VERIFICATION OF ROAD ROUGHNESS BY PROFILE BEAM DURING CONSTRUCTION

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VERIFICATION OF ROAD ROUGHNESS BY PROFILE BEAM DURING CONSTRUCTION

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AN IMPORTANT NOTE FOR THE READER

The research detailed in this report was commissioned by Transit New Zealand, when it had responsibility for funding roading in New Zealand. This funding is now the responsibility of Transfund New Zealand.

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CONTENTS

EXECUTIVE SUMMARY

This project, carried out between 1992 and 1995, investigated the correlation between road roughness, as measured by the NAASRA roughness meter, and the profile factor, measured by 1 m and 2 m profile beams.

The profile beam is supported on the road surface at its ends, with a device to measure the departure of the surface at the centre of the beam from the plane through its end supports. The profile factor is defined as the standard deviation of the departure from the plane of a series of measurements made along the test length of road.

The investigation found the best correlation was for the 2 m profile beam.

Field trials were carried out in the Wellington region, New Zealand, at 10 construction sites, to measure roughness before and after shape correction.

The report gives details of the beams and the test results, and recommends that:

- A standard method should be developed for designers to select a target profile factor, taking account of the relationship between profile factor and roughness, and of the probability of specified roughness being achieved.
- The 2 m profile beam should be specified as the normal means of measuring road roughness during construction.
- The relationship between profile factor, as measured by the profile beam, and NAASRA roughness, should be specified.
- The method of deriving the profile factor should be published as a Transit New Zealand standard.
- Specifications should state that, in the case of a dispute as to the actual roughness, the NAASRA roughness meter should be taken as the primary means of measurement.

ABSTRACT

The correlation between road roughness, as measured by the NAASRA roughness meter, and the profile factor, measured by profile beams, was investigated, between 1992 and 1995. Field trials were carried out in the Wellington region, New Zealand, to measure roughness before and after shape correction at 10 construction sites. The conclusion is that the 2 m profile beam is a suitable tool to verify road roughness during construction.

1. INTRODUCTION

The economic justification for many road improvement projects is based on the expected decrease in pavement roughness, which benefits the road user by reducing vehicle running costs. Although the economic argument can be justified by using RRU[1] Technical Recommendation TR/9, *The Economic Appraisal of Roading Improvement Projects* (Transit New Zealand 1986), the tools are not available to the construction engineer to ensure that target standards of roughness for new construction, reconstruction or shape correction are met.

Transit New Zealand has adopted the NAASRA[1] road roughness meter as the standard device for measuring road roughness. Detailed information on the use and application of the NAASRA roughness meter can be found in RRU Technical Recommendation TR/12, *Roughness Meter Guidelines* (Transit New Zealand 1988). However, this equipment is inappropriate for construction control purposes because of its high cost and limited availability. Thus there is a need for a tool which can measure pavement shape during construction, and enable both the contractor and the client to be confident of achieving the specified finished roughness value.

Stage 1 of this project investigated the correlation of measurements, using a range of straight edge devices, with NAASRA road roughness results (Patrick 1987). It concluded that these traditional tools were too insensitive to attain the precision required for most road improvements. For road roughness values in the vicinity of 50 NAASRA counts per km, an average deviation of approximately 3 mm under a 3 m straight edge, is required. This is difficult to measure accurately.

The final stage of the project, which was carried out between 1992 and 1995, evaluated the use of a profile beam, which had been shown in Australia (Sheldon 1986) to produce parameters which correlate with NAASRA road roughness on concrete pavements. The expectation was that this relatively simple device would be sensitive enough to be a practical control tool during pavement construction.

This report describes two versions of the device investigated, and their correlation with NAASRA roughness values on 11 test sites in the Wellington region, New Zealand. Recommendations are made on the implementation of the techniques for inclusion in specification requirements, and the results of field trials on 10 construction projects.

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[1]

RRU	Road Research Unit
NAASRA	National Association of Australian State Road Authorities

2. DESCRIPTION OF MEASURING DEVICES

2.1 NAASRA Roughness Meter

Transit New Zealand's NAASRA roughness meter, which is installed in a Holden Commodore, was used for the roughness measurements against which the profile beams were compared. This device quantifies road roughness by dynamic measurement of the vertical movements of the vehicle rear axle as it travels at a constant speed. The parameter which it measures is the number of times the axle moves vertically for a standard distance, per kilometre travelled. The instrument has been calibrated at various speeds, and all data were corrected to roughness values of counts/km at 80 km/h.

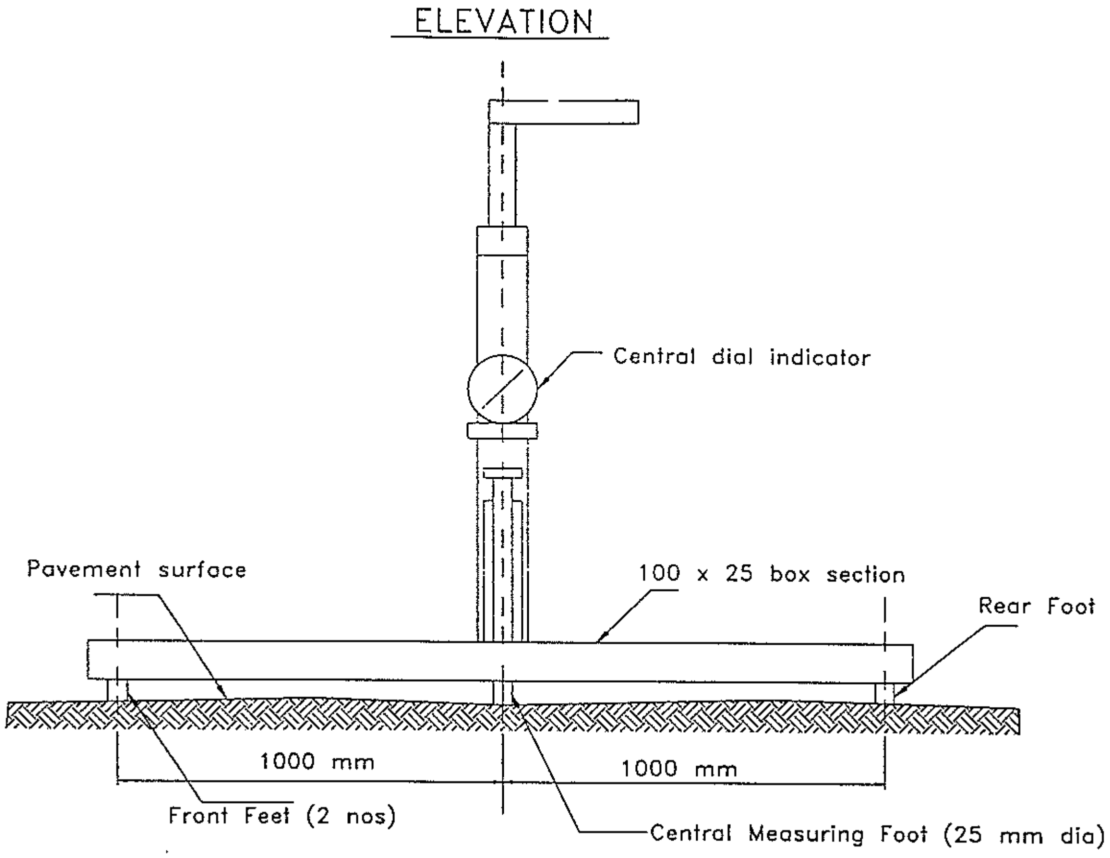
2.2 Profile Beams

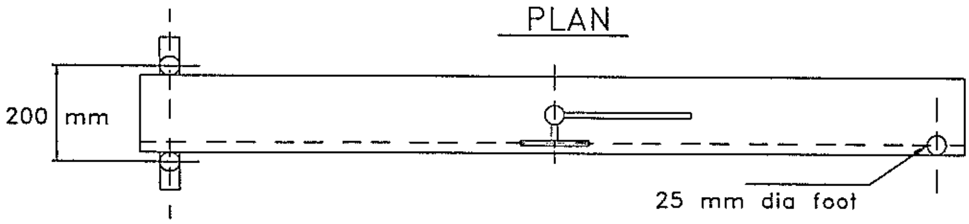
Two profile beams were investigated, with nominal lengths of 1 m and 2 m. In all other respects the beams are identical and both use the same instrumentation. They are based on the design of Sheldon (1986).

Each beam consists of an aluminium box section 100 mm wide by 25 mm deep, supported on three 25 mm-diameter feet, as illustrated in Figure 2.1. A carrying handle is situated close to the centre and an electronic dial gauge with a 25 mm-diameter foot is mounted through the centre of the beam at the mid point. The dial gauge is removable for transport or for use on another beam. A mini-processor is attached to the top of the beam towards one end to record the readings made by the electronic dial gauge. Readings are made using a remote control connected to the mini-processor.

The electronic dial gauge used was a Mututoyo type ID-1050 m with a travel of 50 mm, connected to a Digimatic mini-processor Mututoyo model DP0IDX. Both instruments are battery operated. The mini-processor stores and prints all the readings and computes the required statistics, including mean and standard deviations. The design of the instrument allows all readings and recording to be made by one operator.

Figure 2.1 Diagram of 2 m profile beam.





3. TESTING

3.1 Test Sites

Test sites were required to cover a range of roughness from 50 to 200 NAASRA counts per kilometre, and to be a minimum length of 200 m for low roughness values, but 100 m was accepted where there were site restrictions. Preliminary roughness measurements were made on a range of streets thought to be suitable in terms of width and traffic interference for safety during testing, and from these results the test sites listed in Table 3.1 were selected.

Table 3.1 Test sites in the Wellington region.

Site No.	NAASRA counts/km	Location	Length (m)	Surface
1	36	Martinborough B	200	Sealed
2	117	Port Road 1	200	Sealed
3	82	Port Road 2	200	Sealed
4	55	Whites Line 1	200	Sealed
5	164	Reynolds Street 1	100	Sealed
6	99	Reynolds Street 3	200	Sealed
7	62	Naenae Road 1	200	Sealed
8	122	Kowhai Street 1	100	Sealed
9	193	Kowhai Street 2	100	Sealed
10	49	Tauweru 1	100	Unsealed
11	31	Tauweru 2	100	Unsealed

3.2 Test Procedure

3.2.1 NAASRA Roughness Meter

At the test site the wheeltracks were identified and marked with spray paint at 10 m intervals, to guide the vehicle driver. Measurements were taken from the kerb or centreline along the length of the site, in order to locate the wheeltracks for possible future reference. Five test runs were performed at each test site and the results were averaged. The average values for each site are given in Table 3.1.

3.2.2 Profile Beams

The 1 m and 2 m profile beams were initially calibrated on a flat bed in order to obtain the dial gauge readings corresponding to the plane through the feet of the beam. This initial calibration allowed the variation of the pavement surface from the plane of the beam to be measured. The method as described by Sheldon (1986) uses the standard deviation of the readings, and for that statistic the initial calibration is not required. In this investigation both parameters were compared with the NAASRA roughness value.

After the roughness meter tests, a string line was laid along each marked wheeltrack. The beam was moved end-for-end along the string line, and a reading was taken at each position. This produced 200 readings per wheeltrack with the 1 m beam and 100 readings per wheeltrack with the 2 m beam on a 200 m test section. Any obvious stones or loose debris under a foot of the beam was removed before recording each reading.

3.3 Test Results

The statistical parameters calculated from the test results are given in Tables 3.2 and 3.3. Table 3.4 gives the results of linear regression of NAASRA counts against the various parameters obtained from each device. In this table, r^2 is the correlation coefficient. A value of $r^2 = 1.0$ would imply perfect correlation, and $r^2 = 0$ would imply no correlation. The intercept is the point where the regression line crosses the NAASRA roughness axis. It can be seen that results for all parameters from both profile beams correlate well with those from the NAASRA roughness meter.

The following points emerge from these results:

- The correlation coefficient varies between the inner and outer wheeltracks.
- With the 1 m profile beam, the inner wheeltrack had the best correlation coefficient, but with the 2 m profile beam the outer wheeltrack had the best correlation.
- The best correlation obtained was with the 2 m profile beam using the average standard deviation for each wheeltrack.

In Figures 3.1 and 3.2 the average value of the standard deviation for both wheeltracks (termed the "profile factor") is plotted against NAASRA counts per km for both the 1 m and 2 m beams. The regression equation for the profile factor for each beam is also plotted.

Since the major advantage of the profile beam, as proposed by Sheldon, is that absolute measurements of deviation from the plane through the beam feet are not required, then further investigations into the applicability of the average variation were not explored.

Figure 3.1 **Profile factor v NAASRA counts/km for the 1 m profile beam.**

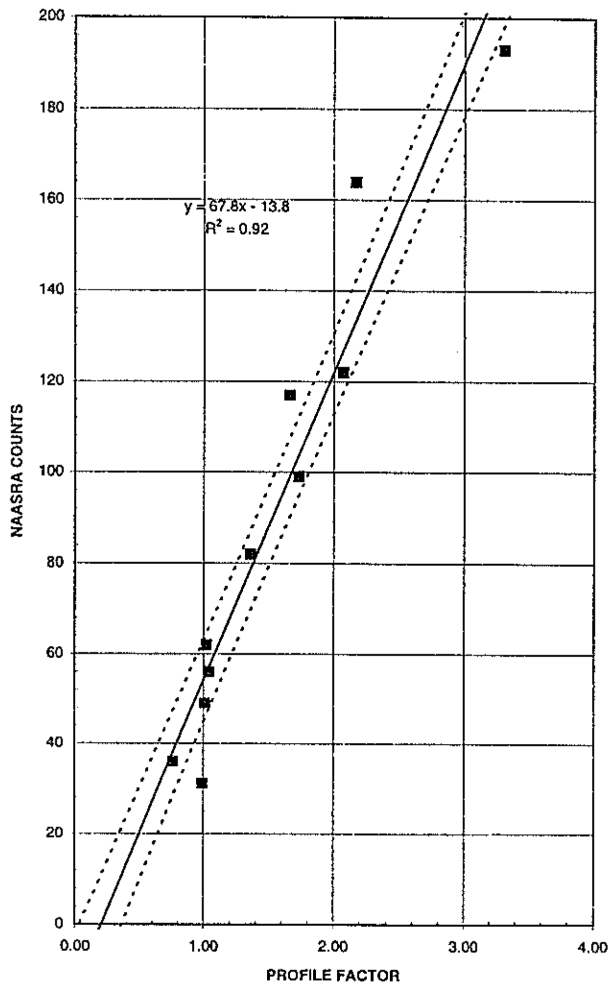
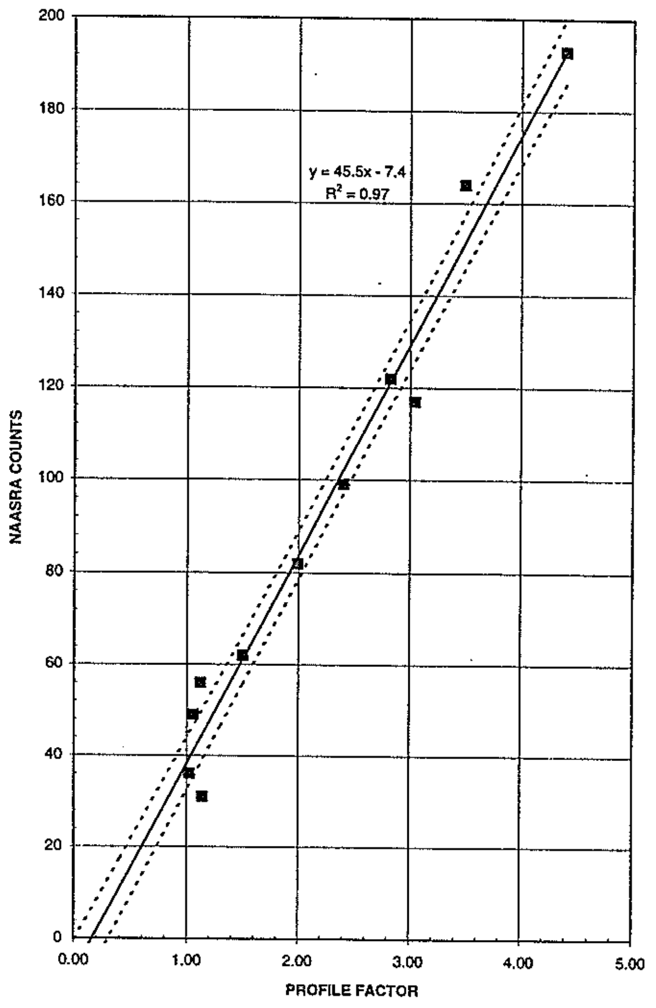


Figure 3.2 **Profile factor v NAASRA counts/km for the 2 m profile beam.**



The readings obtained at two sites using the 2 m profile beam were checked to ascertain whether they conformed to a normal distribution, and thus verify that statistical concepts based on normally distributed data would be valid. A normal distribution plot is compared with histograms of data from Kowhai Street site 2 and Martinborough B, with roughness values of 209 and 41 respectively, in Figures 3.3 and 3.4. The data appear to be normally distributed.

Table 3.2 1 m profile beam results.

Site	Inner wheeltrack		Outer wheeltrack		Average	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	1.04	0.83	1.15	0.68	1.10	0.76
2	1.38	1.85	1.12	1.44	1.25	1.66
3	0.69	1.59	0.78	1.09	0.74	1.36
4	0.60	0.80	0.71	1.24	0.66	1.04
5	1.66	2.21	1.67	2.12	1.67	2.17
6	1.07	1.40	1.18	2.01	1.13	1.73
7	0.79	0.98	0.81	1.05	0.80	1.02
8	1.52	2.11	1.58	2.03	1.55	2.07
9	1.77	2.63	2.24	3.87	2.01	3.31
10		1.01		1.00		1.01
11		1.04		0.93		0.99

Table 3.3 2 m profile beam results.

Site	Inner wheeltrack		Outer wheeltrack		Average	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	0.91	1.23	0.65	0.74	0.78	1.02
2	2.78	3.58	1.93	2.39	2.34	3.04
3	1.36	1.94	1.33	2.03	1.35	1.99
4	0.88	1.11	1.00	1.12	0.94	1.12
5	2.42	3.42	2.46	3.56	2.44	3.49
6	1.73	2.37	1.81	2.42	1.77	2.40
7	1.29	1.43	1.24	1.56	1.27	1.50
8	2.21	2.92	2.00	2.72	2.11	2.82
9	2.77	4.00	3.39	4.76	2.58	4.40
10		1.10		1.03		1.06
11		1.30		0.95		1.14

Figure 3.3 Comparison of distribution plot with frequency histogram for Kowhai Street test site.

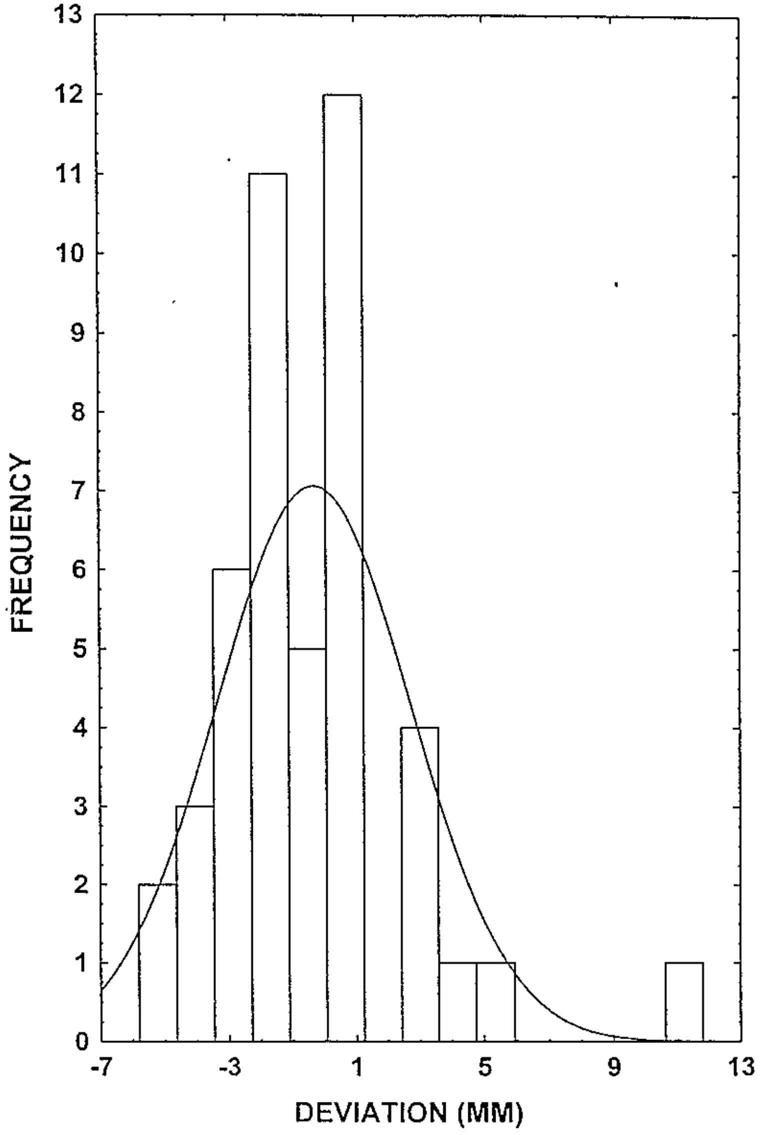


Figure 3.4 Comparison of distribution plot with frequency histogram for Martinborough test site.

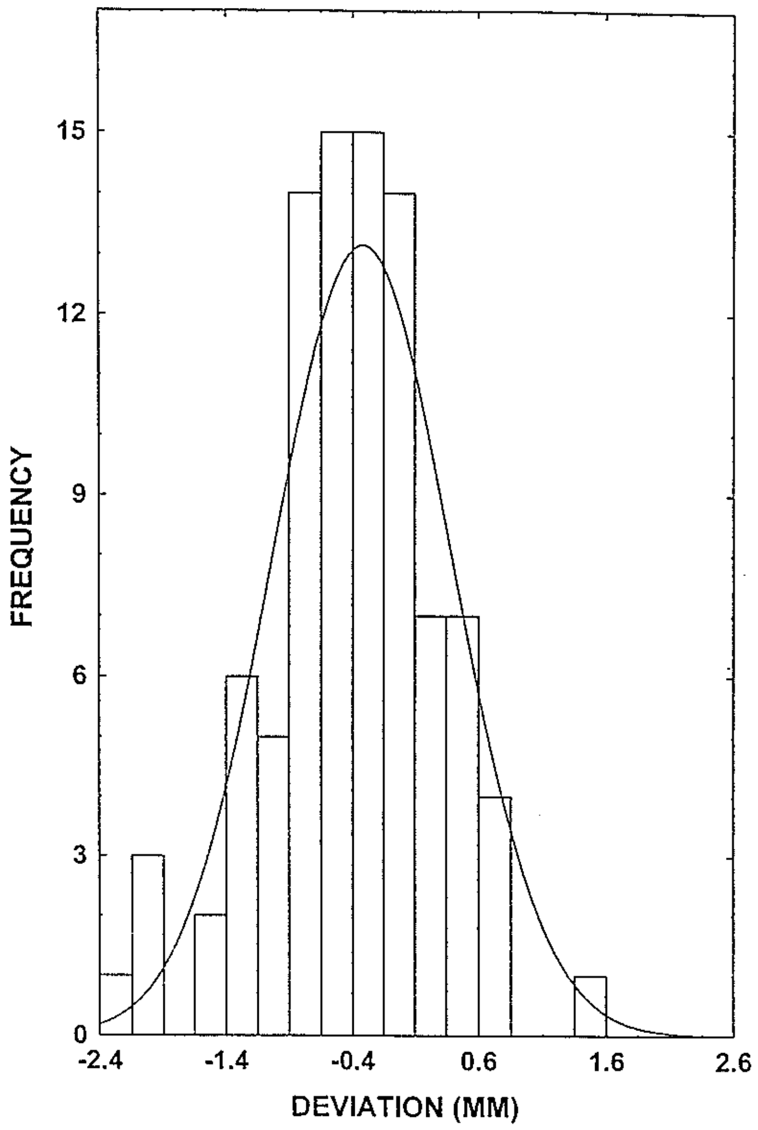


Table 3.4 Linear regression relationships with NAASRA counts.

Beam	r^2	Intercept	Slope	No. of sites
1 m Profile Beam				
Average variation	0.79	-17.4	99.5	9
Average std dev	0.92	-13.8	67.8	11
Inner wheeltrack std dev	0.91	-28.6	80.5	11
Outer wheeltrack std dev	0.81	7.7	52.8	11
2 m Profile Beam				
Average variation	0.90	-22.2	72.5	9
Average std dev	0.97	-7.4	45.5	11
Inner wheeltrack std dev	0.90	-9.9	45.8	11
Outer wheeltrack std dev	0.97	2.5	42.1	11

3.4 Discussion

The results of the regression analyses given in Table 3.4 confirm the results of Sheldon (1986), in that a significant correlation exists between the NAASRA roughness values and the profile factor as measured using the 1 m profile beam. The correlation coefficient for the 1 m profile beam of $r^2 = 0.92$ on 11 sites, compares with $r^2 = 0.81$ on 24 sites reported by Sheldon (1986).

The better correlation of the 2 m profile beam with NAASRA roughness suggests that this device is more suitable for construction control. Some of the variation in the data could be attributed to inaccuracy of the roughness meter measurements. For example, the unsealed sections were only 100 m in length with low roughness values. This length was used because of site restrictions, but it is too short to obtain accurate values.

4. APPLICATION TO SPECIFICATIONS

4.1 Achievement of Design Roughness

The objective of this stage of the project was to assess the applicability of the profile beam as a construction control tool which could be used as a specification requirement. Even though this investigation has shown that good correlation exists between the profile factor, calculated using the 2 m profile beam, and NAASRA roughness, its use in a specification requires a knowledge of achievable roughness and an appreciation of the accuracy achievable when using an indirect measurement technique to predict the value of a given parameter.

At present there appears to be no published New Zealand data on the change in NAASRA roughness value obtainable when granular or asphaltic shape correction material is used. It is likely that the achievable roughness value will be dependent on:

- the initial roughness;
- the thickness of shape correction material;
- the construction technique.

In order to specify a maximum roughness for construction, first it must be demonstrated that, for the particular pavement and using the thickness of material specified, this value is achievable.

The use of the profile beam in a specification therefore requires the pavement designer to appreciate the accuracy of the technique to predict NAASRA roughness and to choose a profile factor which takes into account the uncertainties involved.

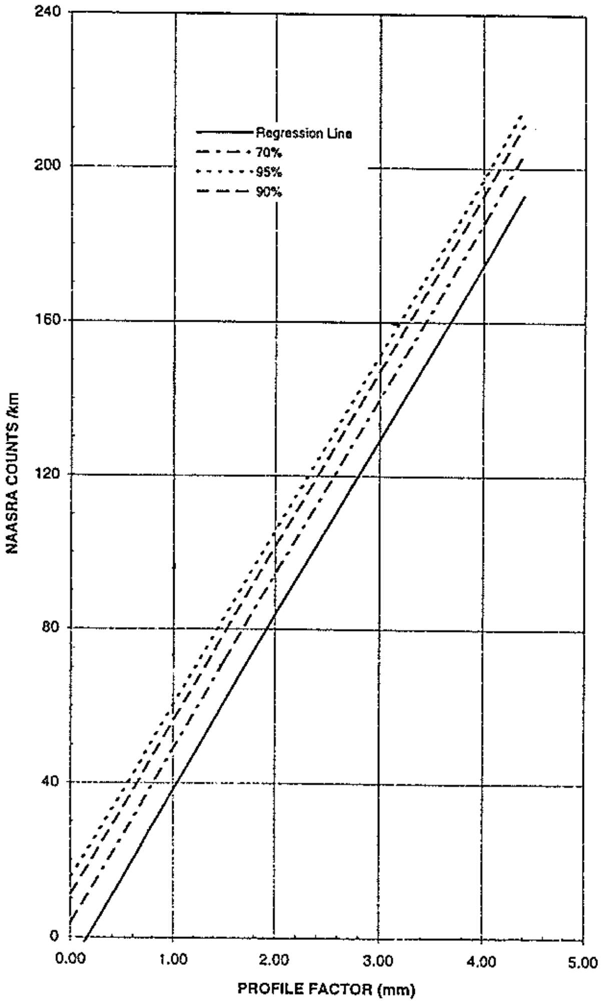
4.2 Selection of Profile Factor

The selection of the maximum allowable profile factor to be specified requires a decision on the level of risk that, even if this value is achieved, the NAASRA roughness may be greater than required.

Figure 4.1 shows the regression line for the 2 m profile beam, together with the 95%, 90% and 70% upper prediction limits. The latter are the lines below which 95%, 90% and 70% of values respectively would fall, and take into account variations in the measurement of NAASRA roughness and the profile factor.

If a maximum NAASRA roughness of say 70 counts per km is required, achievement of a maximum Profile Factor of 1.12 mm would give 95% confidence that 70 counts/km would be achieved. Similarly, achievement of a profile factor of 1.4 mm would give 70% confidence in the result.

Figure 4.1 95%, 90% and 70% prediction limits for the 2 m profile beam.



However, the accuracy with which the profile factor itself is known is dependent on the number of measurements taken. This can be quantified by using the chi-squared distribution, which is a standard statistical tool. The task is to determine the number of observations, n, which are required to ensure that the profile factor will be greater than a factor λ times the value recorded, at a prescribed level of significance, normally 5%. Figure 4.2 shows the operating characteristic curves for 5% level of significance.

Take the required profile factor of 1.0 referred to above, for 95% confidence in achieving a roughness of 70 counts/km. Entering Figure 4.2 at a level of risk (β) of 0.05, or 5%, shows that λ is 1.25 for 100 observations. This means that when 100 observations are made, the client's risk is 5% that the true value of the profile factor is greater than:

1.0 x 1.25 = 1.25 mm, which corresponds to 50 counts/km

If only 20 observations were made, λ is 1.75. Then at 5% risk the true value could be greater than:

1.1 x 1.75 = 1.75 mm, which corresponds to 72 counts/km

As the measurement of the profile factor is relatively quick and simple, it is proposed that normally 100 test points would be measured.

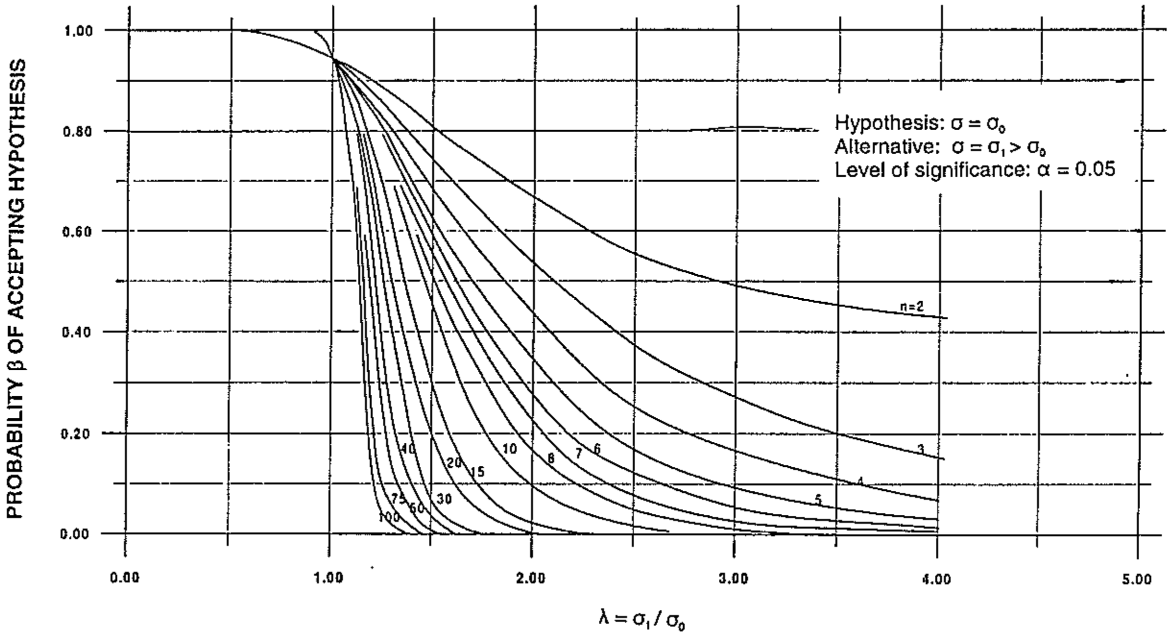
The contractual implications must also be recognised, because the specification of a maximum profile factor of 1.0 mm would mean that the average NAASRA roughness obtained would be 50 counts/km (see Figure 3.2). This is significantly lower than the pavement designer's requirement of 70 counts/km. To consistently achieve the required profile factor may result in increased costs to the contractor and ultimately to the client.

The client has to balance the risk of obtaining a higher than desired pavement roughness with the increased costs that will occur if restrictive requirements are imposed. The client has also to recognise that any test to measure pavement or material properties also has a risk that errors associated with the sampling scheme could mean that the "true" mean property may be outside the specification limit.

If more data are gathered, especially in the roughness range of 30 to 100 counts/km, the prediction limits may be able to be narrowed. This would allow a less severe requirement to be specified without increasing the client's risk.

A specification should also provide for the use of the NAASRA roughness meter as a check on the value derived from the profile factor, if there is any dispute over the reliability of the latter.

Figure 4.2 Operating characteristic (OC) curves for testing the hypothesis $\sigma = \sigma_0$ against $\sigma = \sigma_1 > \sigma_0$ by the x^2 test.



5. TRIALS

5.1 General

The 2 m profile beam was used to measure roughness on a series of 100 m test sections, both before and after shape correction. The method was that described in Section 3.2.2 of this report, and approximately 50 observations were made in each wheeltrack. The relationship for average standard deviation listed in Table 3.4 was used, i.e.:

$$NAASRA\ Roughness = 45.5 * (profile\ factor) - 7.4$$

The initial roughness of test sections ranged from 45 to 230 counts/km.

5.2 Sites Using Granular Overlay

Table 5.1 lists seven projects (A to G) where grader-laid granular material was used for shape correction. A total of 70 separate test sections were measured. The table shows the average NAASRA roughness for all test sections in each project before and after shape correction, as derived from the profile factor. The change in roughness is also shown. All except project B show improvement, although there is a wide scatter. The before and after values for every test section are plotted against each other in Figure 5.1, which illustrates that there is no discernible pattern.

Project B was unusual in that it used a low fines basecourse (as a guard against frost heave), which was laid and primed to resist traffic damage, all on the same day. As this was a non- traditional method, and was concerned with pavement strengthening rather than shape correction, it has not been included in subsequent analysis. It illustrates that design roughness may not be achieved when using unusual methods or materials.

Table 5.1 Roughness change using granular materials.

Project	NAASRA counts/km		
	Before	After	Change
A	64	57	–7
B	103	103	0
C	131	72	–59
D	92	74	–18
E	195	65	–130
F	87	68	–19
G	50	54	+4

5.3 Sites Using Asphaltic Overlay

Table 5.2 lists three projects (H, I, J) where grader-laid asphaltic concrete was used, consisting of 10 mm maximum stone size and with binder content 1.0% below optimum. Normal practice is to specify zero thickness over the high spots and fill in between them as necessary. The NAASRA roughness is shown before and after shape correction, together with the change produced.

On Project I a limit on the quantity of mix was specified, and the contractor contended that this resulted in the limited improvement. However, subsequent overlay of a 20 mm friction course resulted in a roughness of 50 counts/km, which was a substantial improvement. Similarly, on project J, a subsequent 20 mm friction course resulted in a final roughness of 57 counts/km.

Table 5.2 Changes in grader-laid asphalt roughness.

Project	NAASRA counts/km		
	Before	After	Change
H	74 74 55 100 100 97 97	65 58 55 53 61 53 66	–9 –16 0 –47 –39 –34 –31
I	136	123	–13
J	-	94	-

5.4 Discussion of Project Trials

To obtain an overall view of the effectiveness of shape correction in improving roughness, a histogram of the frequency of change in roughness attained is presented in Figure 5.2 (omitting project B). The frequency is in terms of the percentage of the total number of test sections in each increment of roughness change. This figure shows two distinct populations. The greatest changes came from project E, which used lime stabilisation. It also shows that a small percentage of test sections exhibited an increase in roughness. These were typically sections which had a value of less than 90 counts/km before treatment.

Figure 5.1 Relationship between roughness before and after shape correction for granular overlay.

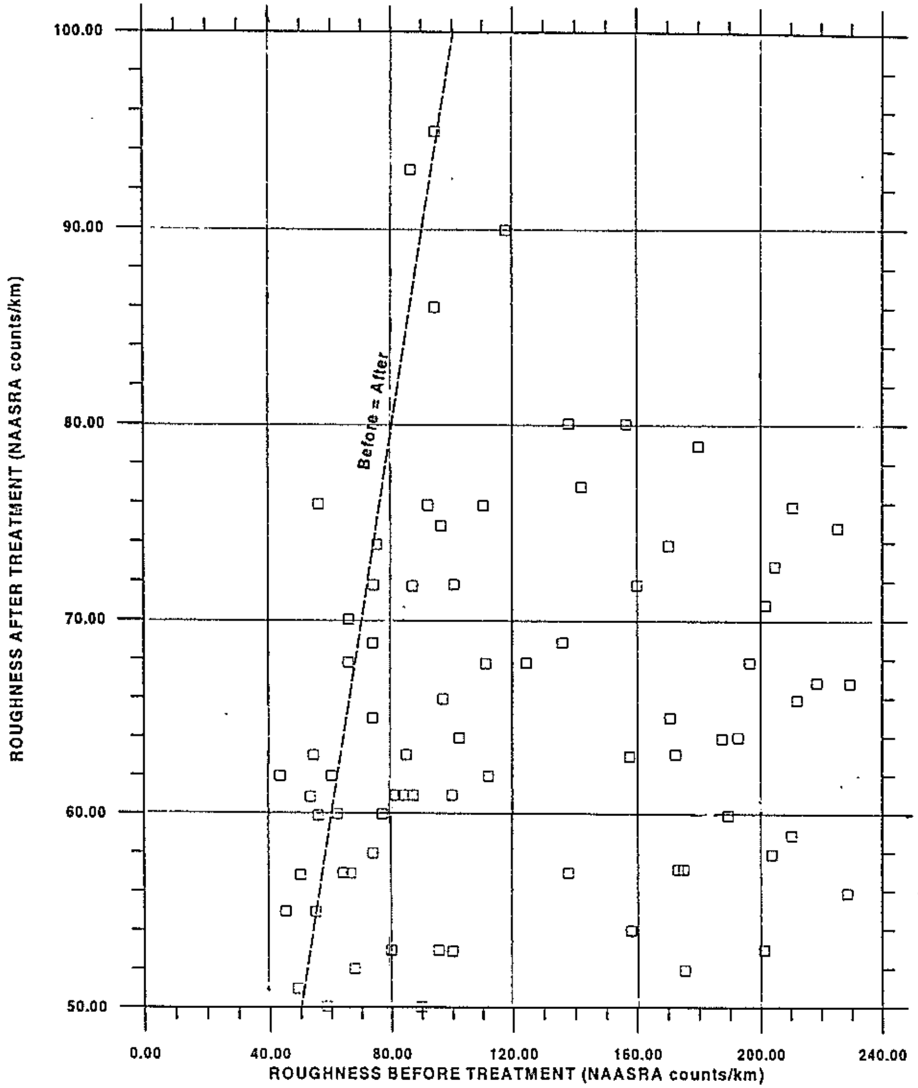
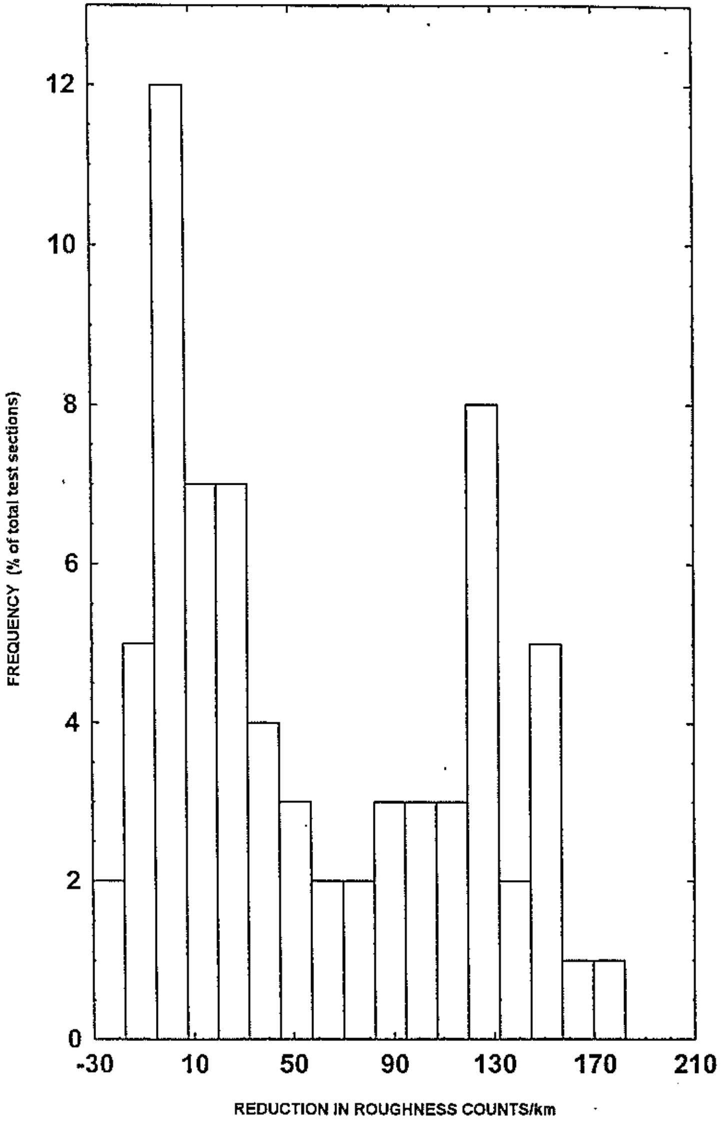
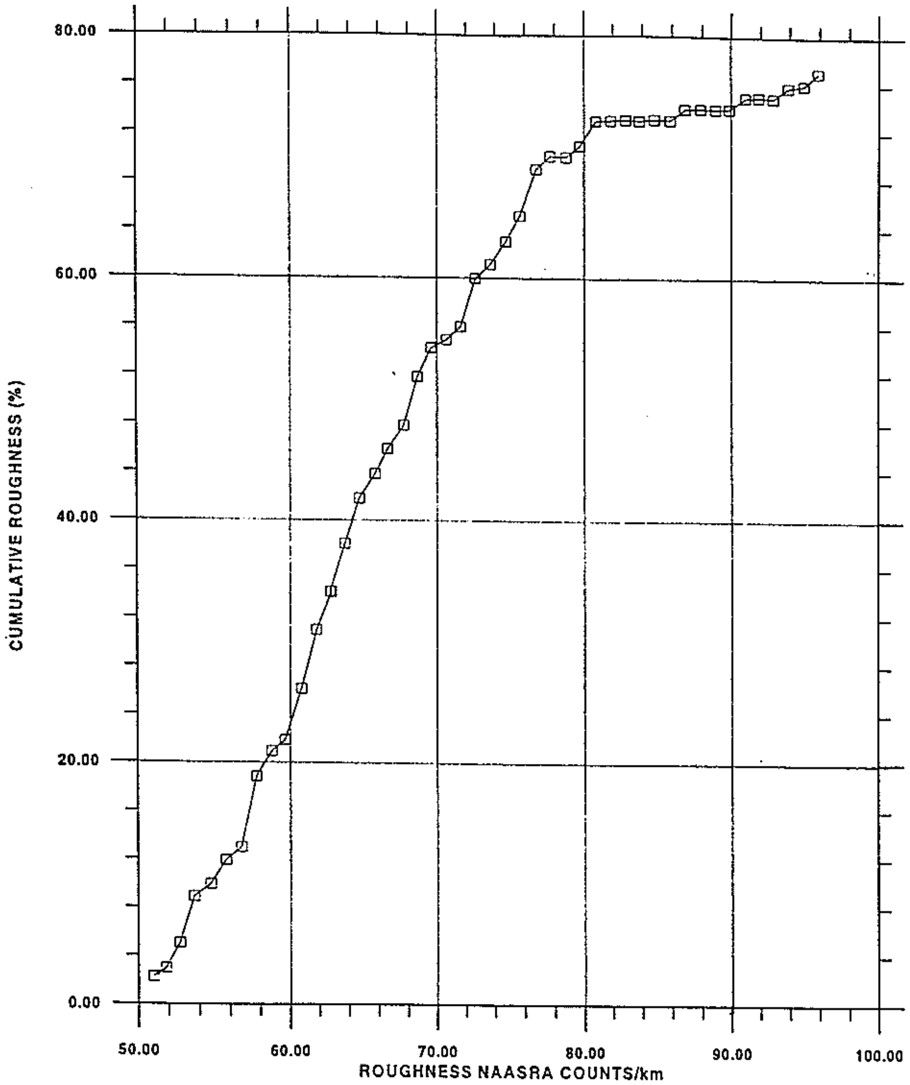


Figure 5.2 Histogram of change in roughness attained by shape correction.



The cumulative frequency of roughness after treatment of those sections with an initial roughness of 80 counts/km or more is shown in Figure 5.3, and shows that only 52% of test sections had roughness of 70 or less after treatment, 64% had less than 75, and 74% had less than 80.

Figure 5.3 Cumulative frequency of roughness after shape correction.



6. CONCLUSIONS

The conclusion is that the 2 m profile beam is a simple and relatively cheap device which can be used to measure road roughness with an acceptable degree of accuracy, and that it is therefore a suitable means of measuring roughness during construction.

7. RECOMMENDATIONS

It is recommended that:

- A standard method should be developed for designers to select a target profile factor, taking account of the relationship between profile factor and roughness, and of the probability of specified roughness being achieved.
- The 2 m profile beam should be specified as the normal means of measuring road roughness during construction.
- The relationship between profile factor, as measured by the profile beam, and NAASRA roughness should be specified.
- The method of deriving the profile factor, given in Appendix 1, should be published as a Transit New Zealand standard.
- Specifications should state that, in the case of a dispute as to the actual roughness, the NAASRA roughness meter should be taken as the primary means of measurement.

8. REFERENCES

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APPENDIX 1

DETERMINATION OF PROFILE FACTOR AS A MEASURE OF ROAD ROUGHNESS

(Using the 2 m Profile Beam)

A1. Scope

This test method sets out the procedure for the determination of the longitudinal road surface profile factor using a 2 m profile beam.

The test consists of measuring the profile readings using a 2 m profile beam along two sample paths over the test length.

The profile factor is calculated and is used to determine the NAASRA roughness of the pavement.

A2. Definitions

(a) The *profile reading* (in millimetres) is the central right angular offset between the profile beam reference plane and the test surface.

The reference plane is parallel to the plane through the three feet of the profile beam, and passes through the dial gauge foot when the gauge reads zero.

(b) *Sample paths* are located parallel to either the road centreline or the longitudinal construction joint.

The two paths are to be located between 1 m and 3 m apart transversely, and at least 0.5 m from a formed edge.

Profile readings are not to be recorded when the profile beam spans a transverse joint shown on the plans or a construction joint.

(c) The *profile factor* (PF) in millimetres is the average of the standard deviation of profile readings for each of the two adjacent sample paths over the test length.

A3. Apparatus

The 2 m profile beam is shown in Figure 2.1, and shall be equipped with a central dial gauge with a resolution of 0.05 mm or better, either manually operated or with an automatic data capture and recording system.

A4. Procedure

(a) The test shall be performed using either one of the following sample path configurations, depending on the continuous length available for testing:

  - (i) Length 100 m or greater: profile readings shall be taken at 1 m intervals over a test length of 100 m;
  - (ii) Length from 50 m to 100 m: profile readings shall be taken at 0.5 m intervals.

(b) Mark the start position and the two sample paths for the length to be tested.

(c) Position the beam in the sample path with the rear single foot on the start position, removing any loose debris from under the feet.

(d) When the beam is steady, freestanding, and the feet of the beam are not in contact with debris, record the profile reading to the nearest 0.1 mm.

(e) If the magnitude of the profile reading appears large, re-check that none of the beam is resting on debris.

Slightly reposition the beam and re-take a reading if the beam is found to be positioned on debris.

(f) Reposition the beam to the next interval in the same sample path.

(g) Continue steps (d), (e) and (f) until the test length has been completed.

(h) Recommence from step (c) for the adjacent sample path and repeat over the same test length.

A5. Calculations

(a) Calculate the sample standard deviation, S_1, of the profile readings over the test length for the first sample path. Calculate S_2 for the adjacent sample path.

$$S_1 = \frac{\sqrt{n \, \Sigma \, X_j^2 - (\Sigma \, X_j)^2}}{n \, (n - 1)} \tag{1}$$

where:
S_1 = standard deviation
n = number of readings
X_j = jth profile reading

(b) Calculate the profile factor, PF, for the test section as the average of the two standard deviations:

$$PF = \frac{(S_1 + S_2)}{2} \tag{2}$$

A6. Reporting

(a) Description of test site.

(b) Lane or section tested.

(c) Length and width represented by test.

(d) Number of readings (n) in each sample path.

(e) Distances and profile readings (mm) for each sample path.

(f) Standard deviation (S_1 and S_2) for each sample path.

(h) Profile factor (PF) (to nearest 0.1 mm).

(i) Date, time and name of operator.