

# MANUAL ON PAVEMENT EVALUATION TECHNIQUES

Pradeep Kumar  
Satish Chandra



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# MANUAL ON PAVEMENT EVALUATION TECHNIQUES

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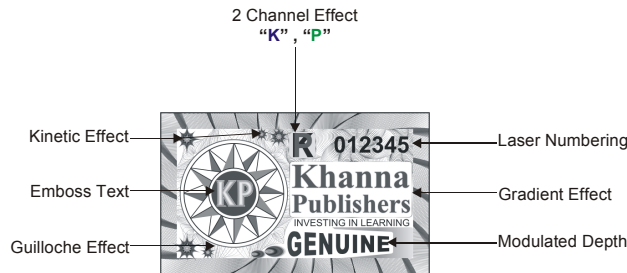
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## *Preface to The First Edition*

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Pavement evaluation techniques which involve the use of state-of-art technologies and tools for functional and structural evaluation of pavements have become necessity today for health monitoring of road infrastructure and to take appropriate decisions for maintenance, planning and budgeting of road network based on scientific tools.

The state-of-art infrastructure facilities available at CSIR-Central Road Research Institute motivates us to write this manual which concisely covers all the major equipment of pavement evaluation, so that the students and field practitioners understand the methodology and follow the correct procedure for functional and structural evaluation of pavement for various purposes.

The first chapter of the manual deals with the evaluation of pavement surface roughness for rating the roads as per riding quality criteria. Apart from the methodology for roughness measurement using various equipment, this chapter will help the readers for deciding the appropriate technology depending upon the location and type of the road under study.

Second chapter of the manual is related to the micro and macro level assessment of pavement surface characteristics which are related to the measurement of pavement surface texture, skid resistance and polish stone value, to ensure the safe riding pavement surface.

Third chapter covers the details about distresses observed on flexible pavements and their measurement techniques. Details of most dominating distresses along with illustrating photographs and severity levels are also given in this chapter. Fourth chapter gives details of axle load surveys using static and weigh-in-motion systems which are required to know the current loading pattern on the project roads for their upgradation and various maintenance needs. Calculation of vehicle damage factor with examples has also been included in this chapter.

The fifth chapter deals with the structural health monitoring of roads using Benkelman Beam and Falling Weight Deflection techniques. The details of these two methods and their measurements techniques are given in details with example for estimating the overlay needs using Falling Weight Deflectometer Technique.

The use of Network Survey vehicle has also become necessity for road asset and pavement condition monitoring for development of pavement maintenance management systems at network level. The details of a typical network survey vehicle system including its calibration and validation details are given in chapter six. This chapter also includes the tentative specifications of Network Survey Vehicle System to meet the requirements of road asset management systems.

We are hopeful that the readers will find the book useful as the procedures of pavement evaluation using equipment have been demonstrated in a simplified way.

Suggestion and observations for further improvement of the manual are welcome.

—Authors

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# 1

## Roughness Measurements

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### 1.1. INTRODUCTION

#### 1.1.1. Road Roughness

Road roughness is the deviations of the pavement surface from a true planar surface with characteristic dimensions that affect vehicle dynamics, ride quality, dynamic loads, and drainage, for example, longitudinal profile, transverse profile, and cross slope (ASTM E867). By causing vehicle vibrations, roughness has a direct influence on vehicle wear, ride comfort, and safety. In turn, the dynamic wheel loads produced are implicated as causative factors in roadway deterioration. The relationship between vehicle operating cost and road roughness are well established through several studies conducted in India and abroad. The effect of roughness on road safety is also being recognized. Roughness measurements are an important factor in making decisions towards spending limited budgets for maintenance and improvements. Analysis of roughness can aid in the diagnosis of roadway deterioration and the design of appropriate maintenance. Due to this, specifications for roughness have been adopted by various highway engineering agencies (Sayers *et. al.*, 1986).

#### 1.1.2. Classification of Road Roughness Measuring Systems

Instruments used for the collection of roughness data are characterized into four classes as defined by Sayers *et. al.*

##### **Class 1: Precision Profilers**

Precision profilers are the instruments that provide the highest standard of accuracy for calculating IRI and are a series of accurately measured elevation points, closely spaced along the section (i.e. with a short sampling interval). The elevations are measured at sampling intervals not more than 250 mm with a precision of less than 0.5mm on very smooth pavements using walking speed profilometers. However, for high speed road profilers such as Laser Profilometer (ASTM E950 Class-1 Compliance) the longitudinal sampling interval is 25 mm with a vertical measurement resolution of  $\pm 0.1$  mm.

##### **Class 2: Other Profilometer Methods**

An instrument not capable of meeting the Class 1 requirements for precision, or sampling interval, may meet the criteria for Class 2. The Class 2 sampling intervals are set at a maximum of 500 mm with a precision on smooth roads of below 1mm for using walking speed

profilometers. However, for high speed road profilers the longitudinal sampling interval is > 25 mm to 150 mm with a vertical measurement resolution of > 0.1 mm to 0.2 mm.

### **Class 3: Response Type Measurements**

All Response Type Road Roughness Measuring System (RTRRMS) belongs to this category of roughness measurement. RTRRMSs measure the dynamic response of vehicles to the road surface by using either mechanical or accelerometer devices. The estimation of roughness index for RTRRMS is made using correlation equation after calibration with Class-1 road profiler.

### **Class 4: Subjective Ratings**

In subjective evaluations of roughness, the investigator physically drives along the road or makes a visual survey.

## **1.1.3. Roughness Standard Units**

### **Units for Measuring Roughness**

Different measuring systems/practices have different units for representing the measured roughness, as discussed below.

### **Roughness Index (RI)**

The pavement surface roughness is expressed as Unevenness or Roughness Index (in mm/km) measured through Fifth Wheel Bump Integrator or Car Axle Mounted Bump Integrator.

### **International Roughness Index (IRI)**

It is the reference average rectified slope, which expresses the ratio of the accumulated suspension motion of a vehicle, divided by the distance travelled during the test. The recommended unit of IRI is m/km.

### **Correlation between IRI and RI**

For correlation with RI values obtained from RTRRMS equipment such as Fifth Wheel Bump Integrator and Car Axle Mounted Bump Integrator, the following equ. 1 may be used for IRI < 17 (Paterson, 1990):

$$RI = 630 (IRI)^{1.12} \quad \dots(1)$$

Where,  $RI$  = Roughness Index in mm/km and  $IRI$  = International Roughness Index in m/km.

## **1.2. METHODS FOR ROUGHNESS MEASUREMENTS**

### **1.2.1. Profilometric Systems**

Systems that measure or base their measurements on the profiles of road are, generally termed as profilometric system. When profile is measured, the continuous representation of the road can be inspected to identify local defects, or processed to yield roughness numeric adapted to specific applications. The various walking type equipment such as Merlin, Dipstick, Walking Profiler, Z-250 and high-speed Laser Profilometer falls under this category.

#### **1.2.1.1. Road Profilers (Walking Speed)**

These devices are “Walked” along the line being profiled. Normally a precision inclinometer measures the difference in height between the two supports, normally spaced not more than 250 mm apart for Class-1 category. With such equipment, the reference elevation is the value calculated for the previous point. The elevations are measured at sampling intervals not more than 250mm with a precision of less than 0.5 mm on very smooth pavements using such walking speed profilometers.

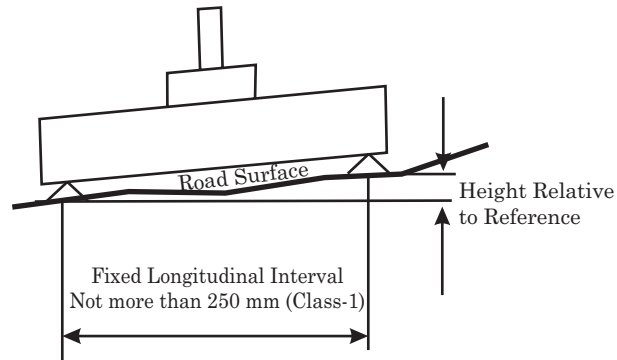


Fig. 1.1. Principal of Class-1 Road Profiler

Road profile data measured using such equipment is processed to give International Roughness Index (IRI) in m/km. Such equipment has self-calibration mechanism. With the highest level of accuracy in road profile measurement, the equipment is used for calibration of response type road roughness measuring system and validation of roughness data. The principle of road profiling using such equipment is shown in Fig. 1.1.

#### 1.2.1.2. Dipstick-Auto Read Road Profiler

It is a precise electronic digital level and profiler (Fig. 1.2). It stands on two support legs. Just by a simple twist of the wrist it can take readings along a survey line. It measures, displays and records the elevation difference between front and the rear leg. The readings that are taken are accurate up to 100th decimal place. It directly gives International Roughness Index in m/km.



Fig. 1.2. A Typical View of Dipstick

#### Measurement with Dipstick

To ensure that the unit is reading accurately, it must be zeroed (leveled) prior to each session. This process is similar to the zeroing process done with precision bubble type levels. The dipstick should be zeroed before each session of data gathering. With a little practice, the user will be able to check the zero in seconds and re-zero the unit completely in a few minutes. The dipstick unit with its various parts marked is shown in Fig. 1.3.

The zeroing of dipstick is done as follows:

1. Dipstick is placed on a flat surface.
2. Two circles 250 mm apart are drawn on the flat solid surface using a marker. These circles are used to relocate the dipstick in the same position during the zeroing process. One of the circles is marked as 'S' (for start end)
3. The on/off switch is used to turn the unit on. A warm up period of 3-4 minutes is given before the zeroing began.
4. The start end swivel foot is placed on the zeroing circle marked with an 'S' and the other swivel foot was placed on the other circle.
5. The reading shown on the LCD at the 'start' end of the dipstick is recorded on a piece of paper. This is the 'start end' reading.
6. The dipstick is then lifted and rotated 180 degrees (end for end) placing the swivel feet on their opposite marks and the reading at the 'S' mark is recorded. This is the 'battery end' reading.
7. The 'start end' reading is added to 'battery end' reading and divided by two, by taking in to account negative signs also.
8. This reading average is taken as the corrected setting for the 'start end' LCD in the next step.
9. The dipstick is returned to the original set-up position and the start end swivel foot is placed on the 'S' mark.
10. The electronic zeroing dial is turned so the reading on the LCD at the start end showed the corrected end reading just calculated.
11. The rotation and battery end reading step described on step 6.
12. The adjusting process is repeated until both LCD's display the same reading when at the 'S' circle within  $\pm 0.0$  mm.
13. The L.C.D readings are re-checked to ensure proper zeroing adjustment has been maintained.
14. If zeroing has not been maintained, hardware was loosened and readjusted using the above described process until zeroing holds.

In the new version of the equipment, after placing the equipment on a flat surface, just by pressing the calibration button, equipment is calibrated in a simplest way.

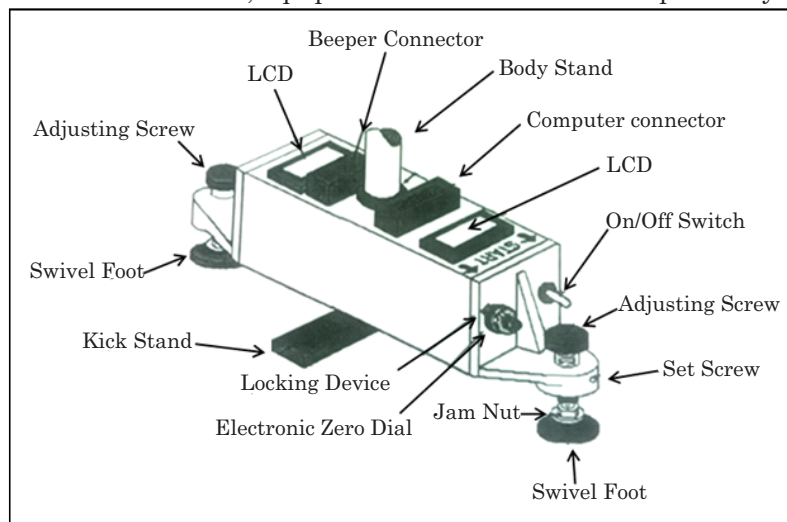


Fig. 1.3. The Dipstick Unit

**Data Collection**

Dipstick is placed exactly on the starting point and the measurement is started. Sequential elevation differences are recorded automatically by the on-board computer and finally IRI value is displayed on the screen. If required, recorded information can be transferred to the PC for further analysis. The distance vs IRI graph obtained from dipstick data analysis software is shown in Fig. 1.4.

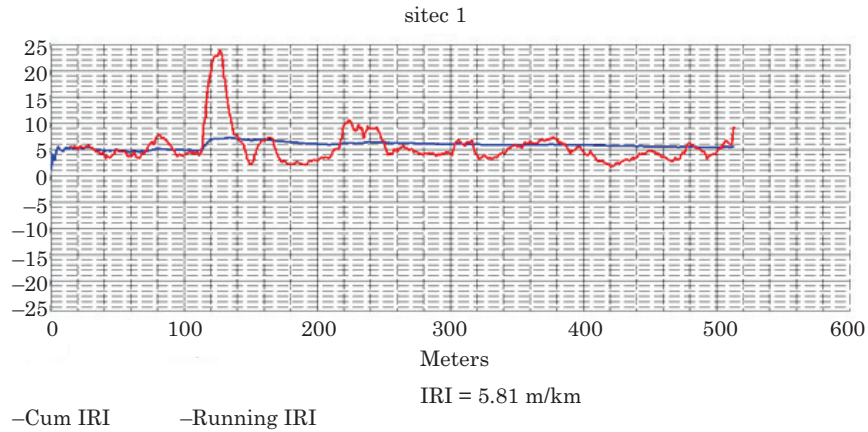


Fig. 1.4. IRI vs. Distance graph (Dipstick)

The field measurements and IRI results can be recorded as per the Performa 1.1.

**1.2.1.3. Walking Profiler**

The Walking Profiler Fig. 1.5 is a precision surveying tool which is designed to operate at a moderate and steady walking pace in a straight line. The equipment has an integral Control Unit which provides all the functions of instrument calibration, survey setup and operator feedback. Like Dipstick, it also directly gives International Roughness Index in m/km.



Fig. 1.5. Typical View of Walking Profiler

### Measurement with Walking Profiler

To ensure the accuracy of IRI results, the following 3 steps are performed for calibration of the equipment, before the field survey.

First calibrate option is selected using the control panel. Then the current values of offset and slope are observed on the calibration screen as shown in Fig. 1.6. The steps for calibration are:

#### Step 1:

Trim platform is placed on the ground alongside the ‘measuring beam’ of the walking profiler on a smooth surface. The measuring beam is removed from the walking profiler (without disconnecting the cables) and placed on the trim platform facing forward. ‘OK’ key is pressed and series of measurements are automatically taken by the controller and after a beep sound, the controller set for the next step.

#### Step 2:

The measuring beam is turned 180 degrees, front to back and placed on the trim platform. ‘Ok’ key is pressed and series of measurements are automatically taken by the controller. A new offset value is calculated and after the beep sound the system is ready for the next step.

#### Step 3:

Both new and old offset values are displayed. When the new value becomes similar to the old value, it is saved by pressing Ok to ensure the system was stabilized, till then “offset” is selected in the calibration menu again and steps 1 and 2 are repeated. The offset trim value should be repeatable to within 0.01 mm of the previous value. When the value became stable “OK” key is pressed, to save the results. The measuring beam is re-connected to the walking profiler.

CALIBRATION MENU	
Current Offset:	-1.09846 mm
Current Slope:	-0.00821 m/V
Slope Calibration Date:	2014-2-23
Press Offset,	to calibrate the Field Offset Trim. Ensure site temperature has stabilised prior to performing calibration
Press Slope,	to perform a Laboratory Slope Calibration. Use the precision calibration kit in a zero vibration and stable temperature environment.
Offset	Slope

Fig. 1.6. Calibration Screen of Walking Profiler

### Data Collection

The survey is performed in walking pace from the starting point. The built-in data acquisition module collects and stores the data and the results are displayed in real time for simple and quick data analysis as shown in Fig. 1.7.

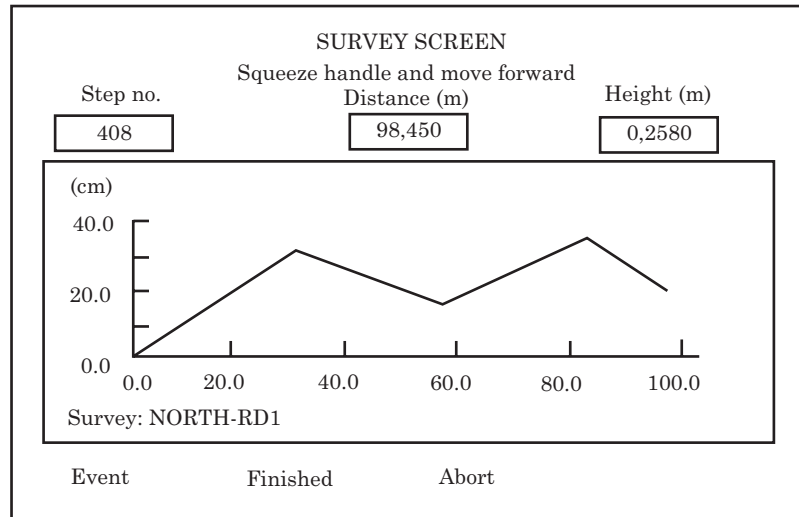


Fig. 1.7. Real Time Graph of Profile Versus Distance

The field measurements and IRI results can be recorded as per the Performa 1.2.

#### 1.2.1.4. Laser Profilometer (LP)

Laser based road profiling is a high-speed road roughness measuring system as per ASTM E950 (Class-1 category). The Laser Profilometer beam is installed in the front of the survey vehicle as shown in Fig. 1.8. This system is based on the measurement of vertical displacements using Laser Rays. Laser Profilometer Bar comprises of two laser sensors used for the measurement of longitudinal profile of two-wheel paths of the pavement surface as shown in Fig.1.9. The system directly gives International Roughness Index (IRI) for both wheel paths viz. Left IRI, Right IRI and Average IRI in terms of m/km as shown in Fig. 1.10. This equipment has self-calibration mechanism.



Fig. 1.8. Laser Profilometer Installed in the Front of Survey Vehicle

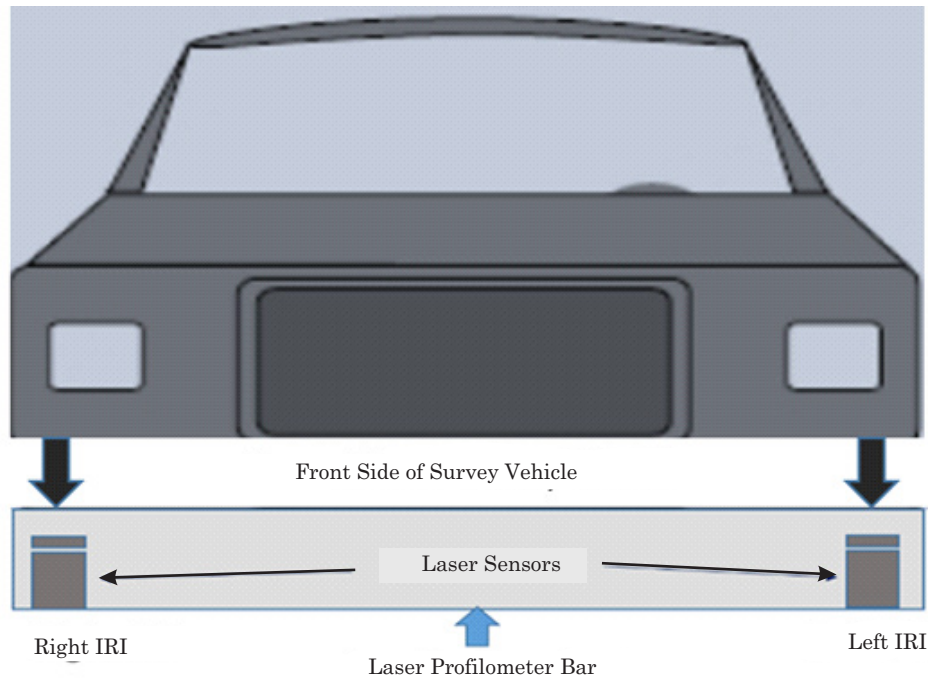


Fig. 1.9. Sketch of Laser Profilometer

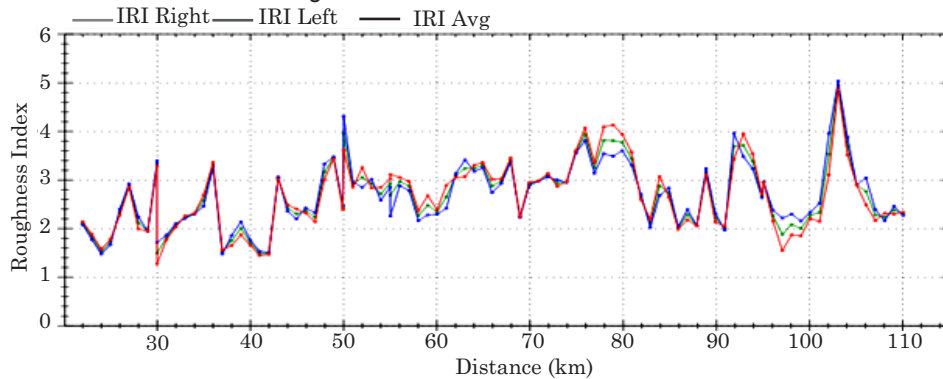


Fig. 1.10. International Roughness Index Calculated Using Laser Profilometer

### Measurement with Laser Profilometer

To ensure the accuracy of IRI results, the following 2 steps are performed for calibration of the equipment, before the field survey.

It is mandatory, that the person performing the calibration test of laser profilometer, must read and follow laser safety instructions and wear laser safety goggle (supplied along with the equipment).

#### Step 1: Digital Laser Profiler Bounce Test

The bounce test verifies that the digital profiler accelerometer sensors arresting the error due to unwanted vertical movement of the survey vehicle.

The procedure for the test is as follows:

1. The survey vehicle is parked on a smooth and flat surface.
2. It is ensured that the 'DP Acquire' is running and 'Profiler Calibration View' module has been selected for performing the Bounce test.
3. Laser sensors are activated by pressing the power ON button and allowed to warm up for at least 10 minutes.
4. The laser calibration plates are placed under both roughness laser sensors of the profilometer. Using laser indicator card and the specified goggles, it is ensured that laser light from both sensors are visible in the centre of the calibration plates. If so, 'Next' key is pressed for the next step.
5. The bounce test dialogue box appears with two countdown phases (still vehicle phase and bounce phase) of 10 sec each. During the still vehicle phase, the vehicle is kept stationary (even movement of driver or any other person inside the vehicle is not allowed) for 10 sec and data is automatically recorded.
6. Immediately after the end of the 'still vehicle' phase, 'bounce phase' countdown starts for 10 sec. During this countdown phase, the laser profiler assembly is manually pushed at an interval of 0.5 sec to 1.5 sec by a person to provide bounces to the laser profilometer.
7. At the end of the bounce phase, the 'Configure IRI Limits for the Bounce Test' dialogue appeared. 'OK' key is clicked after entering the correct values.
8. The IRI values are checked for their acceptability. If IRI is greater than the acceptable limits, the test is repeated after corrective measures, until the acceptable level is achieved. The test is finished by pressing the 'Finish' key.

The wheel path sensor outputs of bounce test are shown in Fig. 1.11.

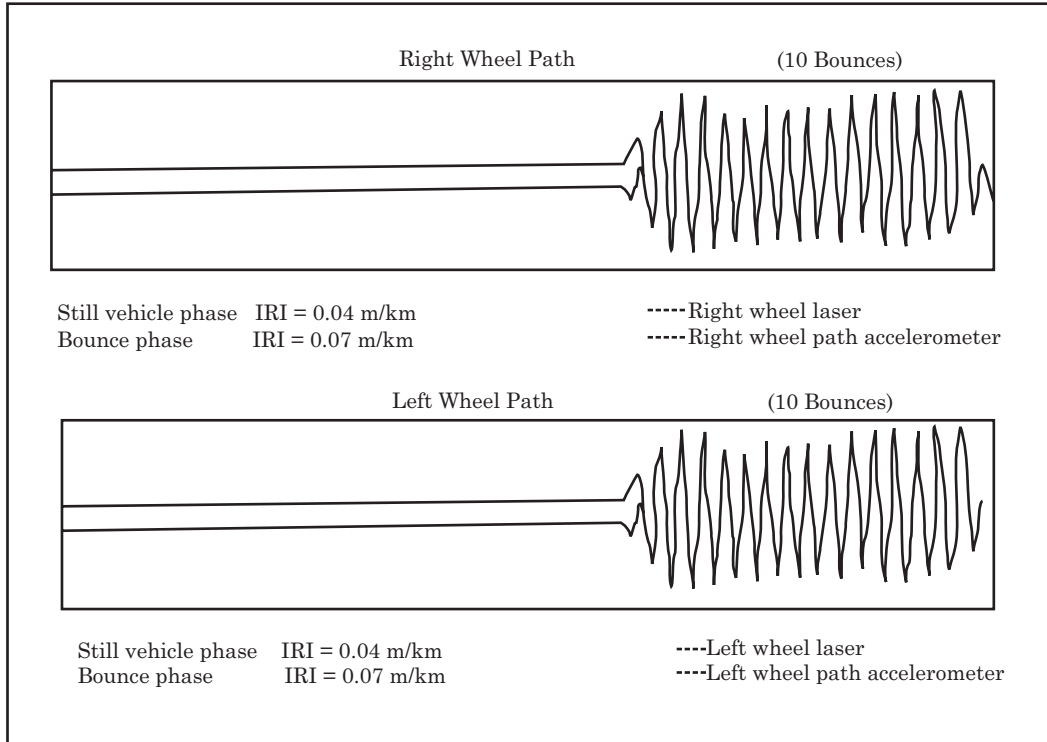


Fig. 1.11. Wheel Path Sensor Outputs of Bounce Test

### Step 2: Digital Laser Profiler Laser Sensor Calibration

This calibration computes calibration constant for individual laser sensor. The calibration methodology involves 1) measurement of distance between laser source and the flat surface (flat calibration plate placed on the ground) and 2) measurement of distance between laser source in the presence of calibration block of known heights (25 mm, 50 mm and 80 mm), placed on the flat surface (flat calibration plate placed on the ground). The 50 mm block dimension is used for calibration while the 25 mm and 80 mm dimensions are used to check the linearity. The various steps are described below:

1. The vehicle is parked on a smooth and flat surface.
2. From the 'Profiler Calibration view', a laser sensor for calibration is selected, and 'Calibrate' key is pressed to open the laser calibration dialogue box.
3. Laser sensor is activated by pressing the power ON button and allowed to warm up for at least 10 minutes.
4. The laser calibration plate is placed under the laser sensor selected for the calibration. Using laser indicator card and the specified goggles, it is ensured that laser light from the sensor is visible in the centre of the calibration plate. If so, when the height reading became stabilized, 'Next' key is pressed for the next step.
5. The calibration block of 50 mm height is placed on the calibration plate and it is ensured that laser light from the sensor is visible in the centre of the block. If so, when the height reading became stabilized, 'Next' key is pressed and calibration results are observed on the screen as shown in Fig. 1.12.
6. In case the results are acceptable, 'Finish' key is pressed, otherwise steps 1 to 5 are repeated until desired results (Measured height shall be as much as close to block height say 50 mm) are not achieved.
7. Now, the same test is repeated (step 1 to 5) for 25 mm and 80 mm blocks.
8. Same steps 1 to 7 are followed for other laser sensors.

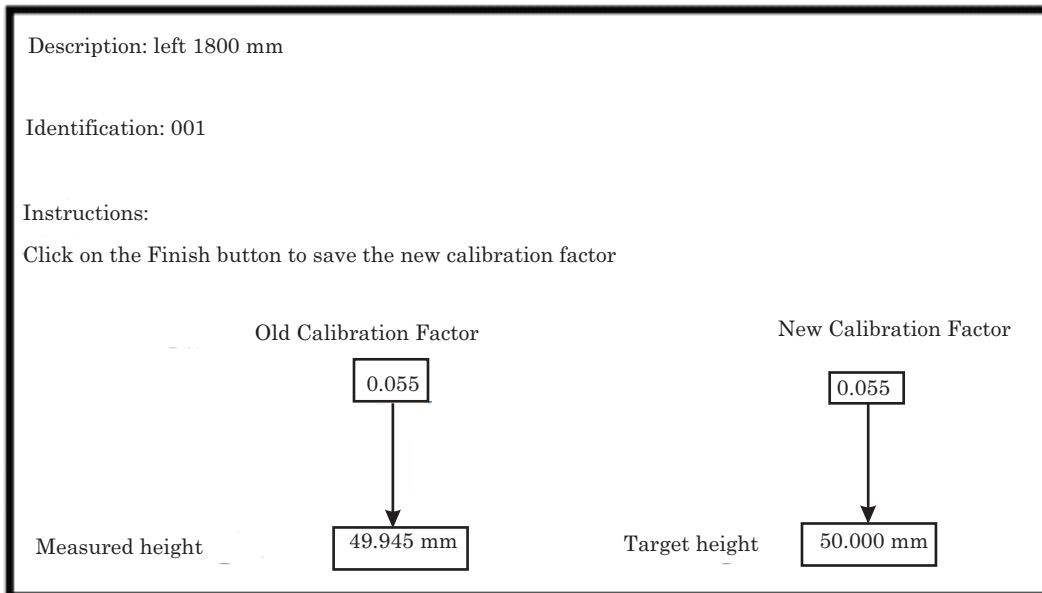


Fig. 1.12. Profiler Laser Calibration Dialogue Box

# MANUAL ON PAVEMENT EVALUATION TECHNIQUES

## About the Book:

The manual presents various methods of pavement evaluation using modern equipment and techniques. Measurement of road roughness by bump integrator as well as laser profilometer, Measurement of pavement surface characteristics like Macro Texture, Skid Resistance and Polished Stone Value, axle load survey for the estimation of vehicle damage factor, methods to evaluate pavement surface distresses and details of latest survey techniques such as Falling Weight Deflectometer and Network Survey Vehicle have been explained. The manual is intended for field engineers, researchers and consultants.

## About the Authors:



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He has more than 25 years' experience in R&D activities and contributed significantly in research and development works related to Nondestructive Test Techniques for Pavement Evaluation, Pavement Maintenance Management Systems for Roads and Runways and Geospatial Techniques for Pavement Evaluation. He is the key person for successfully implementation of modern pavement evaluation technologies in India, mainly the Network Survey Vehicle System first time in the country for road inventory and pavement condition monitoring of road network. He has published 45 research papers, authored book entitled “Condition Evaluation and Classification Using Geospatial Tools”.



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