

Establishing Reference Transverse Profiles for Rut Depth Measurements in New Zealand

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Abstract

This paper describes the development of a portable, low-cost instrument for accurately measuring transverse profiles and rut depths of pavements. Called the 'Transverse Profile Beam' (TPB), it consists of a 3.6 m motorised carriage which travels across the width of the lane. A wheel attached to the carriage measures the vertical distance as the carriage travels across the lane. The results are used to calculate the rut depth under a 2.0 m simulated straight-edge.

The instrument was developed for collecting data for Transit New Zealand's LTPP project, but is suitable for any situation where accurate measurements are required, such as validating profilometers. With a vertical resolution of 0.2 mm and a horizontal resolution of 3 mm, it is possible to get very accurate profiles.

The TPB was calibrated and validated in the field against manual rut depth measurements. It was found to give accurate and repeatable results.

The TPB was used to collect data at 126 locations around the New Zealand State Highway Network as part of the LTPP study. The paper presents recommendations for developers of similar instruments based on these experiences.

INTRODUCTION

In 2001 HTC Infrastructure Management Ltd. (HTC), in association with Data Collection Ltd. (DCL), was appointed by Transit New Zealand to collect data at 126 locations on State Highways for Transit's long-term pavement performance (LTPP). The LTPP data collection requirements were performance based and required that the data be collected to a very strict tolerance.

For rut depths it was concluded that the only way of meeting the specification was by using an instrument capable of quickly measuring the profile with multiple runs, comparing the results of the runs to confirm that the data were within specification. Instruments such as these have been developed overseas, for example Figure 1 shows the laser profiler developed by VTI in Sweden used in the recent FILTER project, but the costs of these instruments were beyond the budget available for the project.



FIGURE 1 VTI Laser Transverse Profiler

An alternative approach was adopted which used two low-cost precision rotary encoders to measure horizontal and vertical location of a wheel as it traversed a 3.6 m beam. The 'Transverse Profile Beam' (TPB) was successfully used to measure the transverse profiles on the Transit LTPP sites and is also being employed for validating measurements of the profilometer used for the annual State Highway rut depth surveys. This paper describes the TPB, its validation, and use of its data.

DCL TRANSVERSE PROFILE BEAM

The TPB is a precision instrument which consists of a 3.6 m wide beam along with a motorised carriage. The carriage moves a wheel across the pavement and vertical and horizontal transducers monitor the position of the wheel and its elevation. With a vertical resolution of 0.2 mm and a horizontal resolution of 3 mm, the TPB provides very precise measurements of the transverse profile. An inclinometer is used to record the temperature and inclination of the TPB, although at present these data are not used.

The concept behind the TPB is straight forward:

- ❑ A horizontal distance encoder records the number of pulses as the carriage moves across the beam. This provides the distance in mm from the start point.
- ❑ Proximity sensors are placed at regular intervals along the beam to provide intermediate check points for the distance measurements.
- ❑ As the wheel travels across the pavement, a vertical distance encoder records the vertical changes in the wheel elevation in mm.
- ❑ When the carriage reaches the end of the beam it stops, and the motor returns the carriage to the start position, recording the profile data in the reverse run.
- ❑ The rut depth under a 2 m straight-edge is calculated using a straight-edge simulation for each wheelpath in the forward and reverse runs. If it is within a user-defined tolerance the measurements are deemed to be acceptable; if not the TPB automatically repeats the measurements until the tolerance is achieved.

Figure 2 shows the TPB (version 2). An improved Version 3 was built in 2002 using a different design of the beam and different bearings to improve on the stiffness and motion of the carriage across the beam.



FIGURE 2 Photographs of TPB and Measurement Wheel

The TPB is designed to be very simple to operate. The operator enters a site identification description and this is used to define a database with that name. The TPB is placed at a location to take measurements and the operator selects the GO button on the computer. All measurements are automatic from that point on. All raw data are stored in the database which allows for post processing. For the Version 3 beam the software was rewritten to run on a Compaq iPaq which is an ideal data logger for applications such as these when enclosed in Compaq's waterproof case.

TPB CALIBRATION AND VALIDATION

Calibration

As mentioned earlier, the active measuring units on the TPB are two precision rotary encoders, one for height measurement and one for distance measurement. The encoders output a series of logic pulses as their shafts rotate, the TPB logging software counts the number of pulses and converts these into measured heights and distance. This section presents the results of the vertical and horizontal measurement calibration.

Vertical Measurements

For the vertical height the static calibration was done using a levelling platform, levelling bubble and two sets of spacers. The levelling platform was levelled and precision ground spacers of 2.0, 5.0, and 10.0 mm in thickness, calibrated using a digital reference calliper, were placed on the platform and the elevation measurements recorded. The results of the vertical calibration are shown in Figure 3. The equation was $V_{dist} = 0.2027 \text{ Pulse} + 0.0091$ $R^2 = 1.0$.

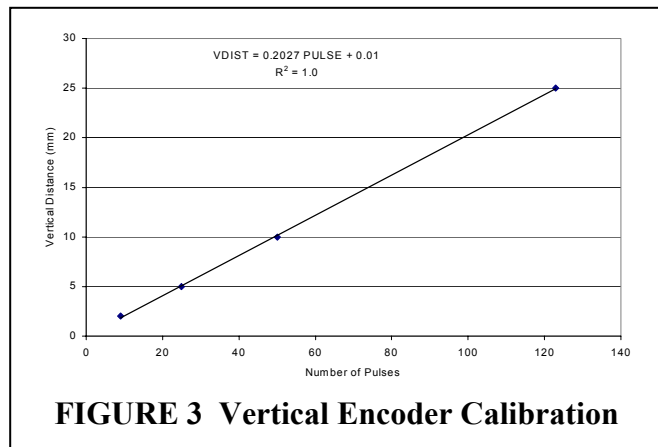


FIGURE 3 Vertical Encoder Calibration

Horizontal Measurements

The TPB has reference locations along the length of the beam these are fitted with magnets that activate a proximity switch mounted on the carriage. As the carriage passes the magnet a pulse is sent to the data logger. The magnets provide start and end reference locations with the intermediate magnets providing additional reference points for ensuring accurate horizontal positioning.

The distance between the magnet positions was measured with a calibrated reference tape measure, and the distance/pulse relationship was established through repeated measurement of the number of pulses between the start and end magnetic sensors. Table 1 shows the repeatability of the distance measurements from 9 runs measured five months apart. These show a precision of 2.97 mm for the horizontal distance measurements.

The position of the measurements was predicted using the equation $H_{dist} = 3.0681 \text{ encoder} + 0.5486$ $R^2 = 1.0$.

TABLE 1 Horizontal Distance Calibration

Date	11/12/01	3/05/02
Measured Distance (mm)	2900	3100
Salient Point From: To	5 to 33	3 to 33
Run 1	970	1035
Run 2	974	1040
Run 3	982	1053
Run 4	978	1041
Run 5	968	1052
Run 6	985	1048
Run 7	975	1041
Run 8	981	1046
Run 9	975	1041
Mean	976.4	1044.1
S. Dev.	5.6	6
Pulses/mm	0.34	0.34
mm/Pulse	2.97	2.97

Validation

Introduction

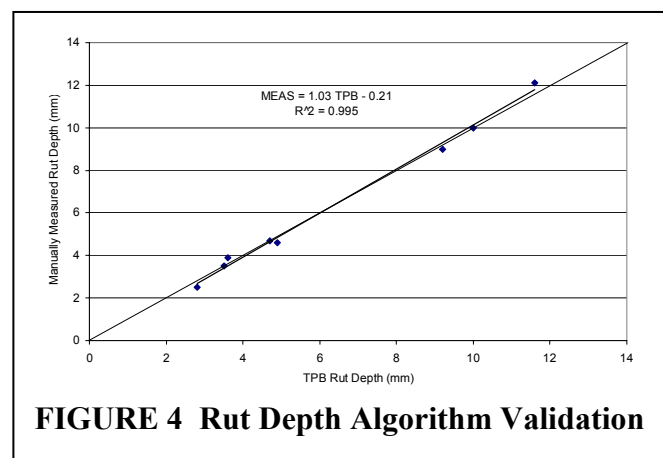
The measurement accuracy was demonstrated through a series of validation exercises to demonstrate that the beam could measure the pavement profile and calculate an accurate rut depth from the profile.

TPB Rut Depth Algorithm

The TPB rut depth algorithm was based on that given in Hadley and Myers (1991). As a check on the depth algorithm, the transverse profiles from four road sections were plotted and the roughness manually measured. As shown in Figure 4, the TPB rut depth algorithm gave virtually identical results to those manually measured and the differences could be ascribed to the manual measurement accuracy.

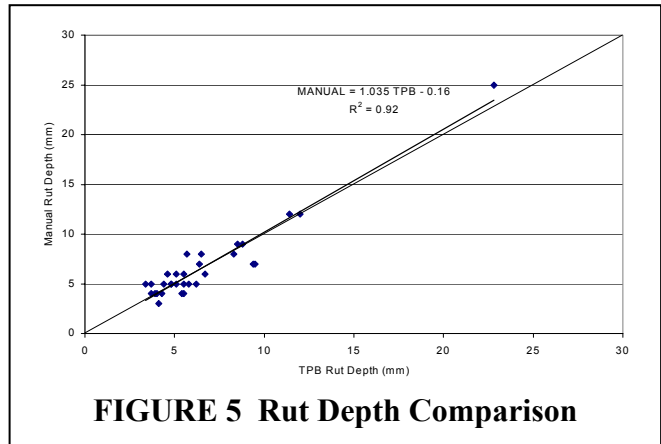
Manual vs TPB Rut Depths

Measurements were made at 30 different locations in the left wheelpath using the TPB and a 2m straight-edge. Figure 5 shows the comparison of these two measures. The differences were in the range of -2.3 to $+2.5$ mm.



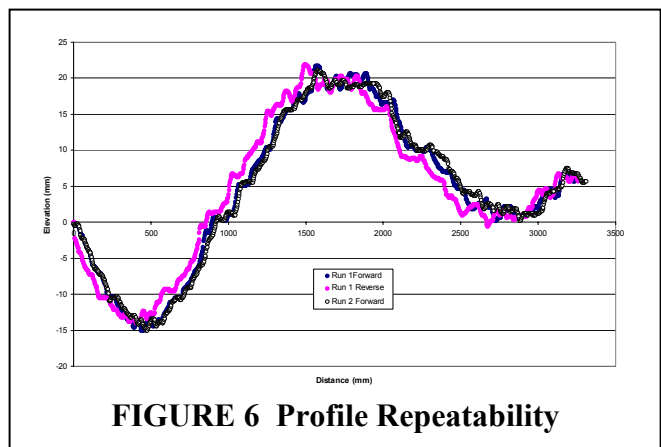
There was a slight difference between the measured manual rut depth and the beam calculated rut depth, and this was ascribed to two factors:

- **Precision.** The beam measurements are to 0.1 mm whereas the straight-edge and wedge measurements are to the nearest mm
- **Measurements.** On surface treated pavements, the wheel on the beam straddles the chips while the wedge can fit between the chips when the chip size is sufficiently large.



TPB Profile Repeatability

Figure 6 shows the repeatability of profiles from two forward runs and a reverse run. It will be noted that the profiles have very similar shapes. The reverse run was offset by approximately 50 mm, but this does not affect the resulting rut depths. The correlation between the forward runs was 0.98.



Rut Depth Repeatability

Figure 7 and the Table 2 show a comparison of rut depth measurements from the forward and reverse runs on several sites, along with the corresponding manual measurements.

There was good correlation between the runs except at high rut depths where the differences were quite large. It was found that this was due to the beam not starting stopping in exactly the same position. This was corrected by improving the horizontal position measurements and decreasing the tolerance whereby additional runs are automatically triggered. During field surveys this tolerance was set at 2.5 mm and in very few locations were more than 2 runs required.

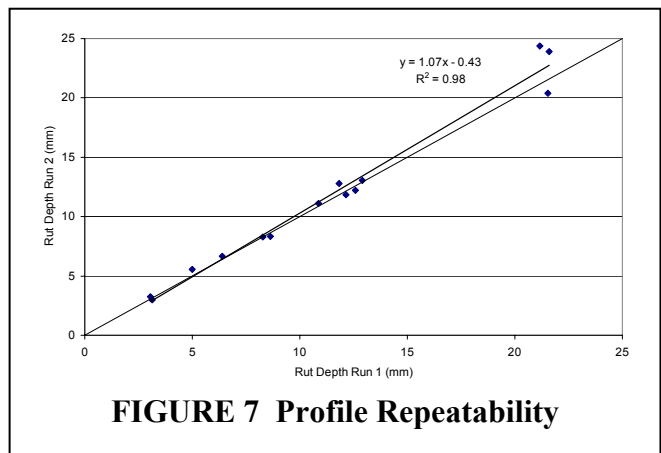


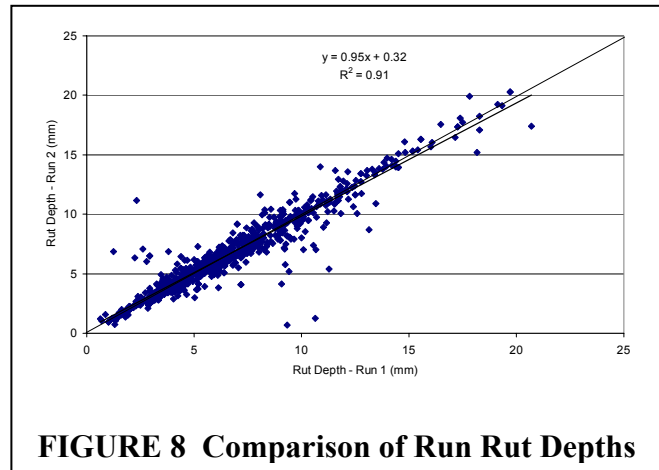
TABLE 2 Profile Repeatability

Site	Manual	L Run 1	L Run 2	Manual	R Run 1	R Run 2
1	9	8.29	8.28	4	3.15	2.99
1	9	8.62	8.33	4	3.04	3.25
2	12	12.92	13.05	8	6.40	6.64
2	12	12.14	11.87	8	5.00	5.58
3	25	21.61	23.90	16	10.86	11.09
3	25	21.16	24.38	16	12.60	12.23
3	25	21.55	20.41	16	11.83	12.78

As a further test of the performance of the TPB, the rut depths from 840 measurements were compared. Figure 8 shows the values calculated from the first two runs at each measurement placement. The correlation was 0.95 ($R^2 = 0.91$) and 94% differed by -1.5 to $+1.5$ mm.

Conclusions

The calibration and validation results presented here were accepted by Transit New Zealand as confirming that the measurements from the TPB met the specification and that the instrument was suitable for use in the LTPP study.



TPB DATA COLLECTION AND USING THE DATA

Transit New Zealand, the organisation responsible for managing State Highways, instituted a long-term pavement performance (LTPP) study in 2001. Figure 9 is an example of a typical site.



FIGURE 9 Example of Transit New Zealand Calibration Section

The data collected at each site consisted of:

- Transverse Profile using the DCL Transverse Profile Beam;
- Roughness using an ARRB TR Walking Profiler;
- Visual condition inspection;
- Video logging;
- Digital photographs; and,
- GPS co-ordinates.

The TPB was positioned every 10 m along the pavement and at least two profiles were measured at each position. If the rut depths calculated from these profiles were not within a +/- 2.5 mm tolerance additional runs were made until the tolerance was achieved. In most instances the tolerance was achieved with only two runs. With a crew of 3 it was possible to measure 2 x 300 m lanes each day (weather permitting), while also collecting all the other data.

The first application of the Transit LTPP data—and more specifically the TPB data—was for a research project investigating harmonising rut depth measurements from profilometers (Bennett and Wang, 2002). Data from one of the calibration sites, constituting a total of 65 profiles were used in the study.

The reference profiles were used as input to a simulation program called HRD which allowed for the implications of different numbers of sensors for measuring rut depth and lateral positions on the calculated rut depth.

Figure 10 is an example of the results of an HRD analysis. The data plot shows the reference profile and the circular points on the profile are the locations of the sensors from the profilometer on the profile (in this example the 30 sensor system). These are governed by the lateral placement of the vehicle and the sensor spacings

The summary data below the plot give the kerb and centre rut depth values, here 7.60 mm and 2.51 mm respectively. The data plot shows the location of the straight-edge, governed by its high points, along with the low point and the rut depth as represented by the vertical line beneath the straight-edge. The lateral placement for the simulation is given in the box to the right of the rut depth values, here 50.82 mm from the start of the profile. The simulation results are given at the bottom of the display.

Among the analyses the HRD software was used for was the implication of the number of sensors on the accuracy of the rut depth measurements. Figure 11 shows the results of this for the kerb and centre wheelpaths.

CONCLUSIONS

The TPB is a simple to build, low-cost instrument which can give very accurate transverse profiles of a pavement. Instruments like the TPB are useful to researchers interested in monitoring trends in pavement deterioration or to agencies wishing to validate the measurements of profilometers prior to undertaking network surveys.

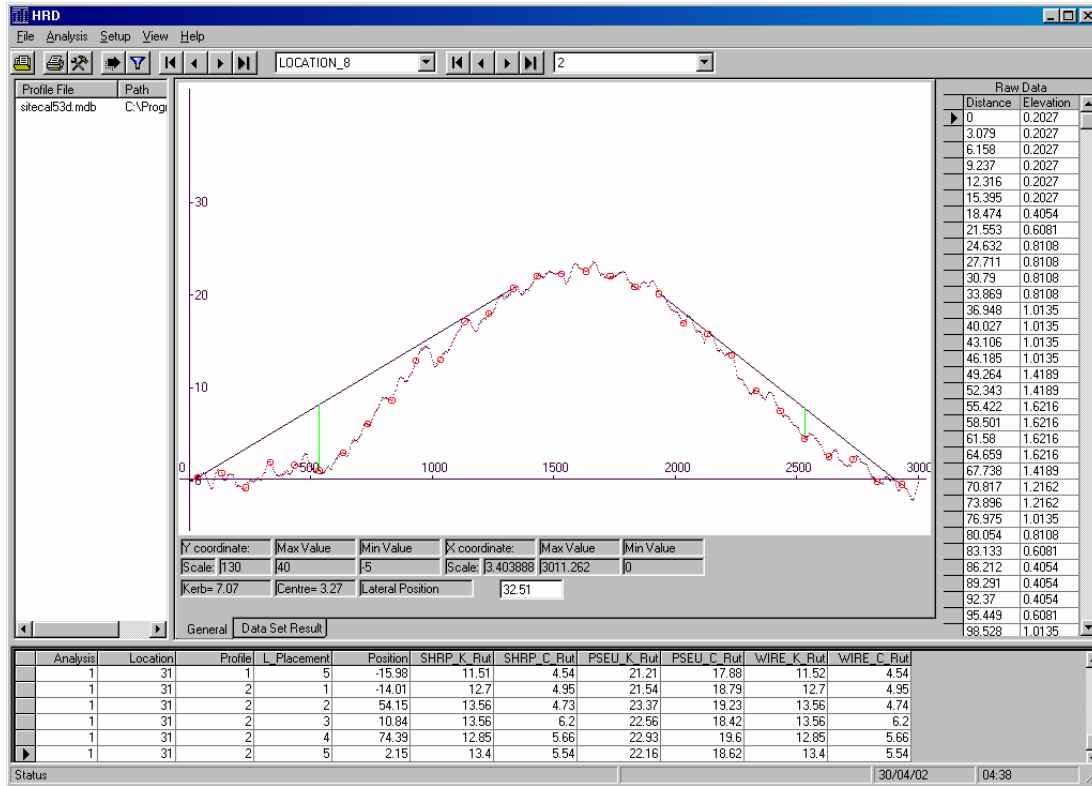


FIGURE 10 Example of HRD Analysis Results

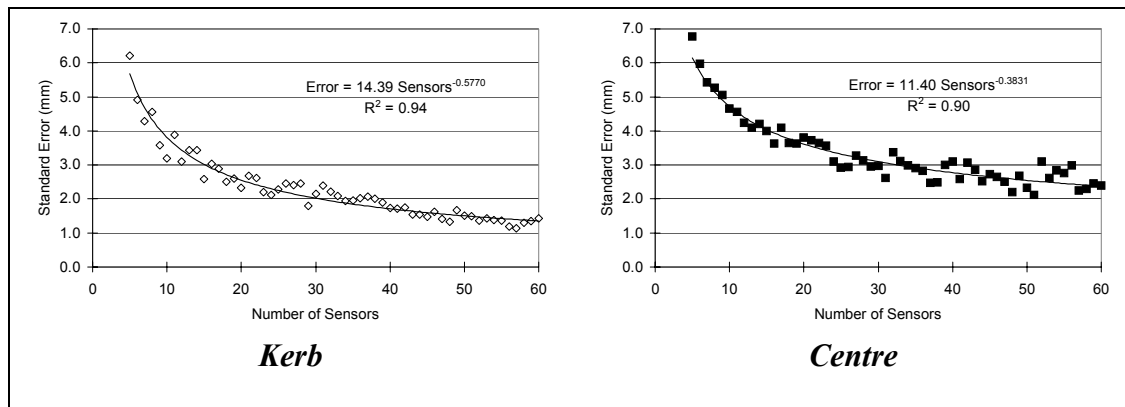


FIGURE 11 Effect of Number of Sensors on Rut Depth Error

The TPB was found to give very repeatable measurements of both the transverse profile and the rut depths calculated from the profile. In 2001-2002 the TPB was used for measurements on over 120 LTPP sections on State Highways in New Zealand.

There were several issues found with the TPB that those wishing to develop similar instruments should be aware of:

- It is necessary to ensure that the vertical measurement wheel has sufficient travel for the pavements under study. The TPB (Version 2) limit of 350 mm was approached on several instances.
- There can be a problem with ‘sag’ of the beam which can be addressed by using an appropriate beam cross-section design and ensuring that the weight of the carriage and computer is minimised. While the sag does not affect the rut depth measurements, it does impact on transverse profile validation.
- In very windy conditions the TPB suffered from sway. This was also caused by large trucks travelling too fast through the measurement area.

REFERENCES

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Hadley, W.O. and Myers, M.G. Rut Depth Estimates Developed from Cross Profile Data. *SHRP Long Term Pavement Performance Program Technical Memo AU-179*, Texas Research and Development Foundation, Austin, 1991.