (1998) and Cenek (1999).

- Assuming one pass of the 8-tonne axle is equal to 10 passes of light vehicles, as used in current chipseal design and performance modelling, then one pass of a 12-tonne axle is equal to 23 passes. However this figure cannot be used directly as not all heavy commercial vehicles will be affected by this particular increase in mass limits.
- The relative surface texture change between the 8-tonne and 12-tonne axle loads can also be considered as a damage law exponent of 2.0.
- A modification of the form of model used by Kinder & Lay to model the rutting of a chipseal surface was fitted to the texture data and resulted in a reasonable fit. The best-fit exponent of the power law for the effect of mass was 2.8. Although this model explicitly accounts for the effect of mass with a power law relationship, it does not fit with the current method of chipseal design and therefore the results were not considered at this stage in recommendations for chipseal design.
- ANOVA analysis (an analysis of variance) of the data showed the difference between the Mean Texture Depths (MTDs) for the 8- and 12-tonne wheelpaths to be significant.
- When calculating chipseal design traffic loading in terms of number of light vehicles, the suggestion is that 1 HCV (Heavy Commercial Vehicle) is replaced by 1 ESA (Equivalent Standard Axle), and that this equivalent is made equal to 10 light vehicle passes. This allows for the consideration that only part of the HCV fleet will be affected by any increases in mass limits, and it is based on the current assumption in design that 1 HCV equates to 1 ESA.
- To calculate the number of ESAs for chipseal design for roads on which axle loads are higher than the current legal load, then a damage law exponent of 2.0 is recommended.

Should an increase in mass limits be allowed, and as 1 HCV equates to 1 ESA which is equal to 10 light vehicles, then the design number of light vehicles would increase. This in turn would result in reduced chipseal binder application rates being required which would help prevent premature flushing. However it would also increase the risk of a stripping failure.

8. References

Arnold, G., Pidwerbesky, B. 1994. *Can chipseals carry even heavier loads?* Transit New Zealand Land Transport Symposium, Wellington, 9-11 August 1994.

Arnold, G., Howard, D. 1996. Chipseal trials for off-highway forestry roads (year two). *LIRO Report 21(25).* Logging Industry Research Organisation, Rotorua.

Arnold, G., Alabaster, D., Steven, B. 2001. Prediction of pavement performance from repeat load tri-axial tests on granular materials. *Transfund New Zealand Research Report No. 214.* 120pp.

Arnold, G., Steven, B., Alabaster, D., Fussell, A. 2005a. Effect on pavement wear of increased mass limits for heavy vehicles – Stage 3. *Land Transport New Zealand Research Report 279.* 112pp.

Arnold, G., Steven, B., Alabaster, D., Fussell, A. 2005b. Effect on pavement wear of increased mass limits for heavy vehicles – concluding report. *Land Transport New Zealand Research Report 281.* 80pp.

Austroads. 1992. Pavement Design – A guide to the structural design of road pavements. *Austroads Publication No. AP-17/92*. Austroads, Sydney, NSW.

Cenek, P. 1999. *Texture Model (Incremental Form).* Presentation to the Technical Workshop on dTIMS, 1 June 1999, Wellington. Opus Central Laboratories, Lower Hutt.

de Pont, J., Steven, B., Alabaster, D., Fussell, A. 2001. Effect on pavement wear of an increase in mass limits for heavy vehicles. *Transfund New Zealand Research Report No. 207.* 55pp.

de Pont, J., Steven, B., Alabaster, D., Fussell, A. 2002. Effect on pavement wear of an increase in mass limits for heavy vehicles: Stage 2. *Transfund New Zealand Research Report No. 231.* 50pp.

Houghton, L.D., Hallett, J.E. 1987. An analysis of single-coat seal design. *New Zealand Roading Symposium (1987) 2:* 249-263.

International Standard ISO. 1997. Characterization of pavement texture by use of surface profiles. Part 1: Determination of Mean Profile Depth. ISO 13473-1:1997(E). 1st edition 1997-09-01. 19pp.

Kinder, D.F., Lay, M.G. 1988. Review of the fourth power law*. ARRB Internal Report AIR000-248.* Australian Road Research Board, Vermont South, Victoria.

Patrick, J.E., Alabaster, D.J., Dongol, D.M.S. 1998. Pavement density. *Transfund New Zealand Research Report No. 100.*

Pidwerbesky, B.D. 1995. Accelerated dynamic loading of flexible pavements at the Canterbury accelerated pavement testing indoor facility. *Transportation Research Record 1482:* 79-86.

Steyn, W.J. vdM., de Beer, M., Visser, A.T. 1997. Thin asphalt and double seal rehabilitated lightly cemented pavements: evaluation of structural behaviour and life cycle costs. Pp. 1181-1201 in *Eighth International Conference on Asphalt Pavements,* August 10–14, 1997. Seattle, Washington, US.

Transit New Zealand. 2000. New Zealand supplement to the document, Pavement Design – A guide to the structural design of road pavements. (*Austroads Publication No. AP-17/92, 1992)*.

Appendix – Surface texture data

Loading Cycles	Wheelpath Texture	
	8.2 tonne MPD (mm)	**12 tonne** MPD (mm)
0	3.59	3.42
500	3.09	3.05
1 500	2.63	2.40
2 500	2.60	2.41
3 500	2.54	2.28
4 500	2.54	2.30
6 500	2.48	2.26
10 500	2.44	2.22
15 500	2.39	2.16
25 500	2.29	2.13
37 500	2.20	2.07
50 500	2.08	
60 500	2.01	
100 500	1.95	