SURFACING FOR HIGH STRESS AREAS

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EXECUTIVE SUMMARY

(1) The project consisted of compilation and examination of a road seal database to examine current practice as regards choice of seal type to counter traffic stress and thus reduce scabbing (chip loss), and to investigate the way in which the degree of scabbing encountered can vary with seal type and traffic stress experienced.

(2) Chipseal and surface type data was gathered from the New Zealand State Highway Road Assessment and Maintenance Management (RAMM) database as at the end of the 1997 RAMM survey. Traffic stresses were indexed as a combination of minimum advisory speed and surface gradient, calculated from road geometry data in the 1992 Road Geometry Data Acquisition System (RGDAS) survey. The two sets of data were matched by computer. The database was supplemented by observing stripping at sites with known traffic stress characteristics (by calculation from the RGDAS data).

(3) Examination of the database for cutback bitumen seals indicated that the pattern of choice of seal type was similar for each type of stress classification, as far as the RAMM data files were able to determine. There was thus no indication, for cutback bitumen seals, that seal designers changed seal type to accommodate the presence of high stress areas.

(4) Analysis of Variance (ANOVA) studies of the database indicated:

(a) There is a hierarchy of stabilities against scabbing of different seal types. In order of decreasing stability against scabbing the chipseal surface types are:

- Grade 5 single coat seal
- Grade 4 single coat seal
- Grades 3/5 two coat seal
- Grade 2 single coat seal
- Grade 3 single coat seal

(b) There is no discernible variation of susceptibility to scabbing from one stress category to another, as far as can be discerned from the data collected.

(5) The observed performance of a given seal type will probably depend not only upon the inherent stability of the compacted seal as regards scabbing, but also upon the type of surface over which that seal type is typically placed.

(6) The method used for classifying seal stress levels, as originally proposed in the brief, did not give any indication that seals lose significantly more chip at high traffic stress levels than at low stress levels. Therefore it is impracticable, at this stage, to provide a set of guidelines for sealing practice that include specific allowance for the traffic stresses experienced at the sealing site.

(7) Work therefore needs to be carried out to devise an alternative method of defining seal stress that relates to scabbing performance. The acceleration or deceleration of traffic as it approaches a seal site will be affected not only by the road geometry at that site but also by the geometry of the preceding road. Taking the details of the preceding road into account may give a better correspondence with chip retention performance.

(8) The apparent lesser susceptibility to scabbing of Grade 2 chip seals as against Grade 3 chip seals was unexpected and its causes need to be investigated. It is premature to recommend that a greater proportion of Grade 2 seals be constructed.

ABSTRACT

Data consisting of levels of scabbing (chip loss) of rating sections of New Zealand state highway chipseals, together with a seal stress classification calculated from the road geometry, were collected and analysed to look for relationships between seal type, seal stress classification and susceptibility to scabbing. The data indicates that there is no evidence of seal designers adjusting the seal type to accommodate for high stress sites. There is a clear hierarchy of seal types as regards susceptibility to scabbing, but no relationship could be found for the proposed stress classification system.

1. INTRODUCTION

With the high stresses developed by modern traffic, the traditional single coat chipseal surface often loses significant amounts of chip very early in its life. Alternative surfacings are available based on a variety of binder types and chip gradings. There is, however, a substantial difference in cost between the surfacings, with costs ranging from $2/m² to over $40/m². The pavement designer at present does not have any guidelines on where the different treatments should be used.

As a step towards developing such guidelines an analysis of current performance is required. This report describes work carried out to achieve this analysis.

2. GENERAL METHODOLOGY

The goal of the work was to develop a system of site classification based on road geometry and traffic volumes. The geometry would be expressed in terms of the "advisory speed" for the site and the longitudinal grade.

Initial work was aimed at obtaining a data file for the New Zealand state highway network (administered by Transit New Zealand) that would list the amount of surface distress of seal sections for different seal types, along with the corresponding road geometry and traffic volumes.

This was followed by classification of the data file sites by seal type, by traffic stress as indicated by road geometry criteria and by amount of chip loss (scabbing) at a set of seal sites.

The file was inspected to see if seal designers were adjusting the seal type to accommodate for high stress sites.

Extra sites for which seal type and stress level were known, but not the level of scabbing, were chosen for visual inspection and estimation of chip loss, to increase the size of the data file used for subsequent analysis.

Proportions of sites stripped for different combinations of seal type and traffic stress level were then calculated to assess the suitability of different seal types for different degrees of traffic stress.

Analysis of variance (ANOVA) studies were conducted on the data file to examine the dependence of scabbing on seal type and traffic stress.

3.0 DATABASE CONSTRUCTION

3.1 Available Data

Advisory speed can be estimated from road geometry data (see below) or measured directly by driving around a curve in a car equipped with a ball bank indicator. Appropriate geometrical data for the complete New Zealand State Highway network was obtained in the Road Geometry Data Acquisition System (RGDAS) survey carried out by the Australian Road Research Board in 1992 under a Transit New Zealand contract. The data has been processed for consecutive 10 m lengths of the network, and is held by Transit New Zealand on compact disk. The formula for calculating advisory speed is:

$$AS = \sqrt{\left(\frac{107.95}{H}\right)^2 + \left(\frac{127000}{H}\right)\left(0.3 + \frac{X}{100}\right)} - \left(\frac{107.95}{H}\right) \qquad (1)$$

where AS = advisory speed (kilometres per hour)
H = curvature (rad/km) = 1000/R
R = radius of curvature (metres)
X = percent cross-slope = 100 tanθ
θ = angle of the cross-slope

Standard Transit New Zealand practice is to assign an advisory speed of 115 km/h whenever equation (1) indicates a larger value than this, and this practice has been followed in the study described in this report.

Any surface distress occurring early in the life of a chipseals is expected to be in the form of chip loss. The standard New Zealand measurement of chip loss is called "scabbing", expressed as the percentage of the area of the road seal surface from which chip has been lost (National Roads Board 1989). Scabbing is estimated annually for the road "inspection sites" on the New Zealand state highway network. The network is divided up into "rating sections" of approximately 500 m with an inspection site of approximately 50 m within each rating section. The inspection sites thus cover approximately 10% of the network. The data is held by Transit New Zealand in their Road Assessment and Maintenance Management (RAMM) system, along with other information on the state of the surface, details of construction and maintenance history, and traffic levels.

3.2 Data Matching

The required data file was obtained by combining information from the RGDAS and 1997 RAMM databases, using the route positions for the rating sections, inspection sites and RGDAS sections to obtain matching of site positions. Matches for 16,496 of the total 21,522 rating sections existing in 1997 were obtained. The resultant file contains data for:

- Rating section position by state highway region, a highway number, and route position. Route position is defined by the distance in kilometres from a state highway route station. Each route station has a fixed location and has been assigned a number unique for the particular state highway by Transit New Zealand.
- Route position of RAMM inspection site.
- Distance in metres from centre of inspection site to the nearest route station.
- Number of lanes.
- Annual average daily traffic (AADT).
- Type of surface.
- Binder type and spray rate.
- Presence of binder additives, type and dosage.

- Presence of cutter, type (kerosene or mineral turpentine) and dosage.
- Sealing date.
- Date of last RAMM survey.
- Seal age at last RAMM survey.
- Percentage of inspection site observed scabbed during RAMM survey.
- Advisory speeds (AS).
- Average, maximum and minimum values for the inspection site.
- Minimum value of AS obtained in the rating section (AS2), along with route position for this site and distance to the nearest route station.
- Gradients, G (as percentages).
- Average, maximum and minimum values for the inspection site.
- Value where AS2 is determined.
- Cross-slopes (X).
- Average, maximum and minimum values for the inspection site.
- Value of G where AS2 is determined.
- Curvatures (H).
- Average, maximum and minimum values for the inspection site.
- Value where AS2 is determined.

3.3 Seal Stress Classification

In the original design of the project it was planned to classify sites with the following categories:

Advisory speed, km/h	<30	30 - 50	>50
Gradient, %	>10	5 - 10	<5

This gives a total of nine separate categories of stress associated with roads.
An examination of the database indicated that there were too few sites in the high stress categories (low advisory speeds and high gradients) to enable a satisfactory statistical study to be carried out, and accordingly the site classifications were adjusted as follows:

Advisory Speed, km/h	<60	60 - 80	>80
Gradient, %	>7	4 - 7	<4

3.4 Current Choice of Seal Types

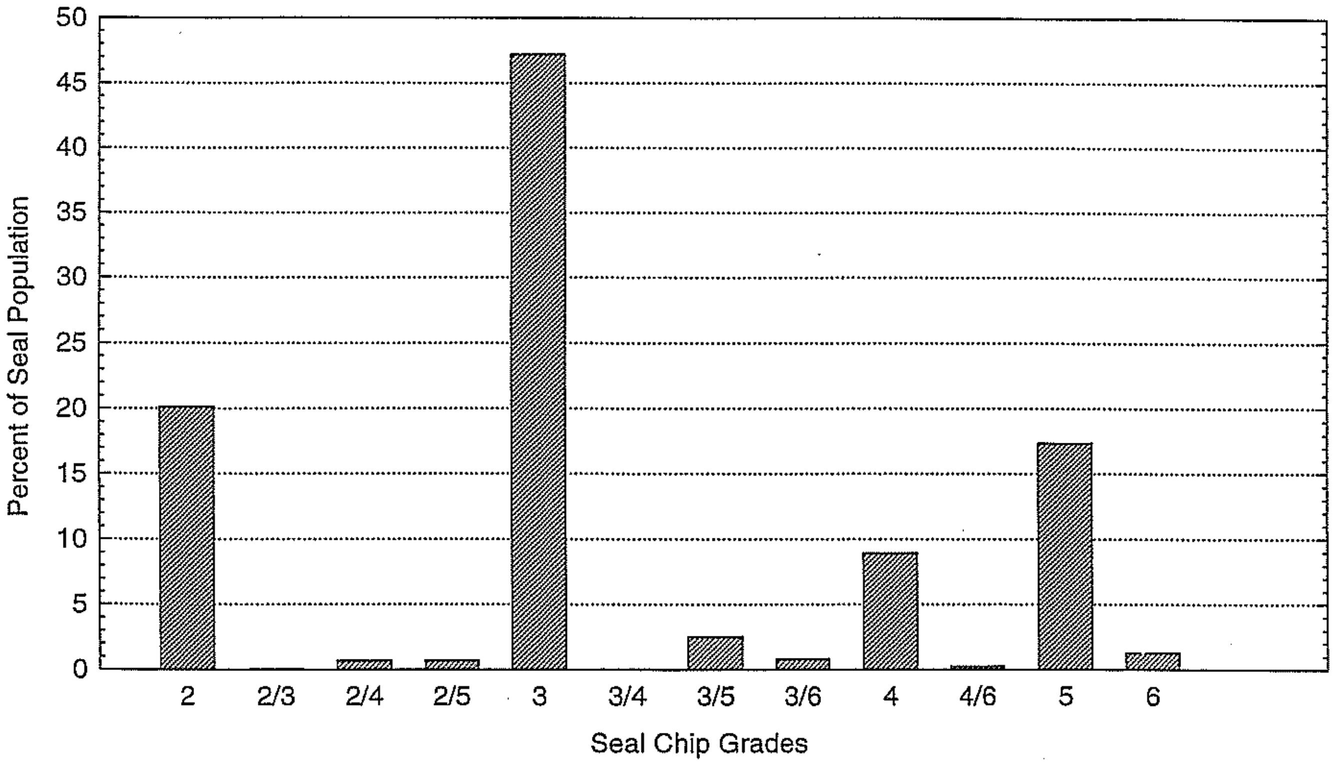
A subset of the 1997 RAMM database consisting of all reseal and second coat seal surfaces constructed using cutback bitumens was analysed to see if the stress levels expected on the surface affected the current choice of seal type. Seal rating sections were classified according to the minimum advisory speed and the gradient at the position where the minimum advisory speed occurred, and the percentage of each type of sealing surface occurring for the classification was calculated. These percentages are listed in Table 1. The overall distribution of seal types for second coat seals and reseals is shown in Figure 1.

Table 1 indicates that the pattern of choice of seal type is similar for each type of stress classification, as far as the RAMM data files are able to determine. There is no indication for cutback bitumen seals that seal designers are adopting particular seal types to accommodate the presence of high stress areas.

Table 1. Percentages of seal types employed for different stress classifications.

Stress range		Surfacing chip grades											
Advisory speed (km/h)	**Road gradient**	**2**	**2/3**	**2/4**	**2/5**	**3**	**¾**	**3/5**	**3/6**	**4**	**4/6**	**5**	**6**
<60	>7%	22.25	0.24	1.44	2.15	45.93	0	4.07	0.96	7.66	0	13.64	1.68
<60	4-7%	24.53	0	2.64	1.03	46.4	0	3.08	0.29	8.66	0.29	12.63	0.44
<60	<4%	21	0	0.77	0.86	47.05	0	4.81	0.36	11.89	0.23	12.48	0.54
60-80	>7%	20.17	0	2.52	0	57.14	0	1.68	0	5.04	0	13.45	0
60-80	4-7%	26.86	0.29	0.57	0.57	46	0	0.57	1.14	6	0	16.57	1.43
60-80	<4%	20.76	0	0.31	0.8	49.33	0	2.17	0.71	10.03	0.19	15.04	0.67
>80	>7%	30	0	0	2.22	45.26	0	2.22	1.11	5.56	0	13.33	0
>80	4-7%	23.42	0	0.53	1.58	49.21	0	1.32	0.79	8.42	0	14.47	0.26
>80	<4%	20.85	0	0.62	0.57	51.76	0.02	2.06	0.87	9.02	0.11	13.40	18

Figure 1. Distribution of reseal and second coat seal types on state highways.



3.5 Selection of Sites for Analysis

3.5.1 Surface type

An initial choice was made of all sites with single or two coat second coat seals and reseals (i.e. seals subsequent to the second coat seals). First coat seals were excluded from the analysis since these are designed to last one or at most two years, so that the requirements for resistance to scabbing are less stringent. In addition, since they are laid directly over basecourse the first coat seals may respond differently to traffic stresses than subsequent seals.

Seals with the following binder types, which are a minority of those used, were excluded from the analysis as they probably have different susceptibilities to scabbing than do cutback bitumens:

- Emulsified bitumens.
- Polymer modified binders. Thirteen different products are in use, and each may behave differently.

3.5.2 Surface Age

Only seals five years old or less at the time of the latest RAMM survey were selected. This means that the age distribution will be approximately the same for all the seal types. To go beyond this age would bias the results, since different seal types are known to have different expected lifetimes (Ball and Owen 1998).

3.5.3 Site Position

The RGDAS survey data had been adjusted for uncertainties in the route positions where readings were taken, by marking where route stations occurred during the survey and adjusting the distance readings for the accurately known positions of the route stations. This means that the closer to a route station the road geometry readings were taken the more accurate the position is likely to be. Accuracy is of obvious importance when it comes to matching up stress level data assessed from the RGDAS road geometry measurements with degrees of scabbing given by the RAMM survey data or subsequent survey.

Consequently, when a large number of data sites were available for a given combination of seal type and seal stress level, the analysis was limited to a selection of those close to route stations.

3.5.4 Selection of Sites for Visual Inspection

For each rating section two sites for sampling were selected:

Type A — The RAMM inspection site. The seal type along with minimum value of advisory speed and the average of the gradient over the 50 m long section were used to characterise this site.

Type B — The site 25 m either side of the position of minimum advisory speed. It was planned to characterise a selection of these sites by seal type, by the advisory speed and the gradient at the centre of the site, and by degrees of scabbing to be observed. Rating sections for which the position of the minimum advisory speed fell within the RAMM inspection site were not included.

The two types of site are not precisely equivalent. There is an indeterminable variation in the position of minimum advisory speed from one RAMM inspection site to another, which would be expected to reduce any correlation between site stress and observed scabbing over the full site. The use of average advisory speed levels over both type A and type B sites was considered as an alternative to minimum values. But this would not be completely satisfactory as the greater degree of scabbing would be expected to occur near the minimum advisory speed positions, and the number of sites available to classify as high stress would be reduced.

The two sets of sites were combined into a single database and then sorted by:

- seal type,
- stress classification, and
- distance from the nearest route station.

The project brief required at least 30 sites for each seal type/stress classification combination for the purposes of the planned analysis. To allow for changes since the RAMM database was compiled (due to work in the 1997/98 sealing season) at least 40 sites of each combination were selected (in some cases 40 were not available; a minimum of 30 was then allowed). From these, the type B sites were then selected for a visual inspection survey.

3.5.5 Visual Survey Procedure

Consultants managing the State Highway Network Maintenance Management contracts for a number of state highway regions were contacted and provided with lists of the sites proposed for inspection within the region. They were asked to verify the site description and note the area of scabbing. A standard report form was supplied. For a variety of reasons it was found that a significant proportion of sites could not be used, due to, for example, replacement of seals by asphaltic concrete or friction course in the immediate area where the minimum advisory speed occurred, more than one type of seal surface being present on the site, the seal having been treated by burning, and application of void fills. Other sites had been resealed, and these were included in the database under their new seal type. In addition, in some cases the visual survey seal description did not match the description in the RAMM system. For these sites, in cases in which the chip grades differed by only one from the description in the RAMM database, the original RAMM survey seal description was retained; otherwise the seal type was altered to that reported from the visual survey. In the end suitable data from 161 sites was available.

3.5.6 Final Database Construction

Because the database from the visual survey was smaller than had been anticipated, it was merged with the full seal database resorted according to inspection site distance from the nearest route station, and sufficiently large samples of each seal type/stress classification combination selected for the planned analysis. In each case all visual survey results were selected.

4.0 ANALYSIS OF DATA

For each seal type/stress classification combination the proportion of inspected sites showing at least 1% (≥1%) and at least 3% (≥ 3%) of the seal as scabbed, as defined for the RAMM system, was calculated as a percentage. The RAMM system takes the 1% and 3% levels as indicating, respectively, the needs to "reseal next year" and to "reseal within budget" (i.e. within the present year). The results of the calculations are shown in Table 2.

Analysis of variance (ANOVA) studies were carried out on the Table 2 data with the seal type and stress classifications being the two factors considered and the percentage proportion of inspected seal sites meeting the "reseal next year" (≥ 1% scabbed) and "reseal within budget" (≥ 3% scabbed) criteria as the variables. Statistica™ software supplied by StatSoft Inc. was employed for the analysis.

There are many seal type/stress classification combinations in Table 2 for which there is no data available, and although the software was capable of dealing with missing data the high proportion of missing data points makes interpretation of the results of the analysis problematical. Accordingly ANOVA studies were also carried out on subsets of the Table 2 data for which inspection will show that values for all data points are available. The three sets of data studied were therefore:

Data set 1. The full set of data in Table 2 with missing data values.

Data set 2. Percent seals stripped values for Grades 2, 3, 4 and 5 single coat seals and Grades 3/5 two coat seals with the following seal stress classifications:

Advisory speed range (km/h)	Gradient range (%)
<60	4 - 7
<60	<4
60 - 80	<4
>80	<4

Data set 3. Percent seals stripped values for Grades 2, 3, and 5 single coat seals and with the following seal stress classifications:

Advisory speed range (km/h)	Gradient range (%)
<60	>7
<60	4 - 7
<60	<4
>80	>7
>80	4 - 7
>80	<4

Table 2. Scabbing data from combined RAMM survey and 1998 target inspection.

Percentage of sections with 3% or greater scabbing

Stress category		Surfacing							
Advisory speed (km/h)	**Road gradient (%)**	**Grade 2**	**Grades 2/4**	**Grades 2/5**	**Grade 3**	**Grades 3/5**	**Grade 4**	**Grade 5**	**Grade 6**
<60	>7	11			30			19	
<60	4-7	15			29	36	13	12	
<60	<4	20			27	17	13	17	
60-80	>7				16				
60-80	4-7	24			18			13	
60-80	<4	26			31	13	12	12	
>80	>7	19			15			10	
>80	4-7	13			44		10	0	
>80	<4	20	0	12	29	6	5	6	9

Percentage of sections with 1% or greater scabbing

Stress category		Surfacing							
Advisory speed (km/h)	**Road gradient (%)**	**Grade 2**	**Grades 2/4**	**Grades 2/5**	**Grade 3**	**Grades 3/5**	**Grade 4**	**Grade 5**	**Grade 6**
<60	>7	26			50			33	
<60	4-7	29			42	36	25	18	
<60	<4	46			39	20	30	22	
60-80	>7				23				
60-80	4-7	42			37			13	
60-80	<4	39			47	17	27	28	
>80	>7	41			31			24	
>80	4-7	16			53		23	0	
>80	<4	44	0	21	42	16	16	10	18

The results of the three analyses are summarised in Appendix 1.

All three analyses indicate that the resistance of chipseal surfaces to scabbing vary significantly from surface type to surface type.

However, there is no discernible variation of susceptibility to scabbing from one stress category to another. These findings are illustrated in Figures 2 and 3. Considering Figure 2, in order of increasing susceptibility to scabbing the seal types, are:

- Grade 5 single coat seal
- Grade 4 single coat seal
- Grades 3/5 two coat seal
- Grade 2 single coat seal
- Grade 3 single coat seal

Seal grades not considered in this analysis are the Grade 6 single coat seal, which would be hard to distinguish from a void fill (if indeed these seals should not have been entered thus into the RAMM database), and the Grades 2/4 two coat seal for which stripping data are available only for low stress category areas. The Grades 2/4 two coat seal shows zero chip loss for low stress areas, so it is possible that this seal type could in fact be the most stable of seal types.

In Figure 3 the three seal stress classifications at the right hand side of the graph are expected to exhibit less scabbing than those on the left hand side. In fact there is no discernible difference in performance.

Figure 2. Mean percentage of seals stripped for different seal types - data set 2.

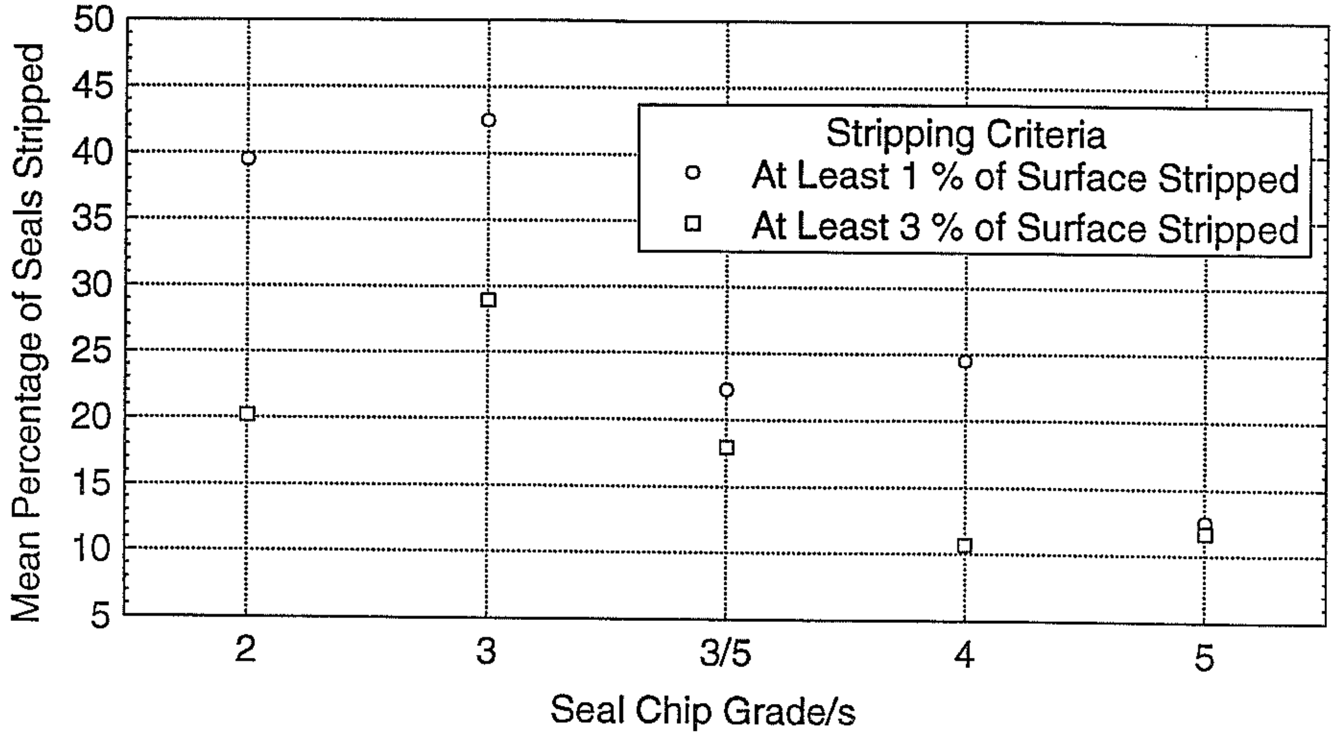
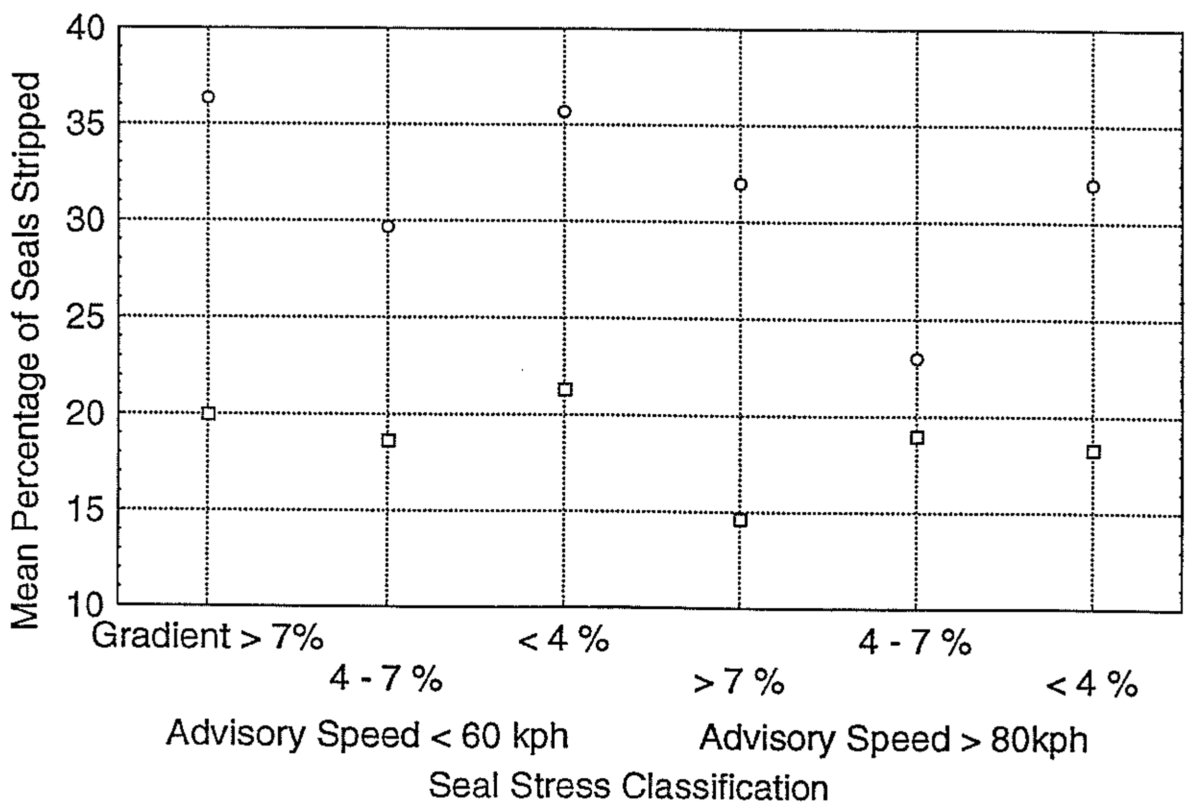


Figure 3. Mean percentage of seals stripped for different seal stress classifications - data set 3.



5. CONCLUSIONS

(1) The pattern of choice of seal type is similar for each type of stress classification, as far as the RAMM data files are able to determine. There is thus no indication for cutback bitumen seals that seal designers are changing seal type to accommodate the presence of high stress areas.

(2) There is a hierarchy of stabilities against scabbing of different seal types. In order of decreasing stability against scabbing the chipseal surface types are:

- Grade 5 single coat seal
- Grade 4 single coat seal
- Grades 3/5 two coat seal
- Grade 2 single coat seal
- Grade 3 single coat seal

The greater susceptibility to scabbing of single coat seals employing Grade 3 chip compared to those employing the larger Grade 2 chip is particularly surprising, as traffic would be expected to exert greater leverage on the Grade 2 chip.

(3) There is no discernible variation of susceptibility to scabbing from one stress category to another, as far as can be discerned from the data collected.

(4) The observed performance of a given seal type will probably depend not only upon the inherent stability of the compacted seal as regards scabbing, but also upon the type of surface over which that seal type is typically placed. The type of underlying surface may explain in part at least the apparent superiority of Grade 2 seals over Grade 3 seals. Again, Grade 5 seals are probably used mainly in texturiser and void fill applications; the frequent entry of this type of surface as a reseal rather than a void fill or texturiser into the RAMM database may indicate an inconsistency of practice in data entry.

(5) The method used for classifying seal stress levels, as originally proposed in the brief, did not give any indication that seals lose significantly more chip at high traffic stress levels than at low stress levels. Therefore it is impracticable, at this stage, to provide a set of guidelines for sealing practice that include specific allowance for the traffic stresses experienced at the sealing site.

6. RECOMMENDATIONS

(1) The method adopted for classifying seal stress levels, as originally proposed in the brief, has failed to give any indication of differences in seal performance across the proposed seal stress categories. Therefore it is impracticable, at this stage, to provide a set of guidelines for sealing practice that include specific allowance for the traffic stresses experienced at the sealing site.

Work needs to be carried out to devise an alternative method of defining seal stress that relates to scabbing performance. The acceleration or deceleration of traffic as it approaches a seal site will be affected not only by the road geometry at that site but also by the geometry of the preceding road. Taking the details of the preceding road into account may give a better correspondence with chip retention performance.

(2) The reasons for the apparent lesser susceptibility to scabbing of Grade 2 chip seals as against Grade 3 chip seals need to be investigated. It is premature to recommend that a greater proportion of Grade 2 seals be constructed. It is possible that the apparent advantage of Grade 2 seals lies in their being used more frequently in situations that are advantageous to single coat seals as a whole, for example in particular areas of the country where the climate is favourable or sealing practices aid early seal stability.

7. REFERENCES

Ball, G.F.A. and Owen, M.T. 1998. Chipseal lifetimes in New Zealand. *Proceedings of the 9th Road Engineering Association of Asia and Australasia Conference* (REAAA), Wellington, New Zealand, 3-8 May 1998, Vol. 1: 452-458.

National Roads Board 1989. Road Research Unit. *RAMM road condition rating manual.* Transit New Zealand, Wellington, 61pp.

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APPENDIX 1

ANALYSIS OF VARIANCE RESULTS

APPENDIX 1

The following abbreviations are used in the tables.

SS	Sum of squares	
MS	Mean square =	SS / (degrees of freedom)
F	F factor =	MS (source of variation) / MS (residual) An F value greater than 1 indicates the corresponding source of variation contributes more to the total variation than random effects
P	Probability level for F factor. A low figure indicates the corresponding source of variation contributes significantly to the total variation. Typically values less than 0.05 are taken to indicate a source of variation is significantly discernable, i.e. this source is influencing the results.	

Data Set 1 (see Section 4 for definition of data set)

	Source of variation	Degrees of freedom	SS	MS	F	P
>1% scabbing	Surface type	7	3655.9	522.3	5.740	0.00082
	Stress category	8	760.3	95.0	1.044	0.43583
	Residual	21	1910.8	91.0		
>3% scabbing	Surface type	7	1716.7	245.2	4.194	0.00490
	Stress category	8	358.3	44.8	0.766	0.63583
	Residual	21	1227.7	58.5		

Data Set 2

	Source of variation	Degrees of freedom	SS	MS	F	P
>1% scabbing	Surface type	4	2511.0	627.8	10.271	0.00075
	Stress category	3	125.4	41.8	0.684	0.57894
	Residual	12	733.4	61.1		
>3% scabbing	Surface type	4	870.7	217.7	5.206	0.01147
	Stress category	3	166.6	55.5	1.328	0.31116
	Residual	12	501.7	41.8		

Data Set 3

	Source of variation	Degrees of freedom	SS	MS	F	P
>1% scabbing	Surface type	2	1919.4	959.7	7.213	0.01150
	Stress category	5	350.4	70.1	0.527	0.75163
	Residual	10	1330.6	133.1		
>3% scabbing	Surface type	2	1057.3	528.7	7.851	0.00891
	Stress category	5	75.3	15.1	0.224	0.9439
	Residual	10	673.3	67.3		