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CHIP SEAL TRIALS FOR OFF-HIGHWAY FORESTRY ROADS

(Year One of a Three Year Research Project)

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Figure 1 - Construction of chip seal trial sections on Railway Road in Kaingaroa Forest

ABSTRACT

In 1986, a main arterial forestry road in Kaingaroa Forest was sealed using public highway design criteria. However, as the majority of traffic on this forestry road was off-highway trucks with axle loads up to two times greater than on public highways, premature flushing occurred. Since 1989, various small trials of new chip seal designs have been undertaken in an attempt to remedy the flushing. The *result of this research led to the establishment of 40 chip seal trial sections in January, 1994. The variables were: (i) level of stress (straight level road versus adverse gradient), (ii) type of bitumen (PMB100, Emoflex, 80/100 and 180/200 bitumens) and (iii) residual bitumen rate (five rates for each type of bitumen). These trial sections are being monitored, with the aim of developing a suitable chip seal design procedure for arterial forestry roads carrying single axle loads up to 16 tonnes.*

A detailed series of tests was conducted on all the trial sections prior to sealing and immediately after sealing. The testing examined the surface texture, structural integrity, surface distress and geometric characteristics of the pavement. Surface texture and distress measurements were repeated 12 months after sealing, and most of the sections exhibited similar characteristics, except for the 180/200 bitumen test sections on the hill which had flushed and are considered to have failed. Monitoring of these test sections will continue annually for three years, at which time firmer conclusions can be made.

INTRODUCTION

Background

The design of New Zealand chip seals is based on theory and mechanisms first proposed by Hanson (1935), who related the bitumen application rate to the size of the stone chip, the ratio of the chip's average, least and greatest dimensions, and the residual void space within the single layer thickness of the aggregate cover. These basic precepts have been refined by experience into a semi-empirical design procedure which provides corrections for existing surface texture and vehicle loading, culminating in the Bituminous Sealing Manual (TNZ, 1993).

The key for effective chip sealing is to apply the bitumen evenly - enough to waterproof the pavement and hold on to the chips, but not so much as to completely submerge the chips and create a sticky, surface, dangerously slippery when wet.

The algorithm is based on observations and studies involving public highways carrying traffic that typically consisted of 10% to 15% heavy commercial vehicles (HCV), with an average axle load of about five tonnes. Therefore, the algorithm does not take into account the effects of off-highway trucks with axle loads up to 16 tonnes.

This algorithm was used to design the chip seal for the off-highway road between Murupara and Kawerau in 1986. Less than two months after the second seal coat had been applied, the bitumen in the wheel paths of the loaded lane had flushed to the extent that free bitumen was present on the surface (Pidwerbesky, 1994). The lane carrying unloaded vehicles was flushing also but to a lesser degree.

In an attempt to remedy the flushing, there have been various trials of new chip seal designs undertaken since 1989, under the direction of Bryan Pidwerbesky (University of Canterbury). The result of this research was that a re-seal with a polymer-modified bitumen and a low application rate with large chips is probably the best option. However, it was not known exactly how much bitumen to apply nor how well it would perform compared to unmodified, standard grades of bitumen. Therefore, in 1994 a total of 40 50m chip seal trial sections were sealed (Figure 1) and will be monitored annually over a three year period. At the end of the three year period guidelines will be developed for the design of chip seals, to withstand axle loads up to 16 tonnes.

Definitions

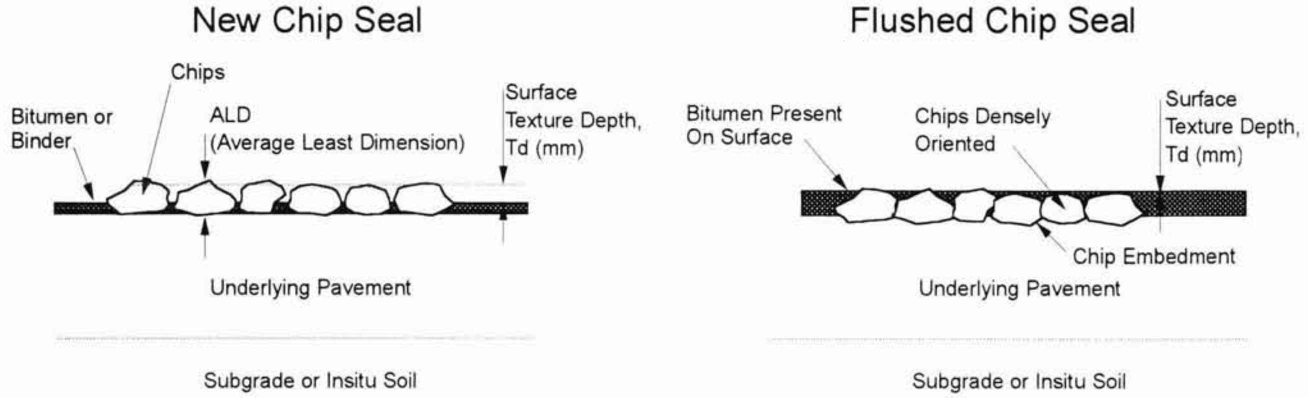

Figure 2 - Terminology

PMB100 and Emoflex (Polymer Modified Bitumens)

PMB100 and Emoflex are proprietary brands of polymer-modified bitumens (PMBs). These are synthetic rubber-based additives, which greatly improve the performance of bitumen binders. Resilience to high and low temperatures is increased and strength and ductility is improved. This may inhibit flushing, reduce chip loss and prevent cracking.

80/100 and 180/200 Bitumen

The 80/100 and 180/200 bitumens are common standard grades of bitumen that are used in New Zealand. The 180/200 is softer and used in colder climates, but is more susceptible to flushing on hot days. The 80/100 is a hard bitumen which is less likely to flush but may crack in temperatures less than 0°C.

The following report summarises two internal LIRO reports: "Chip Seal Trial Sections" (Arnold, Martin, Smith, Pidwerbesky, 1994 and Arnold and Williams, 1995) which includes comprehensive information on the construction and initial testing of the trials.

Aim and Objectives

The aim is to determine a suitable chip seal which provides adequate serviceability under the vehicle loading conditions being experienced on the off-highway road between Murupara and Kawerau. The objectives at the end of the three year project are to:

1. Establish a relationship between residual bitumen rate and different forms of resulting surface distress, to determine the optimal rate.

2. Determine the most effective (with respect to cost and technical performance) type of bitumen for the level of stress expected.

3. Determine whether the bitumen type and application rate must be adjusted for localised areas of increased stress, such as at corners and adverse gradients.

ACKNOWLEDGEMENTS

LIRO acknowledges Bitumix Limited, Tauranga for constructing the chip seal trial sections, Forestry Corporation of New Zealand Limited for their financial assistance, Bryan Pidwerbesky, University of Canterbury and Works Consultancy Services, Central Laboratories for their advice and equipment.

TEST SECTIONS

Four different bitumen types were trialled on two locations, a flat and hill section, each 250m long. There are a total of

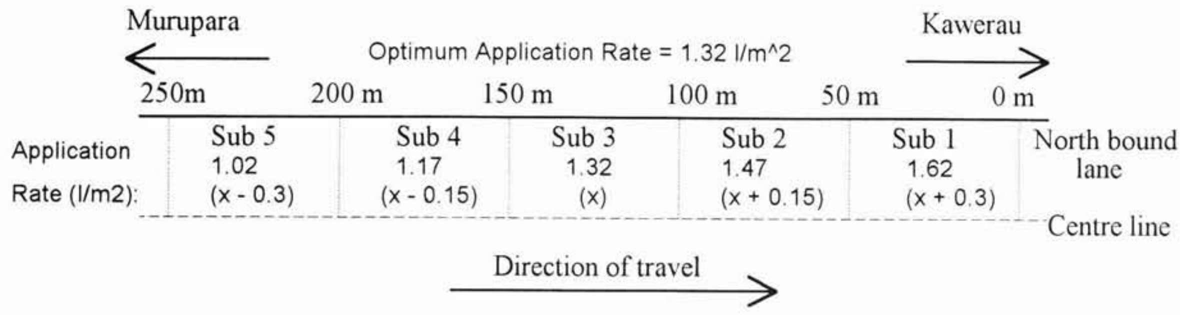

Figure 3 - Typical layout and target application rates of a 250m trial section

eight 250m long trial sections, located on the major haul road between Kawerau and Murupara. These trial sections were further divided into five 50m trial sections to vary the bitumen application rate.

The bitumen application rates trialled were the optimum application rate, 0.15 l/m^2 and 0.30 l/m^2 above and below the optimum rate (Figure 3). The optimum application rate was designed using the procedure outlined in the Bituminous Sealing Manual (TNZ, 1993), using a traffic factor of 0.7, based on previous trials. At the highest rate, the binder is expected to flush, whereas at the lowest rate, chip loss may result.

The section number, bitumen type, road gradient, existing surface texture (Td) and bitumen application rates used are summarised in Table 1.

Table 1 - Summary of trial sections used

				Bitumen Application Rate (l/m^2)				
Sect no.	Bitumen	Grad (%)	Td (mm)	Sub-section (50 m)				
(250 m)	type	(adverse)	(exist)	1	2	**3**	4	5
AS	80/100	4.6	0.7	1.50	1.39	**1.28**	1.21	1.11
BS	180/200	3.8	0.6	1.62	1.47	**1.32**	1.17	1.02
CS	PMB 100	5.1	0.6	1.62	1.47	**1.32**	1.17	1.02
DS	Emoflex	4.8	0.6	1.64	1.46	**1.33**	1.20	1.02
AU	80/100	0.3	0.6	1.68	1.51	**1.49**	1.13	1.20
BU	180/200	0.21	1.3	1.73	1.58	**1.43**	1.28	1.13
CU	PMB 100	-0.72	1.0	1.67	1.52	**1.37**	1.22	1.07
DU	Emoflex	0.2	1.0	1.68	1.55	**1.42**	1.24	1.11

Due to the variation in the truck spraying rates, the actual application rates shown in Table 1 are those measured using carpet mats. These were placed at the end of each 50m section and weighed before (without bitumen) and after spraying (with bitumen) (Figure 4). For a known mat area and bitumen density, the actual bitumen application rate was calculated.

Figure 4 - Carpet mats used to measure bitumen application rate

The trial sections were constructed by Bitumix Tauranga Limited as part of their 1993/94 sealing contract with Forestry Corporation of New Zealand Limited. Sealing of the trials began on 17 January, 1994, and were completed on 15 February, 1994.

TRAFFIC LOADING

For the 11 months February, 1994 to January, 1995 the volume of wood carted over all the trial sections was approximately 565,500 tonnes. This volume was carted by a mixture of on-highway and off-highway trucks (Table 2). The majority of the volume was carted by off-highway Double Bailey Units with an average gross weight of 99.5 tonnes. Figure 5 shows typical on and off-highway truck configurations and axle loads of a Double Bailey Unit, that were measured.

Table 2 - Truck usage and average weights

No. of Units	Gross Weight (tonnes)	Payload (tonnes)	% Usage	No. of Trips (Feb 94 to Jan 95)
ON-HIGHWAY	54.5	35	5.0	808
DOUBLE	99.5	70	92.5	7473
TREBLE	149.5	105	2.5	135

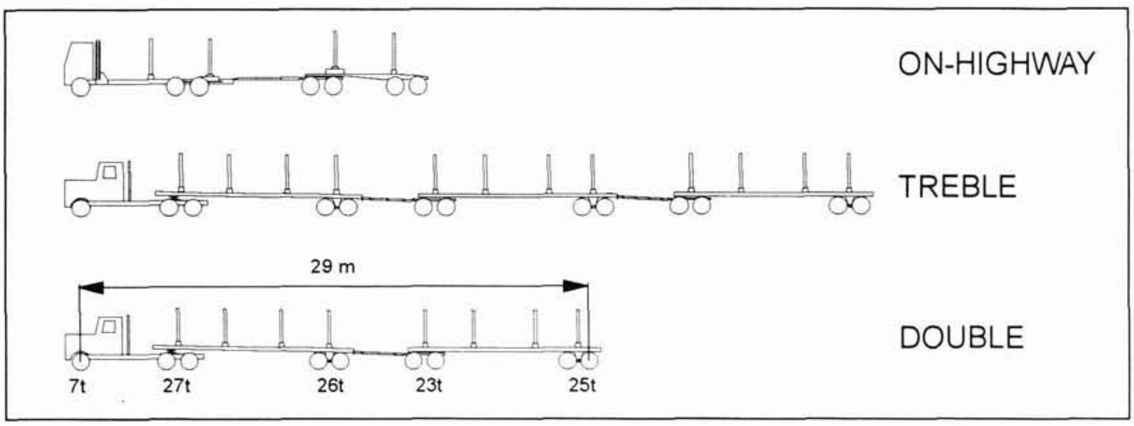

Figure 5 - Typical on and off-highway truck configurations

As the bitumen within the chip seal is affected by loading time, the truck speeds were also measured using a hawk radar. Speeds on the flat sections were from 70 to 100km/hr, while the speeds on the hill sections ranged from 20 to 60 km/hr. Effectively the sections on the hill endure twice the loading of the sections on the flat.

TESTING

Detailed tests examining the surface texture, structural integrity, and geometric characteristics of the pavement were conducted on all the trial sections prior to sealing and after sealing as a reference for future analysis. The tests and initial findings were as follows.

Existing Bitumen Properties

Laboratory tests were conducted on 300mm square bitumen samples removed from the existing chip seal in December, 1993 before the chip seal sections were sprayed. The samples were sent to Works Consultancy Services, Central Laboratories, Lower Hutt for measurement of diluent content and viscosity. Table 3 shows some of the results attained.

Table 3 - Laboratory results of existing chip seal

Section	Diluent Content (%)	Viscosity (Pas)
AS	2.9	8,328
BS	3.2	5,699
CS	2.5	3,128
DS	3.5	5,360
AU	1.4	6,720
BU	1.3	3,173
CU	2.7	8,056
DU	1.6	7,719

The viscosity of a bitumen is its resistance to flow, so the lower the viscosity the softer the bitumen. The low viscosity of sections BU (180/200, flat section) and CS (PMB100, hill section) could indicate that chip embedment from the overlying seal is more likely to occur. To soften the bitumen for spraying diluent at about 7% concentration was added to the bitumen at the time of sealing in 1986. It was thought at the time of sealing that all the diluents evaporate within six months. However, seven years later diluent was still present (1.3% to 3.5%), the effect of which is to soften the bitumen.

Moisture Contents and Subgrade CBR

In the same locations that the existing bitumen samples were collected, the basecourse was removed for analysis. A sample of basecourse and subgrade was taken for a moisture content test, and the depth of basecourse was recorded. The Dynamic Cone Penetrometer test was conducted to obtain the subgrade CBR (California Bearing Ratio).

Moisture contents of the basecourse varied from 2.8% to 4.5% and the depth from 310mm to 390mm. The moisture content for the subgrade was typically between 8% to 13%. However, AS (80/100, hill section) was very dry with a moisture content of 4%, and CS (PMB100, hill section) was particularly wet with a moisture content of 22%. The subgrade CBRs inferred from the Dynamic Cone Penetrometer tests were high (40 to 50) directly below the basecourse, due to the upper subgrade being cement stabilised. Deeper into the subgrade profile, CBR values were as low as 6%.

Chip Application Rate and ALD

The recommended chip application rate was 65 m^2/m^3, with the actual chip rates varying from 58 to 86 m^2/m^3. Three chip samples were taken from the chip truck at the time of sealing to measure the ALD (Average Least Dimension). The ALD test conducted on these samples was in accordance with NRB T/5 (1981), and the average ALD found was 12.40mm. This ALD was slightly smaller than the 13.12mm that was used in calculating binder application rates. However, 12.40mm was still within the specification for a grade one chip (11.5 to 14mm).

Benkelman Beam

The Benkelman beam test measures the pavement deflection caused by a standard 8.2t dual tyred axle (N.R.B, 1981). This test was conducted in both wheel paths, in increments of 10m, starting 5m into each trial sub-section. Most of the deflections were between 0.4mm to 1.2mm, with only six high deflections (approximately 2mm) recorded. These results suggest that the structural integrity of the pavement was good, although there may be some small soft spots present.

Falling Weight Deflectometer

The Falling Weight Deflectometer (FWD) (Figure 6) was used to evaluate the structural characteristics of each pavement layer. A load impulse that closely approximates the effect of a moving wheel load, both in magnitude and duration, is applied by a falling weight. Deflections at the point of loading and at known distances from the point of loading are then measured by geophones.

Figure 6 - Falling Weight Deflectometer

Testing on the trial sections was in the outside wheel track at 10 metre increments. The loads used were: (i) equivalent standard 8.2 tonne dual tyred single axle and (ii) equivalent 14 tonne dual tyred single axle.

The Falling Weight Deflectometer (FWD) test data for the trial sections have been analysed using PAS1 (a computer package which can be used to back calculate layer moduli by a graphical iterative process). The results showed some station points had significantly lower strength. These stations will be closely monitored for distress which could signal an early failure.

Skid Resistance

A Mu Meter was used to assess the skid resistance of the chip seal trial sections. This is an instrumented, light-weight, three-wheeled trailer unit that makes rapid measurements of the friction coefficient on a surface. Mu-Values (a measure of skid resistance) varied from 0.52 to 0.64, with an average of 0.59 for all sections combined. The recommended minimum skid resistance is 0.40 before a reseal is required.

Cross-sections

Cross-sections of the road were measured at the centre of each sub-section using the DIPstick surface profiler. This provides a reference for evaluating the change in cross-section shape over time and in particular rutting in the wheel paths. After one year, the sections showed no signs of further rutting, and cross-section measurements for the 1994/95 summer investigation were not repeated.

Photographs

Photographs were taken of all test sections to provide a reference for future visual assessment. The photographs were long views of an entire 50m sub-sections and close ups to show a detailed seal shot.

Condition Survey

A condition survey was conducted to evaluate the distress exhibited visually on each sub-section, before sealing, immediately after sealing and 12 months after sealing. Pavement distress types included: flushing, scabbing, potholes, patches, cracking, rutting, shoving, edge break, and other. For a full description of each distress type, refer to the TNZ RAMM manual (1994). The level of distress was recorded on a condition survey form, where the position of each recorded distress was sketched on a sub-section map at the bottom of the form.

The existing surface (before sealing) showed severe flushing, with minor cracking occurring in one section (180/200, hill section) only. Immediately after sealing, all the sections appeared to be in perfect condition, showing no signs of distress. This result was expected for a new seal.

Twelve months after sealing, the main form of distress was chip loss occurring on the road shoulder (Figure 7). However, section BS (180/200 on the hill) had cracking that was repaired and also had high flushing.

Figure 7 - Chip loss on the shoulder after 12 months

The reason for the chip loss on the shoulder is due to the underlying existing surface texture being higher than in the wheel paths. Typically, the surface texture on the shoulder was 3 mm and in the wheel paths 0.7 mm, prior to sealing. The bitumen application rates were designed for the existing texture of the wheel paths, resulting in applying too little bitumen on the shoulders to hold the chips in place (Table 4). In order to keep the chips on the shoulder, an extra 1.25 l/m^2 of bitumen would have been required (as calculated using RD286, TNZ, 1993).

Table 4 - The effect of texture depth on bitumen application rate using Section DS4 (Emoflex on the hill) as an example

	Shoulder	Outside Wheel Path
Surface Texture (Td, mm)	3.14	0.68
Design Application Rate (l/m^2)	2.42	1.33
Actual Application Rate (l/m^2)	1.17	1.17
Difference (l/m^2)	1.25	0.16

Table 5 - MTM surface texture results for the middle section of each bitumen type trialled on the flat (AU3, BU3....) and on the hill (AS3, BS3....).

Average MTM Readings (Outside Wheel Track) - Converted to Sand Circle Texture Depth Td (mm)				
Section	Binder	Existing Surface	New Seal	After 12 Months
AU3	80/100	0.4	4.7	3.5
BU3	180/200	1.6	5.5	3.8
CU3	PMB 100	0.6	4.7	4.2
DU3	Emoflex	0.9	4.3	3.9
AS3	80/100	0.7	4.7	4.0
BS3	180/200	0.7	3.3	2.0
CS3	PMB 100	0.9	4.1	3.5
DS3	Emoflex	1.0	4.3	3.9

Surface Texture

Surface texture of each sub-section was measured using the MTM (Mini Texture Meter) (Figure 8) and the sand circle test. The MTM is a device walked along the road, which takes continuous readings of texture every 300mm using a laser. The sand circle test is the diameter achieved when 45ml of sand is spread by revolving a straight edge until the sand is level with the tops of the chips.

Figure 8 - Calibrating the Mini Texture Meter

The surface texture was measured before sealing, immediately after sealing, and 12 months after sealing. A summary of the MTM results for the middle sections in the outside wheel track is shown in Table 5. The trend shown is typical for all other application rates trialled.

There were no significant differences between the surface texture results after 12 months, with the exception of the 180/200 section on the hill. This had about half the surface texture of the other trials and had noticeably flushed. Therefore, the 180/200 bitumen is not suitable for re-seals on the hill sections.

SUMMARY

- Laboratory analysis of the existing underlying flushed chip seal showed a large variation in viscosity, where the lower viscosity the softer the bitumen. There was 1.3% to 3.5% diluent still present (eight years after sealing) in all the sections tested.

- The existing surface (before sealing) showed severe flushing and immediately after sealing, as would be expected, all sections appeared to be in perfect condition showing no signs of distress.

- Twelve months after sealing, the main form of distress was chip loss occurring near the centreline and shoulder only. This is due to the existing surface texture being higher on the shoulder than the wheel paths. Section BS (180/200 on the hill) was flushing and is considered to have failed.

- Twelve months after sealing, there is no significant difference between the surface texture results, with the exception of the 180/200 section on the hill. This has about half the surface texture of the other trials.

No firm conclusions can be made to determine the best chip seal design after only one year. These test sections will be monitored annually for three years, at which time firm conclusions can be made that will satisfy the aims and objectives of the project.

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