ASSESSMENT OF ROAD ROUGHNESS MEASUREMENT SYSTEMS

USED IN RODNEY DISTRICT

by

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1. INTRODUCTION

This paper has been prepared at the request of the Rodney District Council (RDC) Engineering staff. The staff were concerned at major discrepancies in the road roughness measurements for the district roads between 1991 and 1992. The 1991 surveys were conducted by Beca Carter Hollings and Ferner (BCHF) while the 1992 surveys were done by Works Consultancy Services (WCS). It was requested than an independent assessment be made of the accuracies of the different roughness measurement systems and an explanation be given as to why these differences have arisen. It should be noted that these differences have not only arisen in RDC, but have also apparently been reported in at least two other local authorities.

As background, the author of this paper has recently returned to N.Z. after working in Thailand and Myanmar (Burma). While there, he was involved in calibrating roughness vehicles. Before these projects, he worked with BCHF in N.Z. in setting up their roughness vehicle. Among his current projects is the preparation of a report for the World Bank on guidelines for calibrating economic appraisal models for developing countries. Part of these guidelines deal with calibration of roughness meters. He has operated a roughness meter in N.Z. as part of an Auckland University research project, and is thus familiar with both the theoretical and practical implications of setting up, calibrating and operating road roughness meters. He is currently completing a Ph.D. at Auckland University and was engaged by WCS as an independent consultant for this project.

This paper commences with an overview of roughness measurement techniques. This is followed by a summary of the accepted practices for calibrating roughness meters as recommended by the World Bank and recommendations on operating practices. A description is then given of the calibration techniques used by BCHF and WCS along with an assessment of their relative merits and shortcomings. This is followed by recommendations concerning overcoming the differences between the 1991 BCHF and the 1992 WCS roughness surveys.

This paper also discusses the broader issue of roughness meter calibration since during the course of this work the author learned that BCHF and WCS use fundamentally different approaches to roughness meter calibration. BCHF continually recalibrate their vehicle to their test sections while WCS follow a different calibration philosophy based on the Transit N.Z. (TNZ) Technical Recommendation TR12 "Roughness Meter Guidelines" (Duffill Watts and King, 1988). The latter sees a single calibration equation used for the vehicle as long as it is within 2.5%$\pm$5 counts/km of the previous tests. Since roughness meter calibration is fundamental to obtaining accurate measurements, the paper will consider issues arising from these different calibration philosophies.

2. WHAT IS ROAD ROUGHNESS AND HOW IS IT MEASURED

The International Road Roughness Experiment (IRRE) defined road roughness as: "the variation in surface elevation that induces vibrations in traversing vehicles" (Sayers, et al., 1986a). For a long time it has been recognised that roughness is an important issue. Not only does it have a direct influence on vehicle operating costs, ride comfort and safety, but the dynamic loads that are induced by roughness are a factor contributing to pavement deterioration.

In order to measure the roughness, it is necessary to know the surface elevation - the longitudinal profile. The best way of measuring this is with a profilometer. Profilometers range from static profilometers - a straight edge and wedge - to high speed profilometers which use lasers or accelerometers for their measurements. The former are not practical for covering long distances while the latter are relative modern developments and very expensive.

The alternative approach to a profilometer is to use an instrumented vehicle which records how the vehicle responds to the road roughness. These instruments produce a numeric which is proportional to roughness. The systems are called "response-type road roughness measurement systems" (RTRRMS) and have been developed over time in response to a need to measure roughness. There are a variety of different instruments, including the NAASRA meter, TRRL Bump Integrator and the NITRR Linear Displacement Inducer.

All of these instruments operate on a similar principle. The instrument is attached to the floor of a vehicle and is connected to the rear differential by a cable. As the vehicle travels along the road a uni-directional clutch records the displacement of the vehicle floor relative to the axle. The measurements of these instruments is quite crude, being influenced by many factors including:

- Vehicle speed, acceleration/deceleration.
- The lateral placement of the vehicle.
- Changes in suspension components (e.g. shocks, springs, tyres) over time.
- The mechanical components of the RTRRMS wear and are affected by the ambient environment.
- Tyre pressure
- Vehicle load

Because of all these effects, the measurements from an RTRRMS are not very accurate. As described in Sayers, et al. (1986b) there are three main sources of error:

Repeatability Error: This is influenced by (1) the accuracy of the instrumentation; (2) the random locations of the specific points along the wheelpath where the measurements are taken; (3) the partly- random selection of the wheelpath.

Calibration Error: The RTRRMS calibration may not cover all of the variables which affect the measurements. This will mainly be manifested in the form of systematic errors in the RTRRMS.

Reproducibility Error: Two different instruments may rank several roads in different order by roughness. This form of error arises mainly in comparing different types of instruments as opposed to the same type of instrument in different vehicles.

Given the above considerations, what is the magnitude of the error one can expect from an RTRRMS? The following statement from Paterson (1985) gives a good indication:

> [for a run over 3 x 320 m or 1 x 1 km] "the average measurement error observed across time and across test vehicles in the studies ... was approximately 14%, with 95th percentile confidence limits of -27 and +31%"[1]

This error was four times greater than the typical annual changes in roughness on a pavement (Paterson, 1985). It is thus **impossible** to use an RTRRMS for accurate monitoring of road roughness on a year by year basis. Over time - typically about 4 years - the data will give you the trend in roughness progression, but the year to year differences should be used with discretion. It is because of these differences that when accurate roughness measurements are required, for example in pavement deterioration studies, the practice is to use a profilometer.

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[1] Paterson (1985) also states that in PMS studies "interpolation between measurements is often necessary when merging data with other condition data, and this reduces the average measurement error to 10%".

Since the response of a vehicle to road roughness will depend upon the characteristics of the suspension system, tyres and other factors, it is necessary to calibrate the vehicle against a standard reference roughness. There are two commonly used reference roughnesses: the International Roughness Index (IRI) and the TRRL BI. The IRI was developed by the World Bank (Sayers, et al., 1986b) and is based on a complex simulation of a vehicle suspension. The TRRL BI is the roughness as measured by a Bump Integrator trailer at a speed of 32 km/hr. The IRI has become the accepted international standard.

New Zealand has used a NAASRA meter for its roughness measurements. The meter was developed by ARRB and dates back to 1969 (Potter, 1978). The current design appears to be little changed from the original device. The NAASRA meter has its own standard roughness reference and it is understood by the author that it was originally based on the "Golden Vehicle" principle. All vehicles supplied by ARRB were calibrated against the same vehicle. ARRB now operates a laser profilometer whose data is manipulated to produce "NAASRA" counts. The NAASRA value thus has a similar basis as the TRRL BI approach and is markedly inferior to the IRI which is based on a mathematical model of a suspension system.

In addition to calibrating the vehicle against a known roughness measure, it is necessary to verify that the vehicle is still within calibration. This is because, as mentioned above, over time the various components in the vehicle may wear and this will affect the output of the RTRRMS. If the vehicle is not within calibration, it can be expected that the errors in the readings will be **well in excess** of the values reported by Paterson (1985) since these are predicated on the vehicle being correctly calibrated and operated. The issue of verification will be discussed in detail in the following section.

3. CALIBRATING RTRRMS

This section will consider how one calibrates an RTRRMS. It represents what this author considers to be an "ideal" approach. It is based on the recommendations of the World Bank (Sayers, et al., 1986b), TR12 and the experience of the author in calibrating systems overseas. The practices of BCHF and WCS in calibrating their vehicles will be assessed against this recommended procedure.

Calibration can only be achieved by setting up "test sections". These are sections of pavement which have been accurately profiled and which the roughness is therefore a known quantity. This profile is best achieved using a laser or accelerometer system, but can also be accurately done using a straight-edge and wedge, or one of the two low-speed profilers available, the DIPSTICK or the ABAY Beam. Once the sections have been accurately profiled, one can calculate the reference roughness (IRI etc). The vehicle with the RTRRMS is then operated over these sections and a regression equation is developed between the roughness meter readings and the reference roughness. This constitutes roughness meter calibration.

In undertaking the calibration the following issues must be addressed:

- A minimum of eight test sections of 300 m length must be used in developing the calibration equation(s). Ideally, at least 15-20 sites with lengths of 500 m should be used.

- If the vehicle is to be operated on different pavement types - e.g. surface treatment, asphaltic concrete (AC) and unsealed roads - it is necessary to develop separate calibration equations for each pavement type. This is because the vehicle will respond differently to the different surface types. Sayers, et al. (1986a) show that there are significantly different spectral density functions by pavement type. Under certain situations a single equation may suffice, but to ensure complete accuracy it is necessary to have a unique equation for each surface type.

- The test sections must cover the full range of roughnesses which the meter will encounter in the field measurements for each surface type.

- The roughnesses should be equally represented across the full range so as to avoid biasing the analysis.

- If the vehicle is to operate at different speeds additional calibration equations should be developed for each operating speed. The same applies if different loads are used.

- Each test section should be measured at least five times with the same vehicle. If each reading is similar, they should be averaged to obtain a single value. If there are even moderate differences in the readings additional measurements should be made and the inappropriate data rejected.

When sufficient data has been obtained a statistical analysis should be made to develop a relationship between the profiled reference roughness and the RTRRMS readings. This analysis should consider a number of different equations and select the equation which best fits the data. Possible model formulations are:

$$NAASRA = A + B\ RTRRMS + C\ RTRRMS^2$$

$$NAASRA = A + B\ RTRRMS^C$$

$$NAASRA = A \exp(B\ RTRRMS)$$

where	NAASRA	is the profiled test section roughness in NAASRA counts/km
	RTRRMS	is the test section roughness recorded by the vehicle
	A to C	are regression constants

The final formulation will depend upon the data and it is impossible to generalise. There is no *a priori* reason why the equation should be linear. Irrespective of the model formulation, it is important to ensure that the final equation gives good predictions over the full range of roughnesses.

The importance of data reduction must be emphasised. As discussed in Section 2, there are always random errors in recording roughnesses with RTRRMS. To minimise these errors during calibration, one makes repeated runs over the same test section with the RTRRMS. Sayers, et al., (1986b) indicate that the **minimum** number of runs required is 1000/L, where L is the test section length in m. TR12 recommends at least 3 runs over the test sections which is also the policy in the WCS calibration manual, although the latter recommends increasing the number of runs if the standard deviation is too large.

In the authors experience overseas, the practice is to evaluate the data for the runs on the test section to ensure that they are consistent, i.e. that all the values are approximately of the same magnitude. If this is not the case, additional runs should be made until consistency is achieved. This is termed repeatibility and those readings which are found to be inconsistent with the other data are rejected from the analysis. For example, the TRRL recommend 6 runs with the best 5 being used in the analysis. Appendix A contains an example of this issue from an RTRRMS calibration in Myanmar which was done by the author. From the data in the appendix (Site 3 at 30 mph) it can be observed that one reading was 80 NAASRA counts. This was quite inconsistent with the other data and was thus rejected. In the Myanmar study most of the standard deviations were less than 1 NAASRA count, which indicates that there could be 95% confidence that the RTRRMS average was within ± 2 NAASRA counts of the true average.

There is some controversy over whether or not it is appropriate to reject calibration data. However, it is **vital** to ensure that the data are of the best possible quality when calibrating a roughness meter and the author considers that this can only be achieved by repeating calibration runs until consistent readings are obtained and by rejecting incorrect data.

During the regression stage the data should also be critically evaluated for outliers. These will manifest themselves in the form of (x,y) coordinates out of line with the general trend in the data. The reasons for these outliers should be investigated and, if appropriate, they should be rejected from the analysis.

Once the meter has been calibrated against a profiled roughness, it is necessary to check that it is still within calibration. This is done by running over the test sections and checking whether the readings have changed. This is termed verification and it is here that WCS and BCHF have fundamentally different approaches.

The WCS approach, as recommended by TR12, is to test whether the vehicle is within 2.5%±5 counts/km of the previous reading. If it is, the vehicle is considered to be within calibration. If it is not within this limit the vehicle is examined and the reason for the drift is established and corrected so that the vehicle is within the allowable limits. If the vehicle cannot be brought back within the limits TR12 calls for an "interim" calibration equation to be requantified from the test sections until they can be reprofiled.

By comparison, the BCHF verification procedure triggers a full calibration of the vehicle instead of trying to bring it within a certain tolerance. This full recalibration is done every 30,000 km, when it has received any major maintenance, or when its readings have been found to drift over time.

4. OPERATING THE ROUGHNESS METER

There are several points which should be considered in operating an RTRRMS:

Sampling Interval

It is best to record the roughness at the shortest practical interval - if possible, every 100 m. When longer lengths such as 1 km are used, short sections of poor pavements will be disguised by other sections in better condition. However, care must be exercised that the sampling interval is not so short that the courseness of the RTRRMS measurements affect the results.

Measurement Speed

The measurements should be made at a single standard speed. Where data loggers are available and roughnesses are low, this can be upwards of 80 km/hr. If different speeds are to be used, it is necessary to have calibration equations for each speed and to correct the data for the effects of speeds[2]. This is a major benefit which arises from using a computerised recording system since the speed of the vehicle can be monitored continuously.

Vehicle Load

The vehicle should be calibrated and operated at standard loads. It is important that the same number of occupants be in the vehicle and that the fuel be kept within a certain level.

Tyre Pressure/Temperature

It is essential that the vehicles be operated at a standard tyre pressure. The tyres and shocks should be "warmed up" before commencing any survey.

5. CALIBRATION PRACTICES IN NEW ZEALAND

5.1 Introduction

In order to assess the calibration practices of the BCHF and WCS roughness meters, the author contacted both organisations.

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[2] The NAASRA counts/km constitute the ARS (average rectified slope) measurement at a speed V. The ARV (average rectified velocity) is the product of ARS and the speed. Its units are counts/hr and it is the average stoking speed of the vehicle suspension during a roughness measurement. Since both BCHF and WCS have recently begun using data loggers which record vehicle speeds so it is necessary for them to interpolate intermediate speeds. This would probably best be done by calculating the ARV and then converting it back to an ARS at the standard speeds of 50 km/hr and 80 km/hr. This is different to the approach recommended by Sayers et al., (1986b) and it should be verified before being adopted.

Both BCHF and WCS operate Holden Commodore vehicles equipped with NAASRA meters. Both firms use PSION data loggers for recording the data.

There are two calibration procedures followed by each company - full calibration and validation. The following sections will summarise these procedures and then assess the relative merits and deficiencies of each.

5.2 BCHF Calibration Procedure

5.2.1 Full Calibration

BCHF follows a full calibration procedure along the lines of that suggested in Section 3. In 1990 a profilometer from ARRB was used to establish 25 test sections around the Auckland area. These test sections were a minimum of 300 m long and ranged in roughness from 30 to 180 NAASRA counts/km.

The test sections consist of surface treatment, AC and portland cement concrete (PCC). Since two sections have been subjected to shape correction or surface repair, as at June 1992 23 of the original 25 sections were still in use.

The calibration is done by performing 5 runs on each test section. The data from the 5 runs is averaged to give the average roughness for the test section. The average roughnesses from the 23 test sections is regressed against the known NAASRA roughness, as measured by the profilometer, to develop a single equation giving the NAASRA roughness as a function of the vehicle measurements. A linear regression is used, with the average data being evaluated for outliers. If any outliers are found they are rejected and the site is considered to no longer be suitable for calibration. Equations are developed for 50 km/hr and 80 km/hr standard operating speeds.

The full calibration procedure is repeated whenever there is a change to the vehicle, for example new shocks or tyres, every 30,000 km, or when the vehicle fails a verification check.

5.2.2 Verification

A verification procedure is used by BCHF while in the field to verify the stability of the measurements. Upon arrival at an area to be measured, a 1 km road with a roughness of 50-100 NAASRA counts/km is identified. The roughness is measured and for each day during the survey the measurements are repeated. Any consistent variation in reading greater than 2 counts/100 m on all measurements indicates that the vehicle is no longer within calibration. A full calibration is then performed to derive new constants.

5.3 WCS Calibration Procedure

5.3.1 Full Calibration and Verification

The WCS calibration procedure is described in an internal document which is based on the TNZ Technical Recommendation TR12 and the ARRB Standard Operating Instructions. TR12 is regarded by WCS as the standard applicable to operations funded or subsidised by TNZ[3].
There are two levels of full calibration used by WCS. In Wellington test strips have been established and they were profiled with the ARRB laser profilometer. In Auckland and Dunedin the roughnesses of the test strips are measured by the Wellington vehicle. The local vehicle is run over the test strips in tandem with the Wellington vehicle and the roughnesses are used to develop a calibration equation for the local vehicle to the Wellington vehicle. This is the procedure outlined in TR12. In Auckland the calibration is done once a year in August.

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3 It should be noted that TR12 deals only with "second order" calibration - that is, calibrating vehicles against the "Standard NRB" vehicle - not with a "first order" calibration from profiled road data.

As is obvious from the above, the Wellington vehicle is considered to be the 'base' vehicle for WCS in N.Z. WCS have established 22 test sections in the Wairarapa, each 500 m long. There are a further 20 backup sections. As with BCHF, these test sections were measured by the ARRB laser profilometer in 1990. The roughness range is between 30 and 140 counts/km, and all pavements are surface treatment.

For verification the vehicle is operated over the test sections and the roughnesses compared.

Unlike the BCHF approach, once the Wellington vehicle has been calibrated (in 1990) it does not go through a further full calibration. As discussed in Section 3, this is because WCS follows the TR12 approach which embodies a different philosophy towards calibration to that of BCHF. Instead of recalibrating the vehicle, the test sections are **only** used for verification. As long as the vehicle is within 2.5%±5 counts/km of the previous mean for the test section, it is considered to be within calibration. Thus, new calibration constants are never derived for the vehicle. In the event that the vehicle is outside of these bounds, the source of the differences is established and the vehicle adjusted so that it is within the allowable error.

As mentioned above, the Auckland vehicle is calibrated each August against the Wellington vehicle. This calibration consists of running both vehicles over approximately 9.5 km of test strips (in 4 sections). 3 runs are made in each direction. The Auckland and Wellington data for each run are paired. A regression is then made to determine a linear equation between the Auckland and Wellington vehicles.

6. Assessment of Calibration Procedures

6.1 BCHF vs TR12 Philosophy

In assessing the relative merits of the two calibration procedures it is necessary to emphasise the fact that BCHF and WCS are employing what are two fundamentally different calibration philosophies. The BCHF approach is based on the philosophy that whereas the vehicle may change over time, this rate of change is much more than on the test sections that were originally used for the vehicle calibration. Thus, if the vehicle moves beyond an allowable level of accuracy, because of changes to the suspension, tyres shocks etc. it is recalibrated against the original profiled test section values.

The WCS approach for calibrating the base vehicle is essentially based on the criterion in the TNZ standard TR12. The vehicle is checked against the previous raw counts for the test section and as long as the vehicle is within 2.5%±5 counts/km of the previous mean for the test section, it is considered to be within calibration. If the vehicle is found to be outside of these limits it is checked and the source of error found and rectified. WCS indicate in the event that the source of variation could not be found the test sections would be reprofiled and a new calibration equation derived.

Not surprisingly, each consultant maintains that their approach is the correct one, although it must be pointed out that the WCS procedure is keeping with TR12.

In this author's experience overseas, it is more common for the BCHF procedure to be followed than that embodied in TR12. Of concern is the magnitude of the acceptable error limits embodied in TR12. At 50 NAASRA counts/km this means that if the readings are in the range of 43.8-56.3 counts/km the vehicle is considered to be within calibration - this corresponds to 50±12.5%. If the vehicle is outside of this range, it is adjusted so that it is within the range. This is a very significant tolerance for the vehicle to be operating in and, in conjunction with the errors naturally associated with RTRRMS, it could lead to unacceptably large errors in the resulting roughness estimates. Furthermore, since the error limits are independent of the roughness being measured, they allow for more error (as a percentage) on smooth pavements than on rougher pavements.

Given that these two methods may lead to markedly different results, TNZ should address the issue as to what is the acceptable calibration procedure. They should also assess the acceptable tolerances contained in TR12 since these may be leading to significant errors, particularly on smooth pavements.

6.2 BCHF

The BCHF calibration procedure - in the form of data reduction, etc. - closely follows that recommended by Sayers, et al. (1986b). They critically evaluate the test section data and reject test sections which may have changed over time. These are identified through visual inspection of the test sections or by major changes in the relativity of the calibration data.

There are some areas, however, where improvements can be made to their procedure. Firstly, and most importantly, they should not be mixing pavements with different roughnesses together for calibration purposes. The response of the vehicle to roughness will vary by surface type and it is therefore important that the vehicle be calibrated for each surface type that it will be used on. Of particular concern is the use of PCC pavements since the latter tend to have areas which are very smooth interspaced with areas with high roughnesses. This is quite different to flexible pavements which will tend to have more consistent roughness profiles along their entire length.

In the calibration procedure they should also be more critical of the data that they are averaging. This is because you can get outliers from factors such as sudden acceleration or braking, which may often be difficult to control. It is better to do additional runs when data shows itself to be out of line with the other readings than to simply average it.

6.3 WCS

This discussion will address the Auckland WCS vehicle since the main issues pertaining to the Wellington vehicle were raised in Section 6.1. The Auckland vehicle is of primary interest to RDC since it was used for the RDC roughness measurements.

The Auckland vehicle is calibrated via "second order calibration". Its test strips were not profiled, but have been measured with the Wellington RTRRMS. There are always problems with second order calibrations. Since RTRRMS are not exceptionally accurate, you are compounding the inaccuracies of the instruments.

On top of this source of error, there was a flaw in the Auckland calibration procedure which is partially attributable to TR12. In calibration, there is a single point for each test section for both the Wellington and Auckland vehicle. Section C2 of TR12 calls for the mean of all runs on a test section to be used as a coordinate pair and used in a linear regression to develop a regression equation. However, in Figure C.1 of TR12 it appears that the individual points for each run are used for the equation. The latter was used by Auckland WCS in calibrating their vehicle.

This approach would not be overly significant if TR12 addressed data quality. However, **absolutely no provision** is made in the TR12 methodology for evaluating the data, data reduction, and for identifying any data which may be outliers. This is a major oversight since because of the nature of RTRRMS, you must critically evaluate all readings during a calibration. This returns us to the repeatibility issue discussed in Section 4.

This problem is best illustrated by the following simple example which consists of 3 readings made on a hypothetical test strip.

Run	Vehicle A	Vehicle B
1	100	130
2	102	129
3	110	132

The third run with Vehicle "A" is quite out of order with that of the first two runs. It would be appropriate to repeat the exercise to confirm that the roughness is indeed on the order of 100. Instead of this, the TR12 approach treats this reading with the same weighting as the other readings. All three pairs of data are entered as (x,y) coordinates in a linear regression.

In evaluating the Auckland vehicle roughness calibration readings for 1991, it was found by the author that the range of roughnesses measured by the Auckland vehicle against the Wellington vehicle for a single roughness was sometimes on the order of **±25%**. For example, the Wellington roughness would be 80 NAASRA counts/km and the Auckland vehicle would be measuring 110 and 180 counts/km[4]. In evaluating the data the typical range of readings for the Auckland vehicle relative to the Wellington vehicle was 50 counts/km, at high roughnesses 100 counts/km. This corresponds to a range of approximately 25 to 50 NAASRA counts/km for each roughness measured by the Wellington vehicle. Given this range of readings additional runs should have been made and the data critically assessed. The WCS manual indicates that this is required if the standard deviation exceeds a certain value, however, since this can only be checked once the vehicle has returned from the calibration the Auckland policy has been to always do 3 runs.

This is undoubtedly a major contributor to the discrepancies between the 1992 WCS RDC roughnesses and the 1991 BCHF roughnesses. The resulting regression curve often passes through the mean of the range, although in some instances it does even do this[5]. The resulting line may statistically represent the raw data, but it may not be representative of the true relationship between the RTRRMS and the reference roughness. The standard error of the estimate is not reported but given the ranges through which the fit is made it would be relatively large.

These statistical problems have been compounded by the fact that WCS also use a mixture of pavement types for their test strips. It would have been better to segregate the data along the lines of the roughnesses experienced on different pavements than to aggregate all the data.

7. Recommendations

7.1 WCS Auckland Calibration

The following are the observations and recommendations concerning the calibration of the Auckland WCS vehicle.

1. It is not wise to continue with the use of a second order calibration for the Auckland WCS vehicle. The errors associated with RTRRMS are such that the vehicle will probably not have sufficiently accurate output.
2. The data analysis needs to be overhauled. During calibration the runs should be repeated on the test section until a consistency has been obtained for that test section[6]. Only once the roughness of each test section is **accurately known** should the data be used. It is not adequate to lump together pairs of readings and count on the statistical analysis giving the correct result, particularly when the range of readings can be on the order of ±25%.
3. WCS should ensure that a minimum length of 300 m, preferably 500 m, is used for their calibration test sections.
4. There is no theoretical reason why the roughness calibration curve must be linear. Alternative model formulations should be investigated which give a better goodness of fit - and more importantly a lower standard error.

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[4] These are uncalibrated counts per km. Since the Auckland vehicle meter records twice as many pulses per revolution as the Wellington vehicle one would expect a reading on the order of 160 uncalibrated counts per km.

[5] WCS would not permit the author to include actual examples of their calibration curves in this paper.

[6] The author recognises that this is implicitly suggested in the WCS manual in that the number of runs required is proportional to the standard deviation. However, since the latter statistic is calculated once the calibration is over, this procedure appears not to have been followed. By requiring a minimum number of runs within a set tolerance - say ±2 counts/km, the operators have an easy target to evaluate whether or not they have performed a sufficient number of runs.

7.2 RDC Roughness Issue

It is this consultant's opinion that the differences between the 1991 BCHF roughness survey and the 1992 WCS survey have probably arisen because of improper calibration of the Auckland WCS vehicle. In order to rectify the problem the following is recommended:

1. A series of test sections should be identified by WCS covering the full range of roughnesses. These test sections should have consistent geometry, be a minimum of 300 m long, and have good approach and exit lengths.
2. These test sections should be measured by both the BCHF and Auckland WCS vehicles. Sufficient repeat runs should be made so that each vehicle has a consistent reading for the roughness of each test section.
3. These data should be used to develop a calibration equation for the Auckland vehicle, with the data being critically evaluated before commencing statistical analysis.
4. The new calibration equation should be used to adjust the 1992 roughness data and to make it compatible with the 1991 BCHF data.
5. If possible, a check should be made by operating both vehicles over the same section of road. However, this should **not** be used for calibration since it will not give sufficiently accurate results.
6. When the Wellington vehicle is in Auckland it should repeat the same exercise as that done by the BCHF and the Auckland vehicle (steps 2 and 3 above). This would allow for a useful comparison between the differences arising from the BCHF and TR12 approaches.

7.3 General Observations for Both BCHF and WCS

Grouping of Road Types

Both consultants should alter their calibration procedure to reflect the roughness characteristics of different pavement types. Their current practices of lumping together pavements of different types for the purposes of calibration are not adequate. Ideally, calibration equations should be prepared for each road type - or at worst for flexible pavements, rigid pavements and unsealed roads. During the surveys the road types should be recorded so that the appropriate equation is used.

Unsealed Roads

It is of concern that neither consultant have calibrated their vehicles on unsealed roads, yet they are apparently engaged by local authorities to measure these roads.

The roughness profile on unsealed roads may be substantially different to that on sealed roads, for example it is often composed of many short wavelength roughnesses and it has quite a different spectral density function. It is therefore not appropriate to extrapolate a linear equation from sealed roads to unsealed roads. Sayers, et al. (1986b) recommend that the **maximum** extrapolation for a calibration equation is 30%. Assuming that the NAASRA meter is calibrated to approximately 180 NAASRA counts/km, the BCHF and WCS vehicles should not be reporting roughnesses above 225 NAASRA counts/km. TNZ have recently specified that RAMMS should not have any roughness above **500** counts/km - this reflects a lack of awareness on the part of TNZ as to the limitations of the existing roughness measurements.
Although ARRB do not test their meter on unsealed roads, Sayers, et al. (1986a) indicate that the NAASRA meter was found to function on these roads in the IRRE so there are no mechanical reasons limiting the use of the meters.

It is recognised by the author that there are practical limitations in unsealed road test sections, however, it is only by establishing such test sections that the consultants will be able to calibrate their vehicles for measuring unsealed roads.

8. CONCLUSIONS

This paper has raised two issues - that of the differences between the BCHF and Auckland WCS roughness measurements and that of the different calibration philosophies used by BCHF and WCS.

It appears that the differences between the BCHF and WCS roughness readings in RDC can be attributed to an incorrect calibration procedure on the part of WCS. WCS has not been critical in its treatment of calibration data and has tended to rely on the statistical analysis to give the correct results instead of ensuring that the data going into the analysis was of the best possible quality.

It is recommended that the BCHF and WCS vehicles operate over a series of test sections and a conversion equation be established for either adjusting the WCS data to correspond to the 1991 BCHF data, or the 1991 BCHF data to the 1992 WCS data. Since the BCHF vehicle underwent a first order calibration from the ARRB profilometer in 1990, it is considered by the author that their 1991 readings are probably accurate. It would thus be wiser to use these as the benchmark as opposed to those based on a second order calibration such as that used by the Auckland WCS vehicle.

The exercise should be repeated with the Wellington vehicle to obtain insight as to the differences arising from the BCHF and TR12 calibration approaches.

Both consultants should review their analysis procedure and more critically evaluate the data collected in their calibration surveys. They should also develop calibration equations for different types of pavements instead of lumping all pavements types into a single data set. Until equations are prepared for unsealed roads, both consultants should stop measuring on these pavement types since there is no evidence that it is appropriate to extrapolate the sealed road equations to unsealed roads, particularly given the different nature of roughness on unsealed roads. It is recognised that unsealed roads do not hold their profiles over time and thus have a very short life as a test section, however, the consultant's existing calibration equations are only valid to approximately 220 NAASRA counts/km and thus cover only a limited portion of unsealed roads. If BCHF and WCS are to continue offering roughness measurements on unsealed roads they should have their meters calibrated for these pavements.

It is important that the implications of BCHF and WCS following fundamentally different procedures be investigated. There creates a great potential for discrepancies in the roughness measurements between the two firms.

Given the fundamental importance of road roughness data in the road planning process, TNZ should facilitate two actions:

1. Permanent test sections should be set up in the main centres which are independently monitored. The consultants would then be able to use these test sections for calibrating/validating their vehicles.
2. A standard calibration procedure to be used by both consultants should be established. Full consideration should be made as to the merits of the current BCHF and TR12 approaches before this procedure is adopted. It it is decided to continue with the TR12 approach, the following issues should be addressed:
    1. The magnitude of the criterion embodied in TR12 for a vehicle to be within calibration. These criterion appear to allow a generous tolerance for the roughness meter to be considered within calibration. The tolerances should also be proportional to roughness.
    2. TR12 does not consider data reduction/evaluation and thus the number of runs required.
    3. TR12 does not list minimum test section lengths or the number of test sections required for calibration.

Perhaps the most important issue to arise from this evaluation is the general question as to the appropriateness of even continuing with the use of NAASRA meters. With the increased use of RAMM, users are expecting to be able to use their data for planning purposes. The continued use of an instrument with a 23 year old design whose output is not highly accurate and very susceptible to calibration problems is questionable. If roading authorities continue to employ consultant's to use NAASRA meters to measure their roads, it would probably be wiser to continue with a single consultant rather than alternating from year to year. This is because, as the situation in RDC has shown, the inherent inaccuracies of the instruments in conjunction with differences in calibration and operating procedures (e.g. their treatments of intermediate speed roughness measurements) may render the data incompatible.

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