Pavement Design and Management for Forestry Road Network

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Forestry companies are constructing and maintaining networks of high-quality, all-weather private arterial roads by taking advantage of New Zealand's unique highway pavement design and construction techniques, but some aspects required research to suit the specific needs of the forestry roads. Research was initiated to develop seal-coat surfacings that would withstand the high axle loads carried by the log transporters. The capacity of the granular pavement structure to carry the loads (with respect to magnitude and cumulative repetitions) was investigated. A multiyear program of monitoring and documenting the planning, design, construction, performance, and maintenance of the roads was implemented as part of a comprehensive pavement management system. Field test sections of new chip seal designs are being added and existing test sections are being monitored; the performance data are being used to develop a new chip seal design procedure. The successful application of low-cost technology has introduced new design, construction, and management techniques and has encouraged further research. This paper reports activities and results to date.

New Zealand forestry companies are constructing and maintaining substantial networks of high-quality private arterial roads, which are justified economically because logging trucks traveling at speeds of 80 to 100 km/hr over a smooth, all-weather road provide an economical means of hauling logs to the processing and port facilities. The forestry industry takes advantage of the low capital cost highway pavement designs and construction practices commonly used in this country (*1*,*2*). In New Zealand, asphalt pavements are used for some urban streets and motorways, but virtually all highway traffic is carried on chip seal coats over unbound granular pavements. The maximum gross vehicle weight permitted on national highways is limited to 44 tons, and the maximum loads permitted for single-, tandem-, and triple-axle groups are 8.2, 14.5 and 18 tons, respectively.

In 1988 a forestry arterial road was constructed in the northeastern region of the North Island to enhance the transport of logs from the large Kaingaroa plantation forest to the largest pulp and paper mill in the Southern Hemisphere, at Kawerau (Figure 1). The road was built to national public highway standards (*2*). The number of fully laden vehicles traveling over the road averages 140 per day. The maximum gross vehicle weights of the trucks range from 40 tons to 120 tons; the maximum axle loads are 15 tons per axle, in tandem or triple-axle groups. Cold tire pressures ranged from 650 kPa on trailers to 730 kPa on truck driving axles (Mack trucks). The region is in an active earthquake and volcano zone, so the predominant subgrade material is pumice. The temperatures range from −8°C to +35°C, and the mean annual temperature is 12°C. Average annual rainfall is 1500 mm. The area experiences a high percentage of bright sunshine days as well as more than 30 days of frost per year.

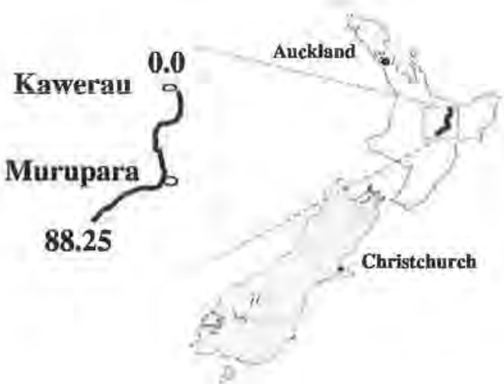

FIGURE 1 Location of arterial forestry road.

Soon after completion of the arterial road, excessive bleeding of the bitumen occurred. Subsequent investigation showed that pavement design and construction techniques had to be devised for the demanding conditions of the arterial forestry roads, and a pavement management system had to be implemented as well. The main objectives were to

1. Develop chip seal designs suited to the high axle loads being imposed,
2. Evaluate the capacity of the unbound granular pavement structure to carry the loads (with respect to magnitude and cumulative repetitions) expected, and
3. Implement a multiyear program of monitoring and documenting the planning, design, construction, performance, and maintenance of the roads.

Thus, the four primary tasks were to

1. Test different chip seal designs under actual loading and environmental conditions,
2. Establish the starting condition of the arterial road for future monitoring,
3. Investigate the capacity of the pavement structure to continue carrying the relatively heavy axle loads over the design period, and
4. Devise and test a preliminary system for managing pavement maintenance.

Management Strategy

First, a location index system was established and marked on the road; Km 0.00 is at the Kawerau mill, proceeding south to Km 53.00 at Murupara in the Kaingaroa forest and then continuing southwest to Km 88.25, as shown in Figure 1. Construction records were reviewed and, if possible, the as-built characteristics of the road, which were not necessarily the same as those documented, were determined. Equipment was selected, and monitoring procedures, including a condition survey form, were devised and implemented. Annual condition surveys have been conducted since 1989.

During the second year of the project, additional lengths of road were included in the annual survey, the field procedures were refined, and research was initiated to evaluate the bearing capacity of the pavement design. In the third year, a management system computer package was selected and modified, and instruction manuals for the modified computer software, road condition monitoring routines, and data analysis were written. Subsequently, additional test sections of innovative seal coat designs were constructed.

Road Construction, Evaluation, and Improvements

During construction, the elastic rebound of the subgrade under the loaded lane was evaluated by Benkelman beam and dynamic cone penetrometer (DCP) tests. Where rebounds exceeded 1.6 mm, the upper 200 mm of the subgrade was stabilized with lime or cement to achieve a higher bearing capacity before the unbound base course aggregate was placed. Initially, lime was applied at an application rate of 2 percent by mass, but lime reacted poorly with the subgrade materials, so portland cement was applied at the same rate to stabilize most of the length. Based on the performance of existing sealed roads in the same forest, a granular pavement thickness of 310 mm was specified. The 200-mm-deep base course layer was specified to be a well-graded aggregate of crushed river gravel with a crushing resistance of at least 130 kN and a maximum particle size of 40 mm (*3*); state highway construction procedures were also specified (*4,5*). The standard cross section of the arterial road is shown in Figure 2. However, the as-built material properties and construction details, such as compaction and weather, were not documented and are thus unknown.

The aggregate in New Zealand seal coats is always crushed cubic stone chips of uniform size; particle size ranges and shape are tightly specified and controlled so that a good mosaic is produced (*6*). The first seal coat consisted of 180/200 penetration grade bitumen (*7*) cut back with 7 percent kerosene and sprayed at 143°C and a Grade 4 [average least dimension (ALD) of 5.5- to 8-mm] chip (*8*). The seal coat was applied in stages during the period December 1986 to March 1988. The application rate of the bitumen (at 15°C) ranged between 1.15 and 1.24 L/m^2. One year later, the road received a second seal coat, as per normal practice (*9*). The bitumen was 180/200 penetration grade cut back with 3 to

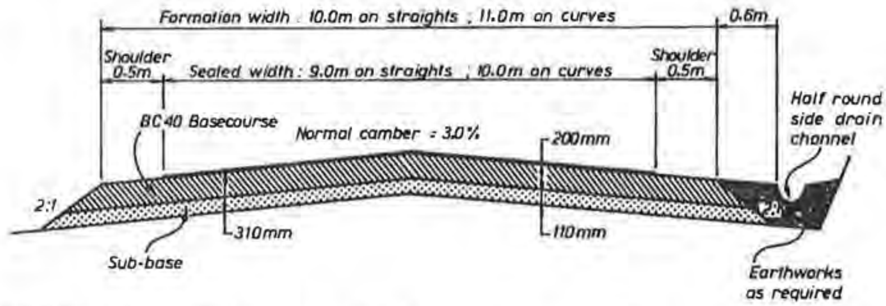

FIGURE 2 Standard cross section of arterial forestry road.

4 percent kerosene. The application rate of the bitumen (at 15°C) ranged between 1.97 and 2.36 L/m^2 depending on the existing surface texture. A Grade 2 (9.5 to 12 mm ALD) chip was spread at an unrecorded rate.

Less than 2 months after the second seal coat had been applied, bitumen in the wheelpaths of the loaded lane had flushed to the extent that free bitumen was present on the surface. The stone chips were still in place and were not being removed by vehicle tires except at intersections where sharp turning was necessary. Surface excavations revealed that the second coat of large particles was being pushed down into the lower layer of smaller particles. The first coat of cover aggregate and bitumen had apparently bonded well to the base course. The base course had a firm, distinct surface, which implied that the chips were not punching into the base course and that the bitumen was not being absorbed into the base. Further details of the site investigations can be found elsewhere (*10*).

Condition Monitoring

The aim was to produce a condition monitoring procedure that could be operated by the field staff and that could generate a data base to be analyzed by either in-house staff or an external consultant. A simple though comprehensive visual condition rating form was devised for recording surface distress; forms were filled out for each 100-m section along the 88.25 km of sealed-off highway. The distress for each lane was rated separately but on the same sheet, as the distress is usually different for loaded and unloaded lanes. Most of the road was surveyed with one person driving the car while another completed the survey sheets. Every 50 m the driver would stop and measure the rut depth in all four wheelpaths.

Beginning in 1989, the road condition was monitored annually by Benkelman beam tests in the inner and outer wheelpaths of both lanes, visual ratings, and photographs at 50-m intervals. Wherever deflections exceeded the maximum allowable, the section of road was inspected closely. A statistical analysis of the deflection data determined the optimum sampling rates for future tests and the overall trends in the data.

The first annual inspection and testing showed that most of the road was in an acceptable condition except for the severe flushing. Typical surface rebounds were in the 0.5- to 1.0-mm range. A 5-km length had deflections ranging from 2 to 4 mm. Excavations at five sites along the road revealed that the thickness of the granular pavement ranged between 320 and 360 mm (Table 1). The base course was firm and well compacted at all five sites. The DCP was used to quantify the bearing capacity of the subgrade at these excavations; Table 1 shows that the bearing capacity had a California bearing ratio (CBR) of 30 or above at all the sites except one (Wineberry). Excess moisture was observed in all the excavations. These and later excavations also revealed that quality control during construction was deficient. Often the granular pavement was placed directly on the topsoil, which should have been removed first. Below the topsoil, the in situ soil was usually pumice but was occasionally a saturated sand.

Reconstruction and Drainage Improvements

Where sections were badly distressed or exhibiting surface deflections (greater than 2 mm), either the road was

TABLE 1 Postconstruction Properties of Arterial Road

Site (km)	Location	Design Subgrade CBR	Actual Subgrade CBR	Pavement Depth (mm)	Surface Rebound (mm)
19.576	Wineberry	24	25	360	1.0
21.876	Motokura	24	50	360	1.1
29.676	Digout	37	30	330	0.7
36.595	Koki	37	50	330	0.8
41.619	Railway	37	50	320	1.2

reconstructed or the side drainage was improved, depending on the specific situation at each site. The most significant deficiency in the pavement was the lack of adequate drainage. In some sections berms had been constructed to prevent trucks from leaving the road if the drivers fell asleep; these berms also trapped the water on and in the road. Sumps had been constructed in some sections, which improved the drainage temporarily, but large volumes of water collected in the sumps and then infiltrated into the subgrade.

Side drainage was improved by cutting large sloping shoulders and grading them, which allowed excess water to drain freely from the pavement and subgrade layers. The only disadvantage is that the ditches restrict the effective road width, and trucks cannot pull off the road safely. Also, the likelihood that trailers will overturn if they get too close to the edge increases, especially if the second and third trailers start to sway or do not track on a true line. However, because of the improved drainage, the surface deflection of the improved sections of road were reduced to less than 1.5 mm.

Statistical Analysis of Deflection Data

The purpose of the statistical analysis was to determine the effect of reducing the intensity of Benkelman beam deflection tests longitudinally and transversely. Originally, the surface deflection was measured in each wheelpath in both directions (or four at each 50-m station). The analysis compared the effects of increasing the longitudinal distance interval to 200, 250, and 500 m compared with a 50-m interval. Another strategy evaluated was to randomly select blocks of the road length for testing at 50-m intervals. All of the alternative strategies above were compared on the basis of averaging the northbound lane only, the southbound lane only, and both lanes combined (the vehicles are fully laden in the northbound lane and return empty in the southbound lane).

Deflection testing both wheelpaths in each direction at minimum distance intervals achieved the highest accuracy. However, increasing the distance interval to 500 m did not significantly affect the confidence level of the results. Therefore, the optimum strategy is to test both wheelpaths in each direction at 500-m intervals. However, the statistical analysis inherently assumes that the road within the intervals is homogeneous. This, of course, is not true, so the pavement conditions must still be visually surveyed over the entire length of road. Also, any new seal coats or pavement construction should be tested every 50 m in each wheelpath in both directions for the first year, after which the intensity can be reduced to 500-m intervals. Additional deflection tests should be done at localized repairs (or other surface discontinuities) and any suspect spots. Then every 3 years the road should be tested at 50-m intervals to confirm the validity of the testing strategy and to identify localized weak spots.

Pavement Response to Heavy Axle Loads

Arterial forestry roads are not subject to public highway limits and often carry considerably greater axle loads, so research was necessary to determine the capacity of the standard pavement design to support the heavier axle loads. A section of pavement in service was instrumented with Bison strain inductance coils, which connected to a portable data acquisition system, to measure the vertical compressive strains induced in the pavement under heavy axle loads. The axle loads were varied from 8 to 16 tons, the vehicle speeds ranged from 5 to 60 km/hr, and single- and tandem-axle configurations were used. There was a linear relationship between the axle weight and the strains induced in the base course and the subgrade. As the vehicle speed increased, the strains induced in the base course decreased linearly and the strains in the subgrade increased linearly. The measured data were compared with the calculated response of the pavement model that was the basis of the pavement design procedure; the back-calculation analysis showed that the strains actually induced in the subgrade can be nearly four times greater than the strains allowed by the design criteria, yet the pavement and subgrade are behaving as predicted by the performance model (*11*).

Seal Coat Design and Performance

The function of seal coats is to provide an impermeable membrane over the base course and a skid-resistant surface, as well as a wearing surface (different systems are illustrated in Figure 3). In addition to material properties and environmental factors, the performance of seal coats is very dependent on operator skills and equipment precision during construction. The evolution of current techniques for designing seal coats has been detailed elsewhere (*10*).

In this case study, the actual application rates of the bitumen and the cover aggregate deviated substantially from specified values because application rates had been adjusted on the spot on the basis of visual assessment of the road surface and experience. In spite of the theoretically rigid specifications, spraying supervisors must exercise an appreciable degree of judgment in determining the appropriate bitumen and aggregate application rates for specific situations. The application rates of bi-

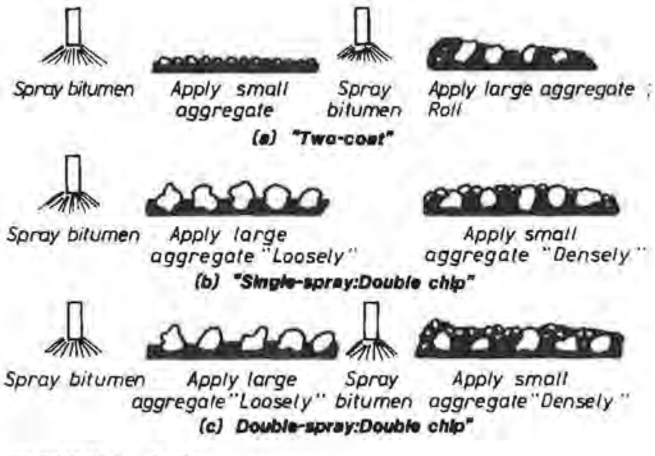

FIGURE 3 Seal coat systems.

tumen tend to be higher to minimize the risk of loss of cover aggregate. As a precaution against loss of chips by traffic action, the actual application rates of chips also tend to be higher than the rates derived from theoretical design procedures, but these application rates must be tightly controlled to produce good seal coats because correct application rates and aggregate retention are the most important contributors to seal coat performance (*12*). Excess chips interfere with particle placement and early alignment under trafficking, both of which are essential for proper embedment at low bitumen contents. Until recently, heavy rollers were considered essential to chip embedment, but this apparently self-evident premise has been disproved; the mass of the roller compactor is less important in creating a tightly locked mosaic of the stone chips than tire action (*13*). Roque et al. (*12*) found that no more than one pass of an 8-ton pneumatic-tired roller was needed to compact cover aggregate.

The chip seal design algorithms are for typical public highway loadings that are substantially less than the axle loads carried by the forestry roads. The intensity of the wheelpath use on forestry roads is much greater than that of a public highway where overtaking, varying vehicle dimensions and tire spacings, and driver behavior provide random deviation of the wheelpaths, yielding a broader transverse distribution. As a result, soon after the seal coat had been applied, bitumen in the wheelpaths of the loaded lane had bled to the extent that free bitumen was present on the surface. However, the bleeding, although severe, differed only in degree from that of normal seal coats made with an excess of bitumen; the prime cause of bleeding was employing the standard seal coat design, which was inappropriate for such a major departure from orthodox highway loadings.

Alternatives Considered to Alleviate Flushing

The following alternative techniques were considered but rejected:

- Removing the flushed seal, which is difficult and expensive. Also the advantages of using the durability of the seal coat underneath will be lost.
- Burning off the excess bitumen on the surface, which is dangerous in a forested area. Other trials in New Zealand have shown that only a small amount of bitumen could be removed at a time, and flushing was soon evident again.
- Applying either cut-back bitumen or a low rate of bitumen emulsion, then adding the chips and rolling, which does not work because the chips applied on the surface are quickly compacted into the flushed surface.
- Applying friction course or open-graded mix to soak up excess bitumen, which prevents the bitumen from sticking to the truck tires on hot days but is removed by traffic action.
- Precoating chips with bitumen, then spreading and rolling them, which is expensive and pushes the chips into the excess bitumen.
- Heating the existing surface, spreading stones, and rolling, which is expensive and dangerous because of the fire risk.

Other trials in New Zealand showed that neither a kerosene nor Gilsabind treatment could solve the flushing problems permanently.

Trials of New Seal Coat Designs

The main focus of the pavement design research has been the development of a new seal coat design procedure suitable for the loading and environmental conditions. Three series of trials, totaling 47 test sections, were established on the same arterial road. The primary variables were the application rate of the residual bitumen, the type of bitumen, and the chip size.

Trial One: First Coat Seals with Lower Rates of Residual Bitumen

Three adjacent test sections each 500 m long were constructed over a new, unbound granular base course in January 1990. The purpose of this experiment was to determine the effect of reducing the residual bitumen application rate and the ALD of the cover aggregate (see Figure 4). All three sections had the same, uniform conditions: vehicle loading, longitudinal and transverse slopes, the underlying unbound granular pavement, and surface deflection response. Standard 180/200 penetra-

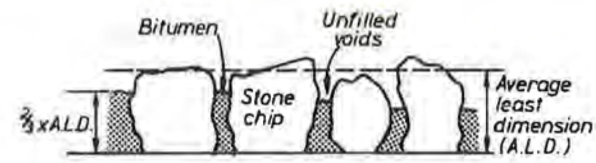

FIGURE 4 **Cross section of single seal coat.**

tion grade bitumen cut back with 7 percent kerosene and 1 percent adhesion agent was used for all three test sections (cutbacks are still the preferred option for reducing bitumen viscosity in the North Island). The weather conditions at the time of sealing and construction details are presented in Table 2.

Section A had a single-spray, single coat of larger chips; Section B had a single-spray, double coat of chips; and Section C had a single-spray coat of smaller chips. The performance of the three sections is shown in Table 2. The only form of surface distress in Sections A and B was flushing, and Section C also exhibited cracking, which was due to the lower durability resulting from the thinner film of bitumen in that section. The sections using the larger chips (Sections A and B) performed better than Section C.

After only 2 years, the test sections had to be resealed because of the severe flushing, but the test sections showed that the application rates of the residual bitumen could be reduced substantially and still retain the cover aggregate. Standard penetration grade bitumen alone was insufficient.

Trial Two: Reseals Using Polymer-Modified Bitumen

A second set of test sections was established in March 1992 to evaluate the performance of polymer-modified bitumen (pmb) in reseals over flushed seals. The liquid synthetic elastomeric rubber, a styrene-butadiene-styrene (SBS) polymer, is first mixed with bitumen at 30 percent concentration, and the mixture is then added to the bitumen to be sprayed. The final concentration of the thermoplastic rubber in the bitumen was 6 percent by weight. The polymer-modified bitumen is then applied using standard spraying equipment. SBS-modified bitumens enhance retention of cover aggregate, reduce thermal susceptibilities, support higher volumes of traffic, and withstand the higher stresses induced in more difficult road sections (*14*).

The locations of the four test sections were selected so that the road geometrics, loading conditions, and exposure to environmental factors were identical. Each 200-m test section is in the northbound lane, and the road is straight and inclining. The sections were separated by 50 m to minimize proximity effects. The bitumen viscosity was temporarily reduced and chip retention was enhanced by adding kerosene (4 percent) and adhesion agent (0.7 percent).

Test Section D has a single-spray, double coat of aggregate; the second layer of graded aggregate is intended to lock in the cover aggregate by filling some of the interstices between the larger particles. Test Sections E, F, and G have single seal coats. The residual bitumen rates in Sections F and G are the normal rates determined from the standard design method, whereas the residual bitumen rates in D and E are the minimum feasible rates, considering the environment, the texture of the existing surface, and the vehicle loading. The characteristics and performance of each section are shown in Table 3.

In Sections D and E, the bitumen viscosity remains high under loading and summer heat; thus flushing is negligible. However, the performance of Section D con-

TABLE 2 **First Set of Seal Coat Trial Sections with Standard 180/200 Penetration Grade Bitumen**

Properties	Test Section A	B	C
Residual Bitumen Rate (ℓ/m²)	1.89	1.97	1.03
Chip ALD (mm)	12	12.0*	6
Spray Temperature (°C)	145 - 155	135 - 155	145 - 160
Shade Temperature (°C)	20 -22	15 - 20	20
Cloud Cover (%)	10 - 30	50 - 70	0
Flushing after 1 year	Moderate	Moderate	Low
Flushing after 2 years	Moderate	High	Very High

* On top of a first layer of graded aggregate ranging in size from 75 μm to 13.2 mm.

TABLE 3 Second Set of Seal Coat Trial Sections with Polymer-Modified Bitumen

Properties	Test Section D	E	F	G
Residual Bitumen Rate (ℓ/m²)	1.34	1.3	1.76	1.7
Polymer Content (%)	6	6	6	0[b]
Torsional Recovery (pmb) (%)	89	93	89	
Chip ALD (mm)	12.1[a]	12.1	12.1	12.1
Spray Temperature (°C)	188	188	190	150
Shade Temperature (°C)	18	18	16	16
Pavement Temperature (°C)	20	20	18	18
Flushing after 1 year	Negligible	Negligible	Negligible	High
Flushing after 2 years	Negligible	Negligible	High	Very High
Chip loss (% Area)	30	0	0	0

[a] Followed with a locking coat of graded aggregate ranging in size from 75 μm to 13.2 mm.
[b] Standard 180/200 penetration grade bitumen

firms that the locking particles must interfere with the aggregate mosaic, leading to loss of cover aggregate. The performances of Sections F and G confirm that the normal application rates are too high, whether or not the bitumen is modified. In December 1993, a layer of small aggregate had to be spread over Section G to mitigate the effects of flushing, which results in tracking of bitumen along the wheelpaths. In all four sections, the seal coat condition outside of the wheelpaths is satisfactory.

Trial Three: Modified Seal Design

The foregoing trials confirmed that an alternative design method is required to satisfy the specific needs of arterial forestry roads. The aim of the third set of test sections is to establish a suitable seal coat design procedure that provides adequate serviceability under the environmental and vehicle loading conditions being experienced. The objectives are to

- Develop a standard procedure for monitoring and evaluating test sections that could eventually be adopted for the entire forestry road network,
- Establish a relationship between residual bitumen rate and different forms of resulting surface distress to determine the optimal rate,
- Determine the most effective (with respect to cost and technical performance) type of bitumen for the level of stress expected, and
- Determine whether the bitumen type and application rate must be adjusted for localized areas of increased stress.

Forty test sections, each 50 m long, were sealed in January 1994. The variables were (a) level of stress (straight road and adverse gradient), (b) type of bitumen (two proprietary pmbs and 80/100 and 180/200 penetration grade bitumens), and (c) residual bitumen rate (five rates for each type of bitumen, with minor compensation for local variations in the texture of the surface being sealed). The application rates of the bitumen and cover aggregate for the 10 control sections were determined using the standard public highway design procedure; the remainder of the test sections were designed to compensate for the high axle loads and gradient of the road.

The test sections are being monitored by condition surveys using walkover inspections and photographs. A falling weight deflectometer, a mu-meter, a mini-texture meter, and dipstick surface profiler are being used to measure structural capacity, skid resistance, surface microtexture, and longitudinal profiles, respectively, to quantify the performance of each test pavement. The devices may also be incorporated into a continuing pavement management system.

SBS-modified cutback bitumens require high amounts of fluxing, which can promote bleeding and severe chip embedment in hot weather when used as a reseal. Also, the working season is shorter compared with that for emulsified pmb. Emulsified pmb adheres to all types of chips, even if damp; can be sprayed on damp surfaces; and can contain a higher SBS content. The main disadvantage of SBS-modified bitumens is slow setting rates (*14*).

Selection of Computer Software for Maintenance Management

The function of a pavement management system (PMS) is to coordinate the planning, design, construction, maintenance, evaluation, and rehabilitation of roads, including research, to minimize the total costs to users and the road operator. A strong emphasis of the PMS in this project is to further the design, construction, maintenance, and rehabilitation of the roads by implementing and monitoring long-term field trials.

A number of maintenance management programs were evaluated; in their present form, most were unsuitable for this specific application because of the difference of loadings and because most required the dedication of substantial resources to monitoring pavement condition and documenting activities. The Flexible Pavement Management System (FPMS) software (*15*) was selected for adaptation because it is easy to use, many of its features suited the application, and it was easy to modify. FPMS determines the condition of the pavement and provides a report to formulate decisions on which type of reconstruction or rehabilitation is required.

First, the function of virtually every line of code and logic of the modules in the program was determined and documented. Then, where necessary, the code was modified to satisfy the criteria and the needs of the user. A substantial number of minor changes were made to improve the operation of the program, including error checking, to make the code more understandable and user friendly, and to add more functions. Major changes included converting all values to International System (SI) units; incorporating maintenance intervention trigger values for rutting, potholes, drainage, shoving, surface chip loss, polishing, and bleeding; and altering the decision trees and priority ranking subroutines. The modifications and additions to the data input to the program are detailed in Table 4.

The modified FPMS generates a program of works for a defined level of service each year. In 1992, the first year of implementation, a maintenance management plan was generated. The output from the FPMS was used by the maintenance supervisor to improve efficiency in the road maintenance budget and to set the maintenance budget for the following year. However, in 1993 the rights to the forest plantation, and the included road network, changed hands. Fortunately, because of the proven success of the FPMS and the previous work, the new management is committed to implementing an even more sophisticated pavement management system. A geographic information system, including a road maintenance management package, is being introduced; the aim is to eventually expand the system to a complete pavement management system.

TABLE 4 Modified and New Input Items for FPMS

Items Entered (and units)	Section Identification
Benkelman Beam Deflection[a] (.01 mm)	Link Record
Rutting Depth (mm), Length (%)	Road Name
Shoving Depth (mm), *Area* (%)[a]	Position
Flushing Severity, Area[a] (%)	Survey Date
Alligator Cracking Area (%)	Lane Width (m), Number
L and T[b] Cracking Area (%)	Length of Section (km)
Edge Breaking Length[a] (%)	*Year Road Sealed*[a]
Polishing Area[a] (%)	From, to (100 m stations)
Chip Loss Area[a] (%)	Lane
Potholes (#/100 m)	
Pothole Patches (#/100 m)	
Patches Condition, Area (%)	
Drainage Type, Effectiveness[a]	

[a] New items added to program are in italics

[b] Longitudinal and Transverse Cracking are combined in one item

Closer supervision of construction and maintenance work, accompanied by enhanced communication of objectives and tasks between field staff and designers, has already yielded improved performance.

Conclusion

The requirements of low-volume arterial forestry roads subjected to heavy axle loads are superior to those acceptable for New Zealand national highways, but the level of resources available is substantially less. Thus, for construction and management practices to be effective, they must be developed to suit the more rigorous requirements.

The primary activities in the development of a management strategy for an arterial forestry road—including condition surveys, surface deflection measurements, a data base, a priority-ranking scheme, new performance models, and commissioning trials—are described. A simple PMS was developed to suit the specific planning, programming, budgeting, design, construction, and monitoring needs of the forestry road network. Initially, low-level technology was selected or developed to match the available resources and to enhance the likelihood of implementation and continuing application. Subsequently, more sophisticated pavement evaluation technology and maintenance management and geographic information systems are being introduced to forestry road management.

Unbound granular pavements with adequate drainage, quality aggregate, and proper construction quality control can carry heavy axle loads of up to 16 tons per axle.

The bitumen application rate can be substantially reduced without incurring loss of cover aggregate because the heavy loads quickly compact the particles to their maximum density, thereby producing a tight surface mosaic essential to a durable seal coat. Reseals of polymer-modified bitumens, which are less susceptible to bleeding, sprayed at lower application rates are performing well as a remedy to flushed seal coats. However, polymer-modified bitumen emulsions could be an even more effective solution and should be evaluated in service.

In reseals for heavy axle loads on sealed forestry roads, larger chips are used with a low bitumen application rate.

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