# Piarc World Road Association

## International Experiment to Harmonise Longitudinal and Transverse Profile Measurement and Reporting Procedures

Draft Report

Danish Road Institute
Report 93
1999

Road Directorate
Ministry of Transport - Denmark

# PIARC World Road Association

## International Experiment to Harmonise Longitudinal and Transverse Profile Measurement and Reporting Procedures

Draft Report

Bjarne Schmidt (Denmark)
Jim Wambold (USA)
Akira Kawamura (Japan)
Guy Descornet (Belgium)

Vejteknisk Institut
Report 93
1999

# Contents

# Executive summary

In 1998, the World Road Association, PIARC, Committee C1 on Surface Characteristics conducted an international experiment to harmonise longitudinal and transverse profile measurement and reporting procedures. The experiment was conducted as three regional experiments with a view to:

1. allow for differences in the needs of the different regions and
2. optimise the costs and the management work of PIARC

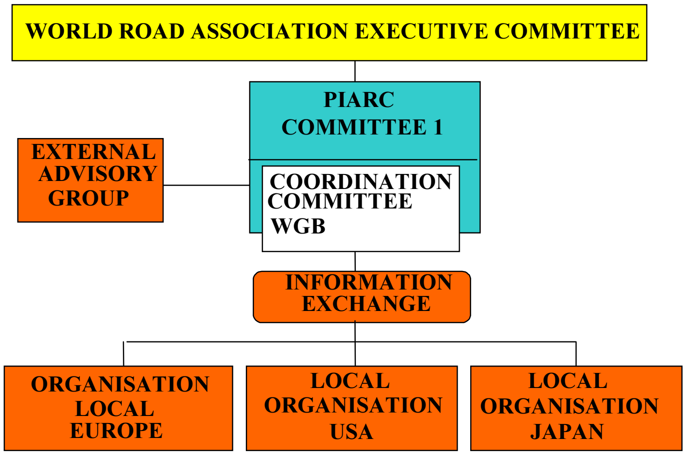
Each region designed, funded and conducted its project according to its particular needs, but had to comply with the core programme designed by Committee C1.

However the regional interest became so dominant that it was not possible for all regions to follow the specifications in the core document, and each deviated to a small extent to comply with regional interests.

Committee C1, however performed reference measurements in all three regions using the same equipment and the same operator for these tests. This make it possible to evaluate each participating device in the three regions against the same reference and therefore enables the Committee to perform an analysis of harmonising many of the devices used around the world.

The attached figure shows the overall organisation of the project. The co-ordination committee had the responsibility to oversee a final synthesis of the regional reports including general recommendations. The advisory group was formed independently of Committee C1 with a balanced membership from the three regions.

**Project Organisation**



# 1.0 Introduction

Road evenness is regarded as one of the most important road surface characteristics. Evenness has an influence on a number of functional characteristics of roads, such as vehicle fuel consumption, tire wear and mechanical deterioration. It also influences effects on road users such as internal noise, infrasound, ride comfort and driver fatigue. Furthermore, there are environmental effects such as exterior noise and air pollution influencing people around the road. High dynamic wheel load variations are also caused by the rough surface and reduce structural performance. The measures presently used to describe road unevenness are generally good at predicting ride comfort because they were developed for that reason. The correlation between measures of road unevenness and other functional characteristics of the road may need further development.

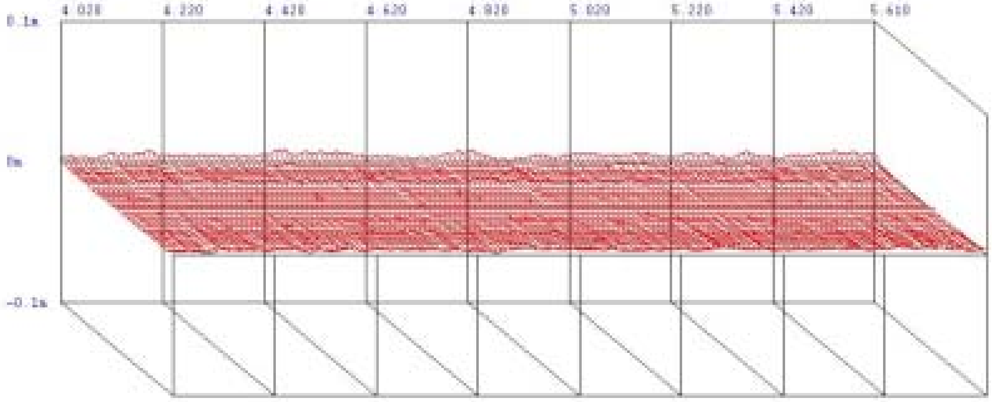


*Figure 1, Three-dimensional plot of a pavement surface, measured by a high speed profiling device*

Road evenness is used as an indicator of both a pavement's functional performance and structural condition. Evenness assessment methods vary widely and include those that measure profile, those that measure response to road unevenness, and subjective evaluation. Profiling equipment and methods of measuring longitudinal and transverse evenness vary widely from country to country. The purpose of this experiment is to provide a means to compare the results of measurements carried out using different equipment and different measurement methods. The results of this experiment will be invaluable in realising consistent pavement management practices (with respect to longitudinal and transverse evenness and cross slope as well as the assessment of their effects on the road user, road owner and environment) across country boundaries. Furthermore, it is necessary that the measurement reporting be harmonised to standardise paving specifications.

In the past, there have been several other studies to compare longitudinal evenness measuring equipment. The most notable was the World Bank International Road Roughness Experiment (IRRE) to establish correlation and calibration standards (World Bank Technical Paper Number 45). This experiment was conducted in 1982 in Brazil. In the IRRE, all types of evenness measuring equipment were included, including response type systems. The IRRE also developed the International Roughness Index (IRI). More recently studies have been conducted by SHRP in Ames, Iowa, the Road Profiler User Group (RPUG), and University of Michigan Transportation Research Institute (UMTRI) for FHWA. In Europe, several administrations have performed comparative tests to select equipment for network surveying.

The experiment drew upon the experience of these studies, but only included profiling equipment. Response-type devices were not included in this experiment. Since the IRRE 1982 study, many new types of profiling equipment were developed, which also measure transverse profile and rut depth, measurements that were not included in the IRRE, nor in other studies. Therefore, there were real needs to update the previous work and to include transverse profile as well.

The experiment was supported and overseen by PIARC Committee 1 on Surface Characteristics (C1) and was subject to PIARC Executive Committee approval. Working Group B of C1 was the group responsible for the experiment and supervised the experiment. In addition, the group assessed technical approaches and made recommendations to C1 for approval. Similarly, a separate group managed those expenses that were funded by PIARC. These funds were required to link the experiments at the three locations and produce the final report.

The experiment was carried out in three locations: North America, Europe and the Japan. Three principal investigators, one English speaking, one French speaking and one Japanese speaking, led the regional experiments. Each of the three regions developed their own work plan, which could expand on the core plan but had to at least include the core elements. When measurements were performed, the same procedure for obtaining the "true profile" was used in all locations. This provided the link between the locations.

The results of the study will be published in a technical report and a summary report. These reports will include procedures for relating pavement evenness, longitudinal and transverse, as measured by different standard methods of test. The various devices will be evaluated for accuracy (vertical, longitudinal, and transverse) and evaluated for their ability to achieve the accuracy required to produce the various summary statistics used by pavement management for longitudinal, transverse and rutting measurements. In most cases these statistics are specified by ISO, CEN, AASHTO or ASTM Standards. Where no existing standard is available, consideration will be given to provide the data needed for the development of standards, particularly for those methods with widespread use.

As in the first major experiment conducted by PIARC C1 on friction and texture, the data base will be extremely important and will be invaluable for further analysis by other organisations. In addition, after the data is collected, the sites will be made available to other researchers who would like to use the sites and the data for other studies. There are presently several studies that are linked to this research project and would use the data from this experiment, e.g. NCHRP project 10-47 “Guidelines for Longitudinal Pavement Profile Measurement” currently being conducted by UMTRI.

## 1.1 Need for harmonisation

### 1.1.1 Road evenness

An uneven road pavement surface causes expenses to both the road user and the road owner. It is therefore important to measure the present unevenness or to monitor the progression of the unevenness characteristics of the pavements. This will enable optimal pavement maintenance strategies which will benefit the road user and the road owner. Unevenness is defined as the difference in the profile from the originally planned surface profile. This difference causes notable dynamic influences on a vehicle travelling on the pavement.

The differences from the planned profile can be described by the level of elevation (amplitude) from a theoretical smoothed pavement surface and the wavelength (m) or frequency (Hz) if related to vehicle speed.

For pavement wavelength less than 0.3 meter the dynamic response from the pavement is generally absorbed in the tyre of the vehicle. Wavelengths greater than 50 meter do not give any notable dynamic response at normal travel speed. It is therefore generally defined that the wavelength span for discomfort and vehicle wear is between 0.3 and 50 meters.

Some of the unevenness on road pavements is related to the used construction technology and the skill of the contractor. For many road administrations, the amplitude of this initial unevenness is controlled by contractual agreements or national road standards.

Other unevennesses occur during the use of the road and will often increase with time. These are often related to plastic deformation in the subgrade, compression of bearing layers and deformation in the asphalt layer. Other types of irregularities in the pavement surface are potholes, stripping, frost heaves etc.

The unevenness of a road profile is normally of a non-periodic character described as a random function. In the interpretation of such a function it is often used to describe the pavement surface by a large number of harmonic functions.
In order to be able to describe the pavement surface in relation to comfort, vehicle wear, maintenance costs etc. it is necessary to have a representation of the road profile. This can be obtained by the true geometric profile, a profile measurement or by a

more or less representative expression for the evenness by measuring the response from the pavement.

Although unevenness of road pavements are defined to have wavelengths between 0.3 and 50 meters, resonance effect in vehicles can occur on pavement surfaces with almost no unevenness.

The experience by vehicle operators or passengers can, of course, be of different experience. In an article in HRB, Bull. 264 (1960) p. 12 this quotation is found:

"....... some undulation in the road surface may break the monotony and definitely add to the pleasant sensation of riding in a motor vehicle".

In spite of this, unevenness is in modern pavement maintenance strategies regarded as one of the major descriptors of vehicle user costs, and therefore should be reduced to a minimum.

### 1.1.2 Harmonisation

The aim of performing better pavement maintenance strategies demands reliable information about the condition of the road network and hence demands reliable measuring devices.

The development of measuring devices for measuring road evenness has been undergoing a tremendous technology evolution within the last decade. Determination of road evenness is now performed by measuring the road profile at normal traffic speed and then calculating various road indices such as IRI. The accuracy of many of these indices depends on the performance of the measuring equipment. Different devices can therefore report different IRI or rut depth numbers, even when measuring the same road section. A method for adjusting differences in reporting indices can be obtained by harmonising the different devices.

Harmonisation means that a method will be developed so that each profile device can make an estimate of the "true profile" from which all indices would be calculated. This allows each device to report the values it normally did in the past and still harmonise it to the common true profile. This then also allows calibration of other and new equipment since it can later be correlated to the true profile. The alternative to harmonisation is standardisation, which requires that everyone must carry out exactly the same procedure.

## 1.2 Objectives

The core document for the experiment specifies the following two major objectives:

1. Harmonise and correlate measures of longitudinal and transverse road surface profiles for application in pavement construction and management.
   This requires that the project will

   - provide data so that other organisations can set requirements and/or ranges and be able to evaluate the analysis methods used by pavement management for roads and airports in order to establish the accuracy requirements.

   - evaluate the ability of each device to produce standard measures of longitudinal and/or transverse evenness to facilitate interchange and harmonisation

2. Provide a basis for the assessment of the reliability of road profile information.
   This requires that the project will:

   - evaluate the accuracy and repeatability of the longitudinal and transverse profiles obtained by each device by direct comparison with the “True Profile”. These comparisons will be obtained under varying physical conditions encountered in the real world. They will include lateral placement, speed variations, climate, pavement type, reflectivity and texture.

   - determine sampling rate and/or sample size required by the various methods to achieve desired accuracy of the applicable summary statistics. Quantify repeatability and errors associated with the various devices.

Due to financial constraints for the experiment only the basis of the objectives has been accomplished in the experiment by executing and completing experiments with a representative selection of available high-speed profiling equipment from around the world. For reasons of practical organisation and so as to make the experiment as attractive as possible to producers and users of high-speed profiling equipment around the world, it was decided to carry out the experiment as three regional experiments with test sections in USA, Japan and Europe.

## 1.3 Benefits

With increasing road traffic follows increasing deterioration of road pavements which results in decreasing serviceability for the road users. This decrease in serviceability is experienced as a decrease in the ride comfort which leads to an increase in vehicle maintenance costs, fuel consumption and freight damage costs. Also issues such as driver fatigue, and potentially reduced productivity need to be considered together with reduced comfort for the driver and passengers, when talking about the price the road users and the society has to pay for deteriorating roads.

The interaction between the cost of maintaining a road network and the benefits for the road users and society are the key objectives in relation to optimising pavement maintenance strategies. Carefully planned pavement maintenance strategies have become a necessity as many road administrations are facing budget constraints on their maintenance budget. A feasible solution for optimised pavement management is to introduce Pavement Management Systems (PM-systems) such as the HDM-4 system. However, reliable output from PM-systems demands reliable input data about pavement conditions and one of the pavement condition data which is the most important is road evenness; this is the key factor for user costs. This can be seen in the HDM-4 system where, evenness plays an important role to determine user costs.

For the purpose of measuring road evenness, many different equipment is available commercially and today many of these are operating in a high speed manner by using laser or other non-contact techniques. Most of the modern equipment is capable of determining the longitudinal and transverse profile of the road in order to determine rutting and longitudinal evenness. In order to determine these parameters, it is necessary to incorporate algorithms into the systems. The results from calculating evenness and rutting from measured profiles depends on the accuracy of the measurement and the algorithms used. If the outcome from a measuring system is influenced by errors, this will have a significant effect on the outcome and use of a PM-system with poorly determined maintenance strategies as a result.

Comparisons of profiling equipment have been conducted around the world by local road administrations or by high level research programmes, such as the Strategic Highway Research Program in USA, in order to find equipment qualified to be used for project or network level measurements.

Several of these investigations have, to some extent, been limited to participation by invitation and the outcome and the results have not been made publicly available as they are commercially related.

The intention with the PIARC experiment was to perform an objective and non-commercial evaluation of the participating devices and hence present a good guidance for selection of measurement equipment and analysis methods.

The benefits of the experiment are:

- Provide for consistent pavement management practices with respect to evenness, rutting and cross slope throughout the world so that road managers can compare road construction and maintenance strategies.

- Allow the opportunity for researchers to compare the results and therefore facilitate road and airport administrations and research organisations in their programs.

- Enable contractors to meet or compare specifications of any agency that implements the results, thus increasing the competitiveness of the bidding process.

- Provide information to any road administration or other potential user on equipment, which is available world-wide.

- Broaden the market for test equipment by increasing the ability to meet the requirements of different countries.

- Classify measuring equipment according to its accuracy and sampling rate.

- Provide information on the various roughness indices that are in use around the world.

- Provide a database that can be used by standards organisations to make national and/or international standards.

- Provide sites with documented surface data to be available for other studies.

## 1.4 High Speed Profiling Equipment

Today many different types of equipment have been developed around the world, and there are many different philosophies of how much must be measured in order to get a good picture of the pavement surface and to determine the longitudinal evenness and transverse parameters of a road.

### 1.4.1 Evolution of evenness evaluation techniques

The evaluation of pavement unevenness can be determined subjectively by a panel of people or by objective measurements by measuring equipment. The subjective evaluation can be performed by letting a rating panel drive over the pavement surface in an ordinary car.

A classical example for this evaluation technique is related to the AASHO tests in USA. During these tests, a large number of test sections were evaluated by a rating panel with the purpose of evaluating the Present Serviceability Rating, PSR, of the test pavements. The evaluation performed by the rating panel was then correlated to objective measurements performed by the AASHO Profilometer.

The AASHO Profilometer measured the slope variance of the pavement surface and a correlation between the objective measured surface characteristics and the subjective evaluated rating was performed. The result of this correlation forms the well-known Present Serviceability Index (PSI), which, besides evenness, includes rutting, patching and cracking.

### 1.4.2 Physical principles for objective measurements

The principles of physical measurement can be described in the following different categories:

1. Geometric methods:

- Rod and level measurements
- Measurement of the difference between a straightedge and the pavement sur face
- Measurement with a horizontal laser beam as reference
- Measurement in relation to a moveable plane
- Measurement of the slope and inclination
- Superposition of measurement results from laser sensors positioned on a straightedge

2. Combination of geometric methods and accelerometer methods

The principle of this measuring procedure is to measure the distance from the pavement surface to the chassis, either by a linear transducer mounted on the chassis and a measuring wheel, which follows the surface, or by a sensor not touching the surface (optical or accoustic). The movement of the chassis is determined by a double integration of the signal from the accelerometer mounted on the chassis. By adding the two measuring results the true profile is determined.

3. Initially held horizontal pendulum

Periodic angle measurement is performed by reference to an inertially held horizontal reference pendulum.

4. Distance measurement between vehicle axle and chassis.

Using this method the relative vertical movement between the axle and the chassis are summarised. This value is then divided by the measured distance (this value is used as evenness index).

5. Accelerometer signals

The measurement signal performed by an accelerometer mounted on a passenger or the vehicle is used as index of evenness.

### 1.4.3 Profile measurement and response measurements

Evenness measurements can be performed by equipment, which makes a “true” geometric profile of the pavement surface, or by equipment giving a more or less representative expression of the evenness by equipment of the response type.
Well-calibrated response type measuring equipment will often be sufficient monitoring equipment for inventory measurements in a road network. However, reliable calibration measurements on well-defined reference pavements are necessary.

Profile measurements vary from the most simple equipment, rod and level, to modern high technology equipment using laser triangulation. Profile devices can be used in all kinds of evenness measurements. The significant increase in efficiency and accuracy over the last decade provides the ability to measure in ordinary traffic flow, and this makes this measuring technique outstanding in relation to other measuring techniques.

Besides reliable information on pavement evenness to be used in pavement management systems, the use of advanced profiling devices also makes it possible to study the pavement surface in more detail by analysis of:

- Pavements profile waveform frequency distribution
- vehicle responses and
- dynamic influences on pavements.

### 1.4.4 Speed dependency of measurement equipment

Due to the increase in traffic volume experienced world-wide, it has become more and more important, for the sake of the road users, to limit the time delays caused by roadworks and by the measurements of pavement conditions.
Measuring vehicles which measure at a constant speed can result in traffic delays and congestion and be the reason for hazardous situations on a crowded road system. One of the advantages with modern profiling devices is their ability to operate at normal traffic speed and often at speeds up to around 100 km/h.

The technical development of the equipment has resulted in an improved quality of measurements. However, the results of the measurements can be influenced by other factors, which are related to the handling of the vehicle in the measurement situation.

### 1.4.5 Data handling and presentation of the results of the measurements

The evolution in handling the measurement data has changed from simple methods of analogue presentation on paper to advanced data acquisition equipment which can handle data collected at intervals of mm and cm.

One of the advantages of modern profiling techniques and sophisticated analysis programs makes it possible to evaluate the profiles in a more detailed way than was possible a few years ago. Having the profile in a digital form, represented by cm or mm intervals, it will be possible to perform analysies tailored to the individual road administration. Simulation of different response type measuring devices can be performed by mathematical simulation programs in order to calculate an index traditionally used in a road administration. The question that often occurs is whether the rut depth shall be determined by one or the other length of straightedge. This can be tested in the transverse profile from the equipment by mathematically modelling several lengths of the straightedge in the cross profile.

### 1.4.6 Use of measurement equipment

One of the most important issues to be clarified when planning the introduction of new measuring equipment is the use of it in the future. Generally it can be said that the ability of the equipment to reproduce a pavement profile and to perform detailed measurements and analysis shall be in reasonable relationship to the purpose of the measurements.

The following main features can be considered for measurement assignments:

- Control of new constructions
- Inventory measurements in road networks
- Detailed investigations of road profiles
  - research related assignments
  - measurement of test sections for calibration of other devices
  - measurement of test section with special unevenness problems

Of special consideration for a measuring equipment is the transfer function, which in relation to wavelength or frequency gives the ability of the equipment to reproduce the amplitude of the unevenness or the profile.

### 1.4.7 Control of new pavements

In the specification for the construction of a new pavement, the type of device used to measure the profile or unevenness is often specified. One of the issues, which should be taken into account is the wavelength significant to the road users. The measuring equipment should be able to measure wavelength according to this.

### 1.4.8 Inventory measurements

Routine measurements of evenness are used to investigate the deterioration of the pavement over time and consequently form the basis for maintenance planning.

Due to the often vast amount of kilometres, it is of great importance that the measurements can be performed with a high capacity. Also it is of great importance that the measurements can be related to a position in the network, as this position will be used in the pavement management process.

### 1.4.9 Detailed investigations of road profiles

For research investigations, measurement of reference test sections and pavements with special unevenness problems, it is necessary to use profiling equipment which records the “true” profile of the pavement surface and makes it possible to perform advanced data handling of the surface profile.

## 1.5 Definition of used indices

### 1.5.1 International Roughness Index

The International Roughness Index, IRI, has become an index used world-wide. The IRI was originally developed based on a time stable index in the late 1970s in the United States. The further developement, which included simplification and standardization of the index was funded by the World Bank and named IRI.

The computing of IRI based on rod and level measurements are described in the ASTM standard E 1364-95.

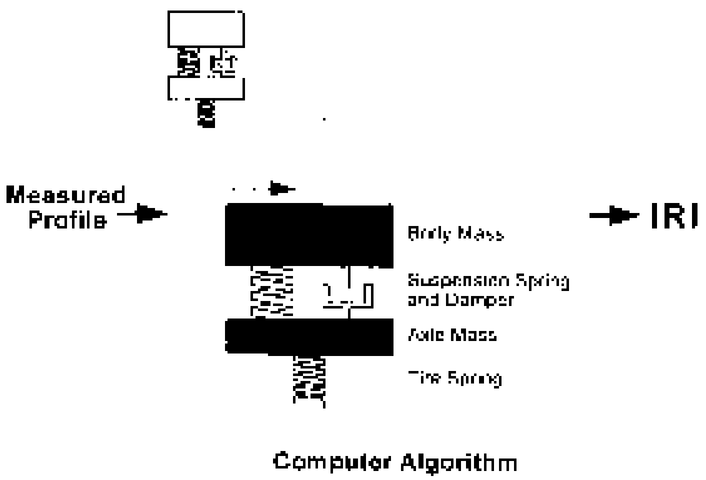


*Figure 2. Concept of model for calculating IRI. (ref. 1)*

The concept for the IRI calculation is to model the quarter of a car moving on the pavement surface, figure 2, and calculate the accumulated suspension deformation. The input to the model is a set of information describing the constants of the springs and dampers together with the sprung and unsprung mass acting in the model.

In 1982, the World Bank initiated an experiment in Brazil to investigate the possibility of a calibration standard for evenness measurements. After several years of research work, it was possible to establish the IRI as a standard measure for road evenness. The World Bank has published guidelines to explain how to measure IRI with different types of equipment. The sprung and unsprung masses and spring and damper constants of the IRI are not formally standardised but specified based on the findings of the Brazilian experiment

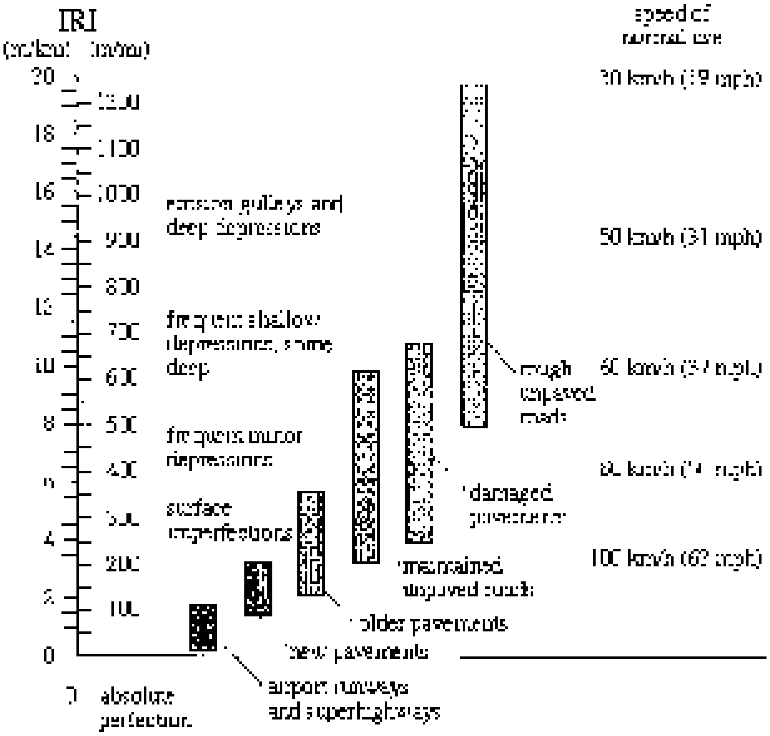


*Figure 3, The range of IRI in relation to road classes. Ref Little book of profiling.(ref 1)*

The IRI has shown to be a very feasible measure of road evenness to be used in relation to vehicle operating cost, road safety etc.

### 1.5.2 Determination of PSD

The Power Spectral Density, PSD, representation assumes that the road roughness data is random. PSD shows the extent that spatial wavelengths within a bandwidth contribute to road roughness. The total area under a power spectrum curve gives the total mean square roughness of the pavement in meters squared or other comparable units.

### 1.5.3 Determination of Rutting

Rutting is determined as the depression in the wheel tracks, which is caused by the traffic. In order to establish this parameter, it is necessary to measure the road's transverse profile and use an algorithm to calculate the rutting number.

Figure 4 shows typical transverse profiles measured on Danish roads.

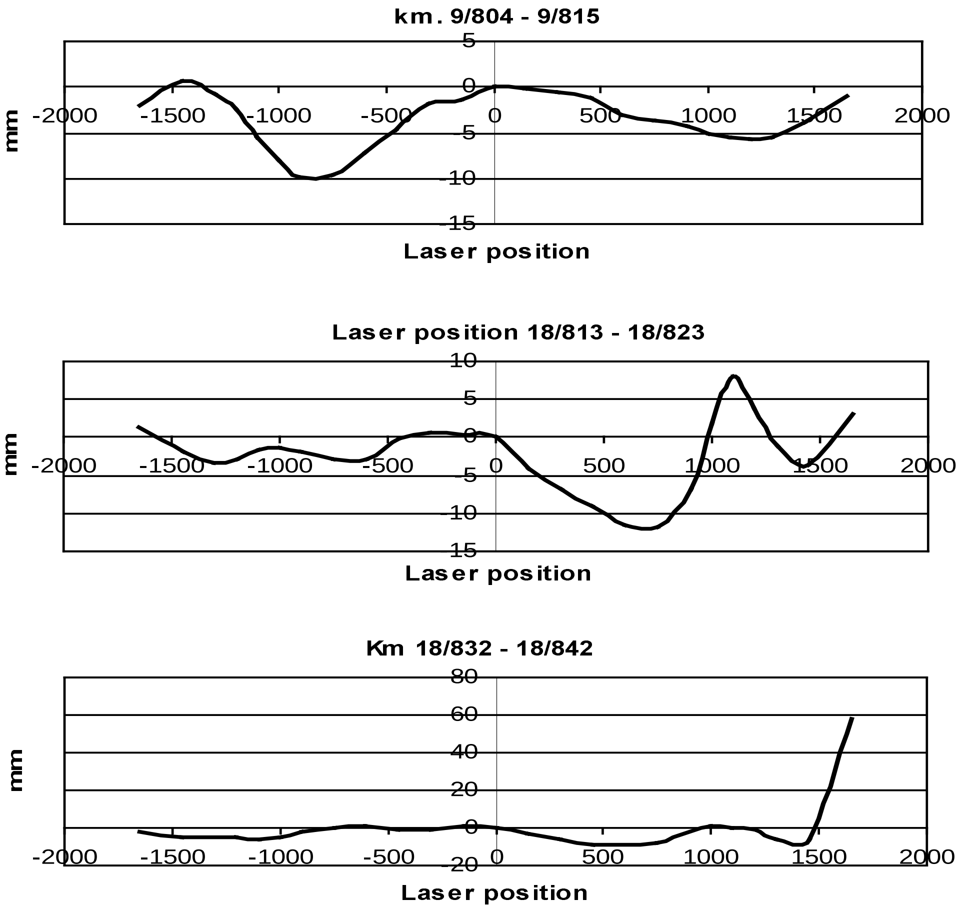


*Figure 4, Typical transverse profiles*

The European Standardisation body, CEN, is also working on standardisation of measurements of the transverse profile and determination of rutting for European roads. For that reason the CEN-group TC 227 Working Group 5 is in the process of preparing the following proposal for a standard: CEN/TC227/WG5 N 89E, wi 00227-133 ex 509, Surface Characteristics, Transverse Evenness, Method of Measurement.

In the proposal it is stated that the measurement of a pavement's cross profile will have different purposes. Immediately after construction, the measurement will be used to control the pavement surface for irregularities, which have occurred during construction. Later, when the road has been in service for some time it is valuable to measure the transverse profile on a routine basis in order to detect any deformation such as rutting, depressions or settlements in the lower layers of the construction due to the stresses and strains applied by the traffic.

The proposed CEN standard gives the following suggestions for transverse profile characteristics to be measured:

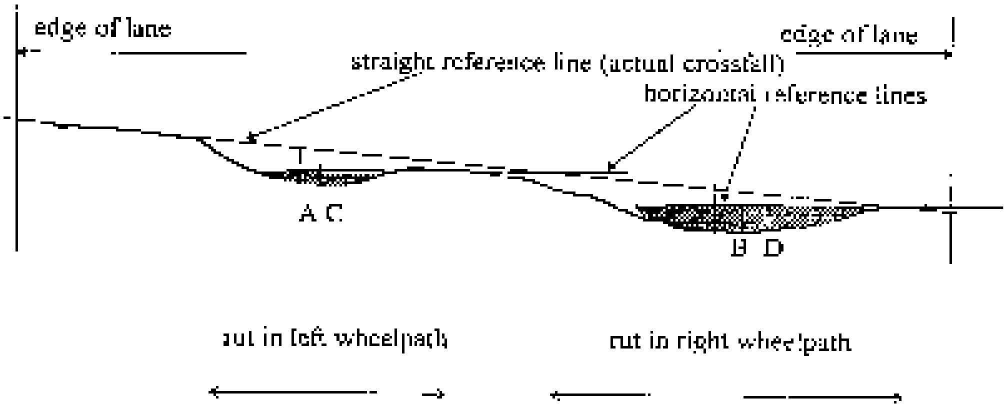


*Figure 5 shows a theoretical cross profile with the most important parameters related to rutting, maximum rutting at A and B and theoretic water depth at C and D. ref(2)*

The CEN proposal describes two methods to determine rutting:

### The straightedge method to determine rutting

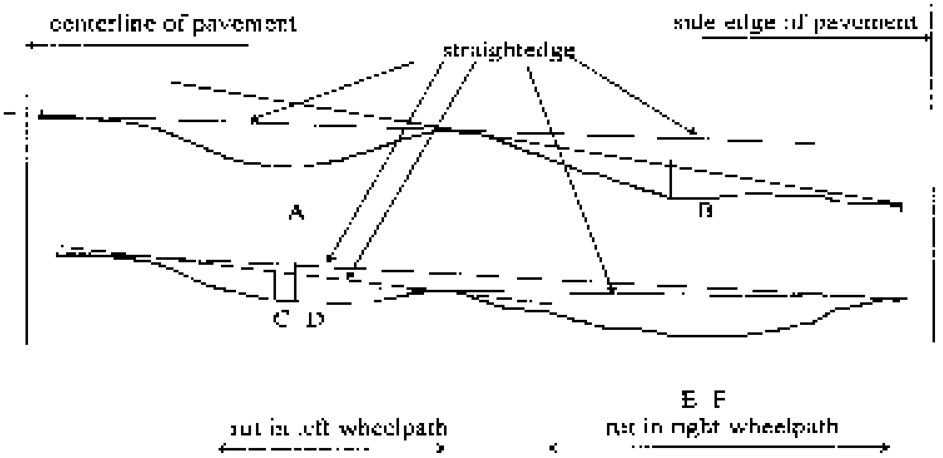


*Figure 6 shows measurement of rutting using the straightedge method. The results vary from A to F depending on the shape of the profile and the straightedge length.(ref2)*

When measuring rutting using a straightedge, the length of the straightedge is an important parameter, which influences the determination of the depth of the rutting. Also the shape of the transverse profile can have a significant influence on the result obtained by using the straightedge as shown in figure 6.

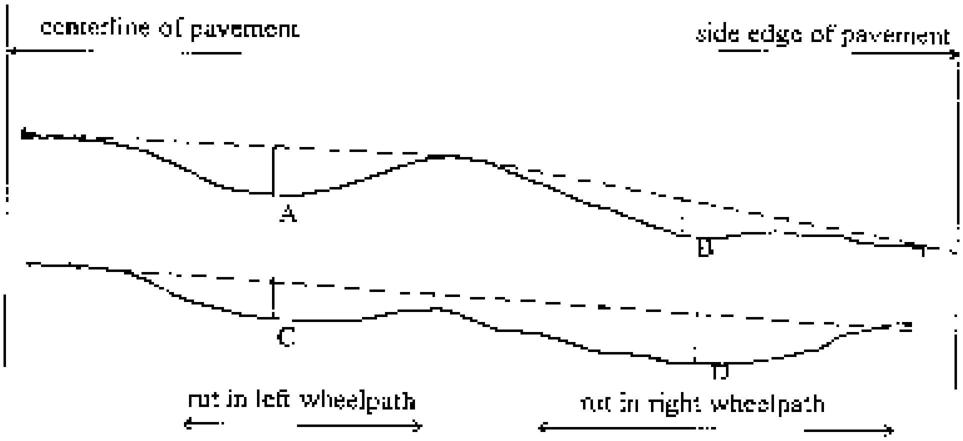


*Figure 7, Rutting determined by using the tensioned wire method. (ref2)*

An alternative to the straightedge method is the tensioned wire method. The method relates the actual pavement surface to a straight line given by an ideal tensioned wire which touches the highest points in the cross profile. With this line as a basis, it is possible to calculate the rutting as the distance between the line and the profile. This method removes some of the variables introduced when using a straightedge.

# 2.0 Experimental Design

## 2.1 Test sites

### 2.1.1 Test sites in USA

The test sites in the experiment in USA were located in the state of Arizona in the area of Phoenix and Tucson (Map Appendix 1). The test sites were located on in-service roads on both interstate and state roads. The test sections were chosen to cover a broad spectrum of service levels in relation to evenness and rutting in correspondence with the core document. Each test site was 1 mile long (1.6 km) and the actual test section was determined to 330 meter in accordance with ASTM draft 'standard test method for determining the precision and bias of equipment used to measure longitudinal profile of a pavement surface' (September 1998)

In total twenty sites were established on in-service roads together with special test sites at Williams Gateway Airport and Sky Harbor Airport in Phoenix and at Tucson Airport in Tucson. The location for the test sections on the in-service roads are shown in table 1.

| **Interstate roads** | **State roads** | **Local roads** | **Special tests** |
|---|---|---|---|
| I10; mp 107 - 106 (westbound) | S83; mp 25.5 - 26.5 (southbound) | Kinney Rd (near Desert Museum) | Williams Gateway Airport |
| I10; mp 106-107 (eastbound) | S83; mp 30 - 31 (southbound) | Sandario Rd (near Manville Rd) | Sky Harbor Airport |
| I10; mp 131-132 (eastbound) | S83; mp 31 - 30 (northbound) | | Tucson Airport |
| I10; mp 174 - 175 (eastbound) | S83; mp 40 - 41 (southbound) | | |
| I10; mp 176 - 177 (eastbound) | S86; mp 131 - 132 (eastbound) | | |
| I10; mp 180-181 (eastbound) | S86; 134 - 135 (eastbound) | | |
| I10; mp 270 - 271 (eastbound) | S86; mp 139 - 140 (eastbound) | | |
| I10; mp 274 - 275 (westbound) | | | |
| I19; mp 57 - 58 (northbound) | | | |
| I19; mp 90 - 91 (northbound) | | | |

Table 1; Location of test sites in the experiment in USA

The test matrix for the test sections in Arizona included test sections with IRI values ranking from approximately 0.5 m/km to 4.5 m/km. The test sections therefore covered road standards ranking from airport runways to older pavements, in according with the world bank specification in figure 3. The matrix for the selected test sections are shown in table 2.

Each test section was marked with reflecting tape to indicate start and stop of measurements. This gave the participating devices the ability to have automatic start and stop of data collection.

| **Test Sections In Arizona** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Target Test Matrix** | | | | | | **SELECTED TEST SECTIONS** | | | |
| Evenness Iri M/Km | MEGA TEXTURE | MACRO TEXTURE | FEATURES | RUTTING | No | ROAD ID | IRI (l/m) | RUT (mm) | MTD (mm) |
| 4.0<Iri<5.0 | LOW | LOW | LOW | LOW | 1 | | | | |
| 4.0<Iri<5.0 | HIGH | HIGH | LOW | LOW | 2 | | | | |
| 4.0<Iri<5.0 | - | - | YES | HIGH | 3 | | | | |
| 4.0<Iri<5.0 | - | - | LOW | MEDIUM | 4 | | | | |
| 2.5<Iri<4.0 | LOW | LOW | LOW | LOW | 5 | | | | |
| 2.5<Iri<4.0 | HIGH | HIGH | LOW | LOW | 6 | | | | |
| 2.5<Iri<4.0 | - | - | YES | HIGH | 7 | | | | |
| 2.5<Iri<4.0 | - | - | LOW | MEDIUM | 8 | | | | |
| 1.5<Iri<2.5 | LOW | LOW | LOW | LOW | 9 | | | | |
| 1.5<Iri<2.5 | HIGH | HIGH | LOW | LOW | 10 | | | | |
| 1.5<Iri<2.5 | - | - | YES | HIGH | 11 | | | | |
| 1.5<Iri<2.5 | - | - | LOW | MEDIUM | 12 | | | | |
| 1<Iri<1.5 | LOW | LOW | LOW | LOW | 13 | | | | |
| 1<Iri<1.5 | HIGH | HIGH | LOW | LOW | 14 | | | | |
| 1<Iri<1.5 | - | - | YES | HIGH | 15 | | | | |
| 1<Iri<1.5 | - | - | LOW | MEDIUM | 16 | | | | |
| Iri<1 | LOW | LOW | LOW | LOW | 17 | | | | |
| Iri<1 | HIGH | HIGH | LOW | LOW | 18 | | | | |
| Iri<1 | - | - | YES | HIGH | 19 | | | | |
| Iri<1 | - | - | LOW | MEDIUM | 20 | | | | |

Table 2; Test Sections in Arizona

### 2.1.2 Test sites in Japan

The test sites for the Japanese experiment were located in the central part of Hokkaido around Sapporo (Appendix 2) to accommodate a variety of surfaces and to ensure that measurements would be carried out on in-service roads. The test sites were selected in accordance with the experimental core document, and consideration was taken towards traffic conditions and the environment in which the measuring equipment performed. Each test site was almost 1 km long with a 500 meter test section used for the measurements. Totally fifteen test sites were established with the location shown in table 3.

| **National Highway (12 sections)** | | **Prefectural Road (1 section)** | | **Expressway (2 sections)** | |
|---|---|---|---|---|---|
| Route 36 | 1 | Kamiatsuma-Tomakomai Route | 1 | Douo Expressway (Eniwa IC - Kitahiroshima IC) | 2 |
| Route 234 | 4 | | | | |
| Route 275 | 1 | | | | |
| Route 276 | 1 | | | | |
| Route 337 | 2 | | | | |
| Route 451 | 1 | | | | |
| Fukagawa-Rumoi Fully-access-controled Highway | 2 | | | | |

Table 3; Location of test sites in the Japanese experiment

The test sites in Japan consisted of a 500 meter test section with 300 meter acceleration section before the test section and a 200 meter deceleration section following the actual test section.

Each test section was carefully marked in order for the test vehicle operator to be able to locate the test sections and where to perform the measurement. A special feature for the experiment in Japan was that the test of the high-speed devices were performed at night time due to traffic control regulations and because several makes of equipment are constructed to perform tests at night time. In order to fulfil the requirement of satisfactory information regarding start and end of the test sections illuminated cone-shaped signs were placed on the sites. Figure 8 illustrates a measurement performed at night.

*Figure 8, High-speed tests performed at night time*

The layout of the 500 metre test section and the position of the different tests are shown in Appendix 3 and 4. This shows the layout of the information signs on the test sections which should secure the accuracy for the measurements.

The test matrix for the test sections in Japan included test section with IRI values ranking from 2.4 to 5.0 m/km and therefore included test sections in the higher end of the test matrix. The test matrix did not include test sections with low and very even test sections with IRI below 2.4. The matrix for the selected test sections is shown in table 4 where it is compared to the target test matrix of the core document.

| TABLE 1 TARGET TEST MATRIX | | | | | | SELECTED TEST SECTIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVENNESS IRI m/km | Mega Texture | Macro Texture | Features | Rutting | No | Road Id | K.P. | | Iri (?/M) | Rut (Mm) | Mtd (Mm) | Air (?) | Pave (?) | Date (1997) | Surface Potentially |
| | | | | | | | B.P. | E.P. | | | | | | | |
| 4.0<IRI<5.0 | Low | Low | Low | Low | 1 | N.H.36 | 47.8 | 47.3 | 5.00 | 5.0 | 0.43 | 10 | 10 | 9/9 | Wave |
| 4.0<IRI<5.0 | High | High | Low | Low | 2 | N.H.276 | 82.4 | 82.9 | 4.02 | 5.1 | 1.01 | 10 | 11 | 9/11 | Porous |
| 4.0<IRI<5.0 | - | - | YES | High | 3 | N.H.234 | 65.2 | 65.7 | 4.21 | 21.2 | 0.22 | 16 | 18 | 9/9 | Ruts |
| 4.0<IRI<5.0 | - | - | LOW | Medium | 4 | N.H.451 | 71.8 | 71.3 | 4.15 | 15.7 | 0.28 | 11 | 13 | 9/10 | Wave |
| 2.5<IRI<4.0 | Low | Low | Low | Low | 5 | N.E. | 23.8 | 23.3 | 2.83 | 4.5 | 0.52 | 22 | 23 | 9/9 | Porous |
| 2.5<IRI<4.0 | High | High | Low | Low | 6 | H.P.R.259 | 0.8 | 1.3 | 3.06 | 4.6 | 0.54 | 11 | 13 | 9/8 | Ccp |
| 2.5<IRI<4.0 | - | - | YES | High | 7 | N.H.337 | 90.1 | 89.6 | 2.71 | 21.0 | 0.22 | 16 | 18 | 9/8 | - |
| 2.5<IRI<4.0 | - | - | LOW | Medium | 8 | N.H.275 | 72.7 | 73.2 | 2.52 | 9.3 | 0.26 | 16 | 18 | 9/10 | - |
| 1.5<IRI<2.5 | LOW | LOW | LOW | LOW | 9 | N.H.234 | 34.0 | 35.0 | 2.33 | 4.5 | 0.28 | 16 | 18 | 9/9 | - |
| 1.5<IRI<2.5 | High | High | Low | Low | 10 | N.H.234 | 34.7 | 35.2 | 2.47 | 3.4 | 0.31 | 16 | 18 | 9/9 | - |
| 1.5<IRI<2.5 | - | - | Yes | High | 11 | N.H.337 | 93.9 | 93.4 | 2.29 | 15.7 | 0.26 | 16 | 18 | 9/8 | - |
| 1.5<IRI<2.5 | - | - | Low | Medium | 12 | N.E. | 22.8 | 22.3 | 2.40 | 6.7 | 0.21 | 22 | 23 | 9/9 | - |
| 1<IRI<1.5 | Low | Low | Low | Low | 13 | N.E. | 9.5 | 10.0 | | | | | | | New |
| 1<IRI<1.5 | High | High | Low | Low | 14 | N.H.234 | 47.5 | 48.0 | | | | | | | New |
| 1<IRI<1.5 | - | - | Yes | High | 15 | - | | | | | | | | | New |
| 1<IRI<1.5 | - | - | Low | Medium | 16 | - | | | | | | | | | |
| IRI<1 | Low | Low | Low | Low | 17 | N.E. | 6.5 | 7.0 | | | | | | | |
| IRI<1 | High | High | Low | Low | 18 | - | | | | | | | | | |
| IRI<1 | - | - | Yes | High | 19 | - | | | | | | | | | |
| IRI<1 | - | - | Low | Medium | 20 | - | | | | | | | | | |

Table 4: Matrix for selected test sections in Japan compared to the target test matrix in the core document

### 2.1.3 Test sites in Europe

The test sites for the European experiment were located in the Netherlands and Germany between Eindhoven and Duisburg, as shown in Appendix 5. A total of 12 test sections was established and 127 test measurements were conducted. These were divided into test sections on in-service roads and at a special test facility owned by the DAF company.

The distribution of test sections and measurements are shown in table 5.

| **Test location**<br>**Road Number/ Country** | **Number of test sections** | **Number of tests** |
|---|---|---|
| E34/A67, Holland | 2 | 21 |
| DAF test facility, Holland | 5 | 45 |
| DAF test facility, Holland<br>Special tests | - | 16 |
| E34/A40, Germany | 5 | 46 |

Table 5: Test location and number of tests performed at the European experiment

The measurements were conducted by performing standard measurements at 60, 75 and 90 km/ h on well-defined test sections on in-service roads. The actual test sections were 500 metres long and had a run-in and run-off section as guidance to the actual test section. The layout of the test sections is shown in Appendix 6.

The test sections on the in-service roads were open to traffic during the tests, whereas the test section on the DAF facility was in a closed environment.

Figures 9 and 10 show the view of the operator of the Profilograph during measurement on one of the in-service test sections and one of the DAF test sections.

*Figure 9 In-service test section*

*Figure 10 Test section from DAF-test track*

As seen from figures 9 and 10, guidelines were painted on the surfaces in order for the operators to follow the same path through the different repeated runs. The guidelines were established to optimise the possibility of the different vehicles to measure the same longitudinal profile on the test sections.

| **Evenness (IRI)** | | **Rutting (Inches)** | | **Location** |
|---|---|---|---|---|
| Good | <1.0 | L | <10 mm | Site no 3, 4, 5, 9, 19, 11, R01 |
| Moderate | 1.0 - 2.5 | L | <10 mm | Site no 6, 7, 8, 13 |
| Severe | >2.5 | L | <10 mm | Site no R02, R03, R23, R050 |
| Good | <1.0 | M | 10-20 mm | Site no 2, R067 |
| Moderate | 1.0 - 2.5 | H | >20 mm | Site no 1 |
| Severe | >2.5 | H | > 20 mm | Site no 12, R22 |

Table 6: Test matrix for the European experiment

The test sites in the European experiment included test sections with IRI values from approximately 0.6 to 9.9. The test sections with the highest IRI were measured at the DAF test facility where the special test sections has been build to accommodate for testing of trucks on very uneven roads. The tests sections at the DAF test track had IRI values from 0.8 to 9.9 and the in-service test sections on the roads in Holland and Germany had IRI values from 0.6 to approximately 2.5.

## 2.2 Reference measurements

### 2.2.1 Devices used for reference measurements

In order to ensure a link between the experiments, reference measurements were conducted in each region using the same device and operators.

In October 1996, a special trial was held at the Federal Highway Administrations Turner Fairbanks facility in United States, to analyse and compare suitable reference devices to be used in the experiment. The result of the test was that three devices were chosen to be used as reference devices as they performed well and because they were easy to transport to the different experiments without significant shipping costs. The devices chosen for linking the three regional experiments together were the Static Dipstick, the Rolling Dipstick and the ARRB Walking Profiler. Each of these devices records the pavement profile by means of an inclinometer. All the devices are operated at walking speed (Fig. 11, 12, 13)

### 2.2.2 Measurement procedures

At each site a rod and level reading has been made every 30 meters for the test section. A static inclinometer has measured every 0.25 meters along with the rod and level measurement. A rolling inclinometer has been used to obtain a continuous profile and the measurements have been adjusted with the rod and level and static inclinometer measurements. The rod and level measurements have been used to ensure that there has been no drift in the static inclinometer and has been used to correct the continuous measurement. The final continuous profile will be used as a reference profile for the measurements performed by the high-speed devices, by comparing the profiles by a point to point comparison. By establishing a continuous profile by the rolling inclinometer it is possible to compare profiles from any profilometer no matter what sample interval is used. For analysis of the transverse profile, reference measurements were performed using the same techniques as described for the reference measurements in the longitudinal direction.

### 2.2.3 Reference equipment

Rod and Level
The rod and level measurements were performed as standard rod and level surveying measurements. The measurements were performed for each 30 meters

Static Dipstick
The Static Dipstick device was designed by the FACE company in USA. The original purpose of the device was to evaluate the flatness of concrete floors. The device consists of an inclinometer to determine the difference in elevation between the feet of the dipstick. This inclinometer works as an electronic pendulum which determines and displays the elevation differences. The accuracy specified by the manufacturer is ± 0.0015 in » to 0.04 mm per reading. The dipstick records the raw elevation data and by a set of application programmes by a PC it is possible to process the data into roughness statistics whereof one is IRI. The dipstick is operated by walking the device down a wheelpath. The operator rotates the dipstick from one elevation location to the next, leaving the front foot of the dipstick on the pavement surface while the back foot is rotated forward. If the front foot is lifted from the pavement, the reference elevation will be lost and the procedure must be started over. The operator waits until the display has settled and then calls out the reading.

*Figure 11, Static Dipstick*

Rolling Dipstick

The Rolling Dipstick operates in the same principle way although this device is continuously rolled down the wheelpath and continuously collects the elevation data. Also this device gives the opportunity to calculate roughness statistics.

*Figure 12, Rolling dipstick*

ARRB Walking profiler

The Walking Profilometer is a manually operated device for measuring the profile of the paved surfaces at walking speed. The measurements are performed by a walking beam that measures the true gravitational slope between front and back feet, 241.3 mm apart. When the foot of the device moves the back foot lands where the front foot was positioned. Data are displayed graphically on an onboard laptop computer and can be set up to include standard roughness statistics. The accuracy of relative height measurements from one point to the next in sequence is of the order of ± 0.005 mm, corresponding to an expected final height accuracy of about ± 1 mm over a 50 metre profile run.

Figure 13, ARRB Profiler

## 2.3 Measurement procedure

### 2.3.1 Test procedure in Arizona

Each high-speed device performed tests at 60 and 90 km/h and the minimum speed of the device specified by the manufacturer. Special tests were performed by requiring the devices measure from dead stop and then accelerating up to 90 km/h and decelerating down to a complete stop.

### 2.3.2 Test procedure in Japan

In Japan, the measuring speed of the vehicle depended on the speed regulation on the tests sites with the following procedure:

- Test sections with speed limits of 50 km/h, measuring speeds of 50 km/h and 30 km/h were used
- Test sections with speed limits of 60 km/h, measuring speeds of 60 km/h and 30 km/h were used.
- Test sections with speed limit of 90 km/h, measuring speeds of 90 and 60 km/h were used.
- Test section located on a non in-service site, measuring speeds of 90 km/h, 60 km/h and 30 km/h were used

### 2.3.3 Test procedure in Europe

In Europe, the measuring speed of the vehicles in the European experiment were divided in a standard and special measuring mode as follows:

- Standard test mode on DAF test facility and on in-service test sections:
  60 km/h, 90 km/h and the optimum speed for the device
- Special test mode on DAF test facility only:
  Slow speed in the range of 5 - 25 km/h
  Variable speed deceleration and acceleration from 50 to 75 to 50 km/h.

## 2.4 Test schedule

Dates of testing in the three experiments are shown in table 7.

| Region | Location | Date of execution | Number of participants |
|---|---|---|---|
| USA | Arizona | April 15 - May 1, 1998 | 6 |
| Japan | Hokkaido | July 6 - July 17,1998 | 8 |
| Europe | Holland and Germany | September 15 - September 25 | 30 |

### 2.4.1 Test schedule for the experiment in USA

The participants met on April 15, 1998 for a pre-meeting at the Arizona Department of Transportation Office.

On the following day, April 16, 1998, special tests began on the Williams Gateway Airport. These tests continued on the following day. On April 18, 1998 evening tests were performed at Sky Harbor Airport.

From April 19 to April 21, 1998 tests on the in-service test sections were performed on those test sections located in the Phoenix area. The low speed measurements, including reference measurements were performed on the test sections on 19 and 20 April covering 6 test sections. The high speed devices performed measurements on April 20 and 21. This meant that the high-speed measurements were performed the day after the reference measurements.

For the test sections located in the Tucson area these were measured from April 21 to April 28, 1998. As for the Phoenix area sites, the Tucson area sites were first measured with the reference devices and then followed by measurements of the high-speed devices. In the evening of April 24, 1998, special tests were performed at the Tucson Airport.

Following the end of the measurements a wrap-up meeting was held in Tucson.

### 2.4.2 Test schedule for the experiment in Japan

The experiments in Japan were initiated by an opening ceremony on July 6, 1998. On the evening of July 6, 1998 special tests were performed on the fully access controlled highway, where all measuring devices performed low speed operation and speed fluctuation tests. On the following days, measurements were performed on the in-service test sections in Hokkaido. The reference and the low-speed measurements were performed in the daytime and the high-speed measurements were performed at nighttime from approximately 8 pm to 3 am.

The experiment in Japan were closed on July 17, 1998, with a successful execution of the measurements which were finished in due time.

### 2.4.3 Test schedule for the experiment in Europe

The experiment in Europe was opened on September 14, 1998 starting with a participants' meeting followed by an opening ceremony and a presentation of the participating devices in Eindhoven in Holland.

The test sections in the European experiment were located both in Holland and Germany, hence the organisation of conducting the experiment was the responsibility of DWW in Holland and BASt in Germany respectively.

The opening day ended with a free training session at the DAF test facility.

Each testing day started with a daily briefing for the participants. The tests in Holland were carried out from September 15 until September 18, where September 17 was assigned to perform special tests on the DAF test facility. All tests in Holland were completed by September 18, 1998.

On Monday 21, the second part started with a short briefing at the AM Rheinberg Highway Department after which all participants left to perform their measurements on the German Highway Test sites. Most participants finished their measurements on the September 22, 1998 and all measurements were completed in due time before the closing of the experiment on September 25, 1998. The experiment were closed by a debriefing and a farewell reception at the AM Rheinberg in Germany.

# 3.0 Conclusion and Recommendation

The PIARC World Road Association, International Experiment to Harmonise Longitudinal and Transverse Profile Measurement and Reporting Procedures, completed the data collection phase in 1998 in the three different locations Arizona USA, Hokkaido Japan, and Holland/Germany,Europe.

The experiment included a significant amount of the high-speed profiling equipment available today. Many of these devices are used as routine devices in connection with monitoring the evenness of a road network in relation to pavement management and pavement rehabilitation strategies. As a road network often includes roads with large differences in evenness it is important that an investigation of such devices' repeatability and reproducability in relation to a reference are tested on number of test sections with a large variety of IRI.

The PIARC experiment, overall, included IRI values from approximately 0.5 m/km to 9.9 m/km, which in accordance with the World Bank classification shown in figure 3 ranks the test section from airport runways and super highways to rough unpaved roads.

The highest IRI-values were found at the special DAF test track, which gave the possibility for the devices participating in this experiment to be tested at this IRI level. In the experiment in USA and Japan the test sections had IRI values ranging from 0.5 to 5.0, meaning that the devices participating in these experiment were tested on pavement surfaces which in accordance with figure 3 are classified to be from airport runways and superhighways to maintained unpaved roads and damaged pavements.

The experiment has provided reference measurements from all three experimental locations. The reference measurements were conducted by the same two devices in all three locations with the Dipstick and Rolling Dipstick. The reference measurements were carried out by the same operator in all cases.

One of the major problems for the experiment was to assure that the devices were measuring the same profile line and that the devices in their repeated runs were measuring the same line every time. Therefore, test sections were marked with the line which should be measured by the devices. It was realised that driving at speeds up to 90 km/h creates difficulties of measuring exactly the same line. Therefore it will be taken into account that although the same device or two devices are not able to record the same profile and evenness is not an necessarily an indication of errors.

# 4. References

1. The little book of Profiling. Basic Information about Measuring and Interpreting Road Profiles, October 1997, by Michael W. Sayers, Steven M. Karamikas

2. CEN/TC 227/WG5 N89E, wi 00227-133, ex. 509, Surface Characteristics, Transverse Evenness, Method of Measurement

Road Directorate
Danish Road Institute
Elisagaardsvej 5
P.O. Box 235
DK-4000 Roskilde
Denmark
Telephone: +45 46 30 70 00
Telefax: +45 46 30 71 05

| | |
|---|---|
| Title: | Piarc World Road Assioation<br>International Experiment to Harmonise Longotudinal and<br>Transverse Profile Measurement and Reporting Procedures, Draft Report |
| Author: | Bjarne Schmidt, Jim Wambold, Akira Kawamura and Guy Descornet |
| Dated: | Aril 2000 |
| Copyright: | Road Directorate, All rights reserved |
| Published by: | Road Directorate, Danish Road Institute |
| ISBN: | 87-90145-74-7 |
| ISSN: | 0909-1386 |

# PIARC World Road Association

## International Experiment to Harmonise Longitudinal and Transverse Profile Measurement and Reporting Procedures

Draft Report

Bjarne Schmidt (Denmark)
Jim Wambold (USA)
Akira Kawamura (Japan)
Guy Descornet (Belgium)

Vejteknisk Institut
Report 93
1999

# Contents

# Executive summary

In 1998, the World Road Association, PIARC, Committee C1 on Surface Characteristics conducted an international experiment to harmonise longitudinal and transverse profile measurement and reporting procedures. The experiment was conducted as three regional experiments with a view to:

1. allow for differences in the needs of the different regions and
2. optimise the costs and the management work of PIARC

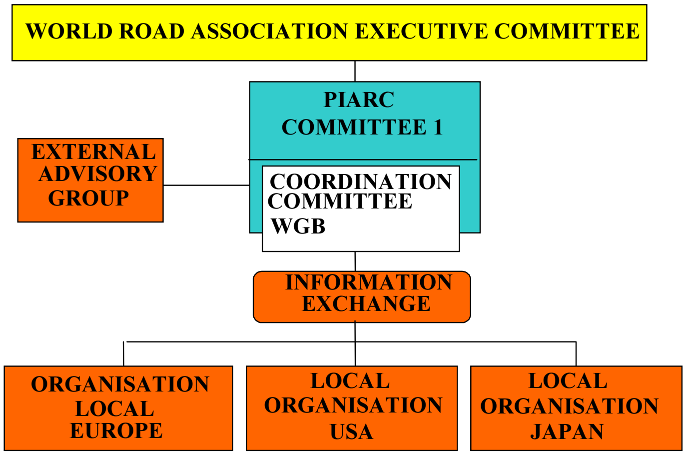
Each region designed, funded and conducted its project according to its particular needs, but had to comply with the core programme designed by Committee C1.

However the regional interest became so dominant that it was not possible for all regions to follow the specifications in the core document, and each deviated to a small extent to comply with regional interests.

Committee C1, however performed reference measurements in all three regions using the same equipment and the same operator for these tests. This make it possible to evaluate each participating device in the three regions against the same reference and therefore enables the Committee to perform an analysis of harmonising many of the devices used around the world.

The attached figure shows the overall organisation of the project. The co-ordination committee had the responsibility to oversee a final synthesis of the regional reports including general recommendations. The advisory group was formed independently of Committee C1 with a balanced membership from the three regions.

**Project Organisation**



# 1.0 Introduction

Road evenness is regarded as one of the most important road surface characteristics. Evenness has an influence on a number of functional characteristics of roads, such as vehicle fuel consumption, tire wear and mechanical deterioration. It also influences effects on road users such as internal noise, infrasound, ride comfort and driver fatigue. Furthermore, there are environmental effects such as exterior noise and air pollution influencing people around the road. High dynamic wheel load variations are also caused by the rough surface and reduce structural performance. The measures presently used to describe road unevenness are generally good at predicting ride comfort because they were developed for that reason. The correlation between measures of road unevenness and other functional characteristics of the road may need further development.

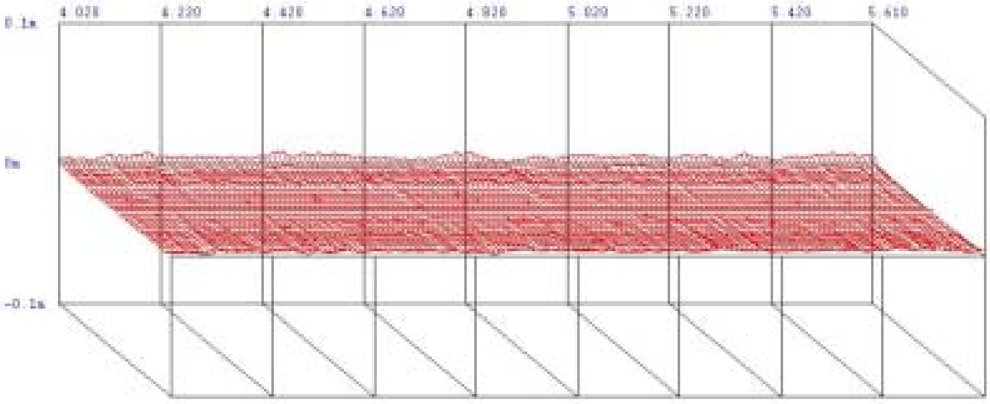


*Figure 1, Three-dimensional plot of a pavement surface, measured by a high speed profiling device*

Road evenness is used as an indicator of both a pavement's functional performance and structural condition. Evenness assessment methods vary widely and include those that measure profile, those that measure response to road unevenness, and subjective evaluation. Profiling equipment and methods of measuring longitudinal and transverse evenness vary widely from country to country. The purpose of this experiment is to provide a means to compare the results of measurements carried out using different equipment and different measurement methods. The results of this experiment will be invaluable in realising consistent pavement management practices (with respect to longitudinal and transverse evenness and cross slope as well as the assessment of their effects on the road user, road owner and environment) across country boundaries. Furthermore, it is necessary that the measurement reporting be harmonised to standardise paving specifications.

In the past, there have been several other studies to compare longitudinal evenness measuring equipment. The most notable was the World Bank International Road Roughness Experiment (IRRE) to establish correlation and calibration standards (World Bank Technical Paper Number 45). This experiment was conducted in 1982 in Brazil. In the IRRE, all types of evenness measuring equipment were included, including response type systems. The IRRE also developed the International Roughness Index (IRI). More recently studies have been conducted by SHRP in Ames, Iowa, the Road Profiler User Group (RPUG), and University of Michigan Transportation Research Institute (UMTRI) for FHWA. In Europe, several administrations have performed comparative tests to select equipment for network surveying.

The experiment drew upon the experience of these studies, but only included profiling equipment. Response-type devices were not included in this experiment. Since the IRRE 1982 study, many new types of profiling equipment were developed, which also measure transverse profile and rut depth, measurements that were not included in the IRRE, nor in other studies. Therefore, there were real needs to update the previous work and to include transverse profile as well.

The experiment was supported and overseen by PIARC Committee 1 on Surface Characteristics (C1) and was subject to PIARC Executive Committee approval. Working Group B of C1 was the group responsible for the experiment and supervised the experiment. In addition, the group assessed technical approaches and made recommendations to C1 for approval. Similarly, a separate group managed those expenses that were funded by PIARC. These funds were required to link the experiments at the three locations and produce the final report.

The experiment was carried out in three locations: North America, Europe and the Japan. Three principal investigators, one English speaking, one French speaking and one Japanese speaking, led the regional experiments. Each of the three regions developed their own work plan, which could expand on the core plan but had to at least include the core elements. When measurements were performed, the same procedure for obtaining the “true profile” was used in all locations. This provided the link between the locations.

The results of the study will be published in a technical report and a summary report. These reports will include procedures for relating pavement evenness, longitudinal and transverse, as measured by different standard methods of test. The various devices will be evaluated for accuracy (vertical, longitudinal, and transverse) and evaluated for their ability to achieve the accuracy required to produce the various summary statistics used by pavement management for longitudinal, transverse and rutting measurements. In most cases these statistics are specified by ISO, CEN, AASHTO or ASTM Standards. Where no existing standard is available, consideration will be given to provide the data needed for the development of standards, particularly for those methods with widespread use.

As in the first major experiment conducted by PIARC C1 on friction and texture, the data base will be extremely important and will be invaluable for further analysis by other organisations. In addition, after the data is collected, the sites will be made available to other researchers who would like to use the sites and the data for other studies. There are presently several studies that are linked to this research project and would use the data from this experiment, e.g. NCHRP project 10-47 "Guidelines for Longitudinal Pavement Profile Measurement" currently being conducted by UMTRI.

## 1.1 Need for harmonisation

### 1.1.1 Road evenness

An uneven road pavement surface causes expenses to both the road user and the road owner. It is therefore important to measure the present unevenness or to monitor the progression of the unevenness characteristics of the pavements. This will enable optimal pavement maintenance strategies which will benefit the road user and the road owner. Unevenness is defined as the difference in the profile from the originally planned surface profile. This difference causes notable dynamic influences on a vehicle travelling on the pavement.

The differences from the planned profile can be described by the level of elevation (amplitude) from a theoretical smoothed pavement surface and the wavelength (m) or frequency (Hz) if related to vehicle speed.

For pavement wavelength less than 0.3 meter the dynamic response from the pavement is generally absorbed in the tyre of the vehicle. Wavelengths greater than 50 meter do not give any notable dynamic response at normal travel speed. It is therefore generally defined that the wavelength span for discomfort and vehicle wear is between 0.3 and 50 meters.

Some of the unevenness on road pavements is related to the used construction technology and the skill of the contractor. For many road administrations, the amplitude of this initial unevenness is controlled by contractual agreements or national road standards.

Other unevennesses occur during the use of the road and will often increase with time. These are often related to plastic deformation in the subgrade, compression of bearing layers and deformation in the asphalt layer. Other types of irregularities in the pavement surface are potholes, stripping, frost heaves etc.

The unevenness of a road profile is normally of a non-periodic character described as a random function. In the interpretation of such a function it is often used to describe the pavement surface by a large number of harmonic functions.
In order to be able to describe the pavement surface in relation to comfort, vehicle wear, maintenance costs etc. it is necessary to have a representation of the road profile. This can be obtained by the true geometric profile, a profile measurement or by a

more or less representative expression for the evenness by measuring the response from the pavement.

Although unevenness of road pavements are defined to have wavelengths between 0.3 and 50 meters, resonance effect in vehicles can occur on pavement surfaces with almost no unevenness.

The experience by vehicle operators or passengers can, of course, be of different experience. In an article in HRB, Bull. 264 (1960) p. 12 this quotation is found:

"....... some undulation in the road surface may break the monotony and definitely add to the pleasant sensation of riding in a motor vehicle".

In spite of this, unevenness is in modern pavement maintenance strategies regarded as one of the major descriptors of vehicle user costs, and therefore should be reduced to a minimum.

### 1.1.2 Harmonisation

The aim of performing better pavement maintenance strategies demands reliable information about the condition of the road network and hence demands reliable measuring devices.

The development of measuring devices for measuring road evenness has been undergoing a tremendous technology evolution within the last decade. Determination of road evenness is now performed by measuring the road profile at normal traffic speed and then calculating various road indices such as IRI. The accuracy of many of these indices depends on the performance of the measuring equipment. Different devices can therefore report different IRI or rut depth numbers, even when measuring the same road section. A method for adjusting differences in reporting indices can be obtained by harmonising the different devices.

Harmonisation means that a method will be developed so that each profile device can make an estimate of the "true profile" from which all indices would be calculated. This allows each device to report the values it normally did in the past and still harmonise it to the common true profile. This then also allows calibration of other and new equipment since it can later be correlated to the true profile. The alternative to harmonisation is standardisation, which requires that everyone must carry out exactly the same procedure.

## 1.2 Objectives

The core document for the experiment specifies the following two major objectives:

1. Harmonise and correlate measures of longitudinal and transverse road surface profiles for application in pavement construction and management.
   This requires that the project will

   - provide data so that other organisations can set requirements and/or ranges and be able to evaluate the analysis methods used by pavement management for roads and airports in order to establish the accuracy requirements.

   - evaluate the ability of each device to produce standard measures of longitudinal and/or transverse evenness to facilitate interchange and harmonisation

2. Provide a basis for the assessment of the reliability of road profile information.
   This requires that the project will:

   - evaluate the accuracy and repeatability of the longitudinal and transverse profiles obtained by each device by direct comparison with the “True Profile”. These comparisons will be obtained under varying physical conditions encountered in the real world. They will include lateral placement, speed variations, climate, pavement type, reflectivity and texture.

   - determine sampling rate and/or sample size required by the various methods to achieve desired accuracy of the applicable summary statistics. Quantify repeatability and errors associated with the various devices.

Due to financial constraints for the experiment only the basis of the objectives has been accomplished in the experiment by executing and completing experiments with a representative selection of available high-speed profiling equipment from around the world. For reasons of practical organisation and so as to make the experiment as attractive as possible to producers and users of high-speed profiling equipment around the world, it was decided to carry out the experiment as three regional experiments with test sections in USA, Japan and Europe.

## 1.3 Benefits

With increasing road traffic follows increasing deterioration of road pavements which results in decreasing serviceability for the road users. This decrease in serviceability is experienced as a decrease in the ride comfort which leads to an increase in vehicle maintenance costs, fuel consumption and freight damage costs. Also issues such as driver fatigue, and potentially reduced productivity need to be considered together with reduced comfort for the driver and passengers, when talking about the price the road users and the society has to pay for deteriorating roads.

The interaction between the cost of maintaining a road network and the benefits for the road users and society are the key objectives in relation to optimising pavement maintenance strategies. Carefully planned pavement maintenance strategies have become a necessity as many road administrations are facing budget constraints on their maintenance budget. A feasible solution for optimised pavement management is to introduce Pavement Management Systems (PM-systems) such as the HDM-4 system. However, reliable output from PM-systems demands reliable input data about pavement conditions and one of the pavement condition data which is the most important is road evenness; this is the key factor for user costs. This can be seen in the HDM-4 system where, evenness plays an important role to determine user costs.

For the purpose of measuring road evenness, many different equipment is available commercially and today many of these are operating in a high speed manner by using laser or other non-contact techniques. Most of the modern equipment is capable of determining the longitudinal and transverse profile of the road in order to determine rutting and longitudinal evenness. In order to determine these parameters, it is necessary to incorporate algorithms into the systems. The results from calculating evenness and rutting from measured profiles depends on the accuracy of the measurement and the algorithms used. If the outcome from a measuring system is influenced by errors, this will have a significant effect on the outcome and use of a PM-system with poorly determined maintenance strategies as a result.

Comparisons of profiling equipment have been conducted around the world by local road administrations or by high level research programmes, such as the Strategic Highway Research Program in USA, in order to find equipment qualified to be used for project or network level measurements.

Several of these investigations have, to some extent, been limited to participation by invitation and the outcome and the results have not been made publicly available as they are commercially related.

The intention with the PIARC experiment was to perform an objective and non-commercial evaluation of the participating devices and hence present a good guidance for selection of measurement equipment and analysis methods.

The benefits of the experiment are:

- Provide for consistent pavement management practices with respect to evenness, rutting and cross slope throughout the world so that road managers can compare road construction and maintenance strategies.

- Allow the opportunity for researchers to compare the results and therefore facilitate road and airport administrations and research organisations in their programs.

- Enable contractors to meet or compare specifications of any agency that implements the results, thus increasing the competitiveness of the bidding process.

- Provide information to any road administration or other potential user on equipment, which is available world-wide.

- Broaden the market for test equipment by increasing the ability to meet the requirements of different countries.

- Classify measuring equipment according to its accuracy and sampling rate.

- Provide information on the various roughness indices that are in use around the world.

- Provide a database that can be used by standards organisations to make national and/or international standards.

- Provide sites with documented surface data to be available for other studies.

## 1.4 High Speed Profiling Equipment

Today many different types of equipment have been developed around the world, and there are many different philosophies of how much must be measured in order to get a good picture of the pavement surface and to determine the longitudinal evenness and transverse parameters of a road.

### 1.4.1 Evolution of evenness evaluation techniques

The evaluation of pavement unevenness can be determined subjectively by a panel of people or by objective measurements by measuring equipment. The subjective evaluation can be performed by letting a rating panel drive over the pavement surface in an ordinary car.

A classical example for this evaluation technique is related to the AASHO tests in USA. During these tests, a large number of test sections were evaluated by a rating panel with the purpose of evaluating the Present Serviceability Rating, PSR, of the test pavements. The evaluation performed by the rating panel was then correlated to objective measurements performed by the AASHO Profilometer.

The AASHO Profilometer measured the slope variance of the pavement surface and a correlation between the objective measured surface characteristics and the subjective evaluated rating was performed. The result of this correlation forms the well-known Present Serviceability Index (PSI), which, besides evenness, includes rutting, patching and cracking.

### 1.4.2 Physical principles for objective measurements

The principles of physical measurement can be described in the following different categories:

1. Geometric methods:

- Rod and level measurements
- Measurement of the difference between a straightedge and the pavement sur face
- Measurement with a horizontal laser beam as reference
- Measurement in relation to a moveable plane
- Measurement of the slope and inclination
- Superposition of measurement results from laser sensors positioned on a straightedge

2. Combination of geometric methods and accelerometer methods

The principle of this measuring procedure is to measure the distance from the pavement surface to the chassis, either by a linear transducer mounted on the chassis and a measuring wheel, which follows the surface, or by a sensor not touching the surface (optical or accoustic). The movement of the chassis is determined by a double integration of the signal from the accelerometer mounted on the chassis. By adding the two measuring results the true profile is determined.

3. Initially held horizontal pendulum

Periodic angle measurement is performed by reference to an inertially held horizontal reference pendulum.

4. Distance measurement between vehicle axle and chassis.

Using this method the relative vertical movement between the axle and the chassis are summarised. This value is then divided by the measured distance (this value is used as evenness index).

5. Accelerometer signals

The measurement signal performed by an accelerometer mounted on a passenger or the vehicle is used as index of evenness.

### 1.4.3 Profile measurement and response measurements

Evenness measurements can be performed by equipment, which makes a “true” geometric profile of the pavement surface, or by equipment giving a more or less representative expression of the evenness by equipment of the response type.
Well-calibrated response type measuring equipment will often be sufficient monitoring equipment for inventory measurements in a road network. However, reliable calibration measurements on well-defined reference pavements are necessary.

Profile measurements vary from the most simple equipment, rod and level, to modern high technology equipment using laser triangulation. Profile devices can be used in all kinds of evenness measurements. The significant increase in efficiency and accuracy over the last decade provides the ability to measure in ordinary traffic flow, and this makes this measuring technique outstanding in relation to other measuring techniques.

Besides reliable information on pavement evenness to be used in pavement management systems, the use of advanced profiling devices also makes it possible to study the pavement surface in more detail by analysis of:

- Pavements profile waveform frequency distribution
- vehicle responses and
- dynamic influences on pavements.

### 1.4.4 Speed dependency of measurement equipment

Due to the increase in traffic volume experienced world-wide, it has become more and more important, for the sake of the road users, to limit the time delays caused by roadworks and by the measurements of pavement conditions.
Measuring vehicles which measure at a constant speed can result in traffic delays and congestion and be the reason for hazardous situations on a crowded road system. One of the advantages with modern profiling devices is their ability to operate at normal traffic speed and often at speeds up to around 100 km/h.

The technical development of the equipment has resulted in an improved quality of measurements. However, the results of the measurements can be influenced by other factors, which are related to the handling of the vehicle in the measurement situation.

### 1.4.5 Data handling and presentation of the results of the measurements

The evolution in handling the measurement data has changed from simple methods of analogue presentation on paper to advanced data acquisition equipment which can handle data collected at intervals of mm and cm.

One of the advantages of modern profiling techniques and sophisticated analysis programs makes it possible to evaluate the profiles in a more detailed way than was possible a few years ago. Having the profile in a digital form, represented by cm or mm intervals, it will be possible to perform analysies tailored to the individual road administration. Simulation of different response type measuring devices can be performed by mathematical simulation programs in order to calculate an index traditionally used in a road administration. The question that often occurs is whether the rut depth shall be determined by one or the other length of straightedge. This can be tested in the transverse profile from the equipment by mathematically modelling several lengths of the straightedge in the cross profile.

### 1.4.6 Use of measurement equipment

One of the most important issues to be clarified when planning the introduction of new measuring equipment is the use of it in the future. Generally it can be said that the ability of the equipment to reproduce a pavement profile and to perform detailed measurements and analysis shall be in reasonable relationship to the purpose of the measurements.

The following main features can be considered for measurement assignments:

- Control of new constructions
- Inventory measurements in road networks
- Detailed investigations of road profiles
  - research related assignments
  - measurement of test sections for calibration of other devices
  - measurement of test section with special unevenness problems

Of special consideration for a measuring equipment is the transfer function, which in relation to wavelength or frequency gives the ability of the equipment to reproduce the amplitude of the unevenness or the profile.

### 1.4.7 Control of new pavements

In the specification for the construction of a new pavement, the type of device used to measure the profile or unevenness is often specified. One of the issues, which should be taken into account is the wavelength significant to the road users. The measuring equipment should be able to measure wavelength according to this.

### 1.4.8 Inventory measurements

Routine measurements of evenness are used to investigate the deterioration of the pavement over time and consequently form the basis for maintenance planning.

Due to the often vast amount of kilometres, it is of great importance that the measurements can be performed with a high capacity. Also it is of great importance that the measurements can be related to a position in the network, as this position will be used in the pavement management process.

### 1.4.9 Detailed investigations of road profiles

For research investigations, measurement of reference test sections and pavements with special unevenness problems, it is necessary to use profiling equipment which records the “true” profile of the pavement surface and makes it possible to perform advanced data handling of the surface profile.

## 1.5 Definition of used indices

### 1.5.1 International Roughness Index

The International Roughness Index, IRI, has become an index used world-wide. The IRI was originally developed based on a time stable index in the late 1970s in the United States. The further developement, which included simplification and standardization of the index was funded by the World Bank and named IRI.

The computing of IRI based on rod and level measurements are described in the ASTM standard E 1364-95.

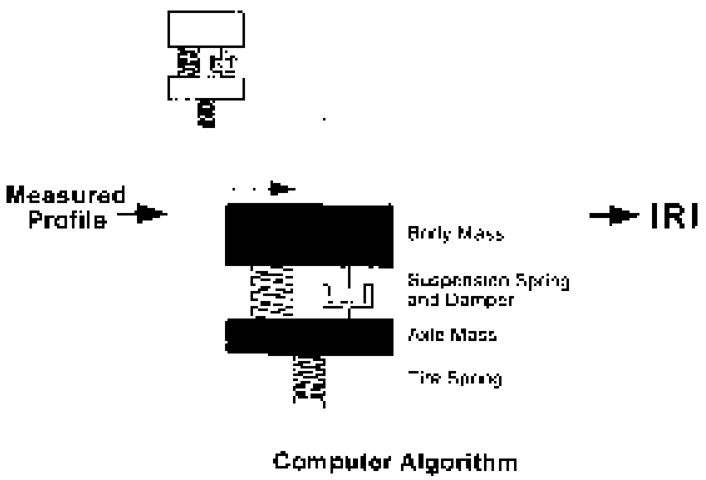


*Figure 2. Concept of model for calculating IRI. (ref. 1)*

The concept for the IRI calculation is to model the quarter of a car moving on the pavement surface, figure 2, and calculate the accumulated suspension deformation. The input to the model is a set of information describing the constants of the springs and dampers together with the sprung and unsprung mass acting in the model.

In 1982, the World Bank initiated an experiment in Brazil to investigate the possibility of a calibration standard for evenness measurements. After several years of research work, it was possible to establish the IRI as a standard measure for road evenness. The World Bank has published guidelines to explain how to measure IRI with different types of equipment. The sprung and unsprung masses and spring and damper constants of the IRI are not formally standardised but specified based on the findings of the Brazilian experiment

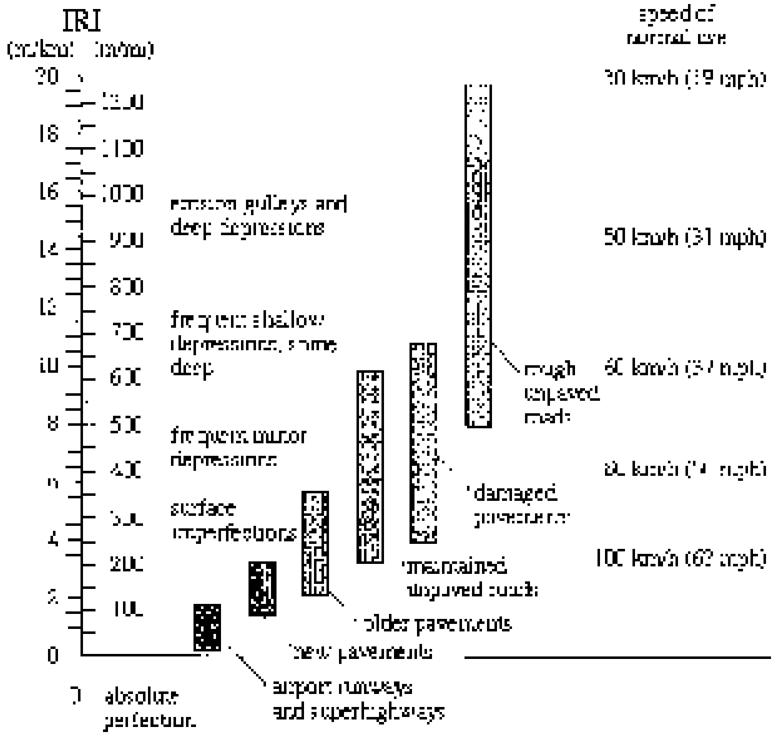


*Figure 3, The range of IRI in relation to road classes. Ref Little book of profiling.(ref 1)*

The IRI has shown to be a very feasible measure of road evenness to be used in relation to vehicle operating cost, road safety etc.

### 1.5.2 Determination of PSD

The Power Spectral Density, PSD, representation assumes that the road roughness data is random. PSD shows the extent that spatial wavelengths within a bandwidth contribute to road roughness. The total area under a power spectrum curve gives the total mean square roughness of the pavement in meters squared or other comparable units.

### 1.5.3 Determination of Rutting

Rutting is determined as the depression in the wheel tracks, which is caused by the traffic. In order to establish this parameter, it is necessary to measure the road's transverse profile and use an algorithm to calculate the rutting number.

Figure 4 shows typical transverse profiles measured on Danish roads.

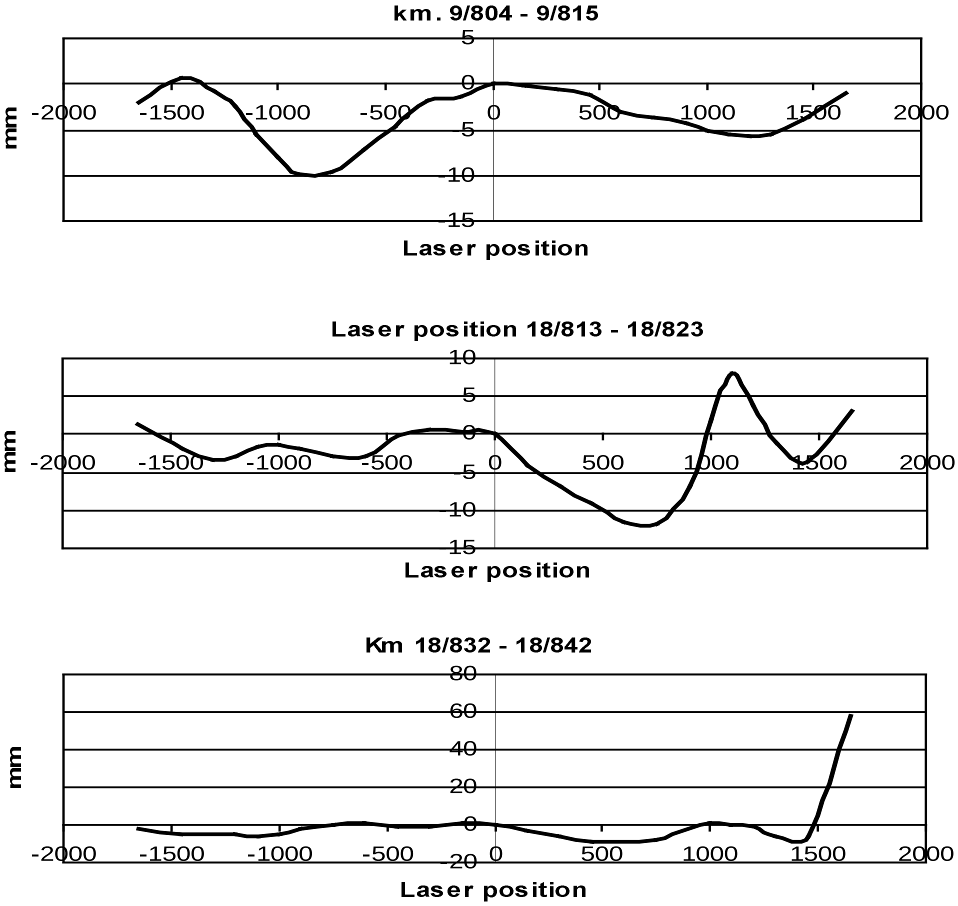


*Figure 4, Typical transverse profiles*

The European Standardisation body, CEN, is also working on standardisation of measurements of the transverse profile and determination of rutting for European roads. For that reason the CEN-group TC 227 Working Group 5 is in the process of preparing the following proposal for a standard: CEN/TC227/WG5 N 89E, wi 00227-133 ex 509, Surface Characteristics, Transverse Evenness, Method of Measurement.

In the proposal it is stated that the measurement of a pavement's cross profile will have different purposes. Immediately after construction, the measurement will be used to control the pavement surface for irregularities, which have occurred during construction. Later, when the road has been in service for some time it is valuable to measure the transverse profile on a routine basis in order to detect any deformation such as rutting, depressions or settlements in the lower layers of the construction due to the stresses and strains applied by the traffic.

The proposed CEN standard gives the following suggestions for transverse profile characteristics to be measured:

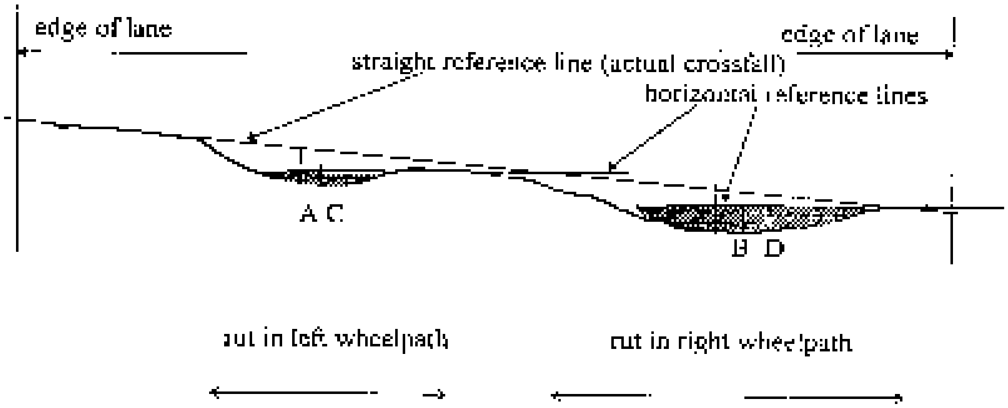


*Figure 5 shows a theoretical cross profile with the most important parameters related to rutting, maximum rutting at A and B and theoretic water depth at C and D. ref(2)*

The CEN proposal describes two methods to determine rutting:

**The straightedge method to determine rutting**

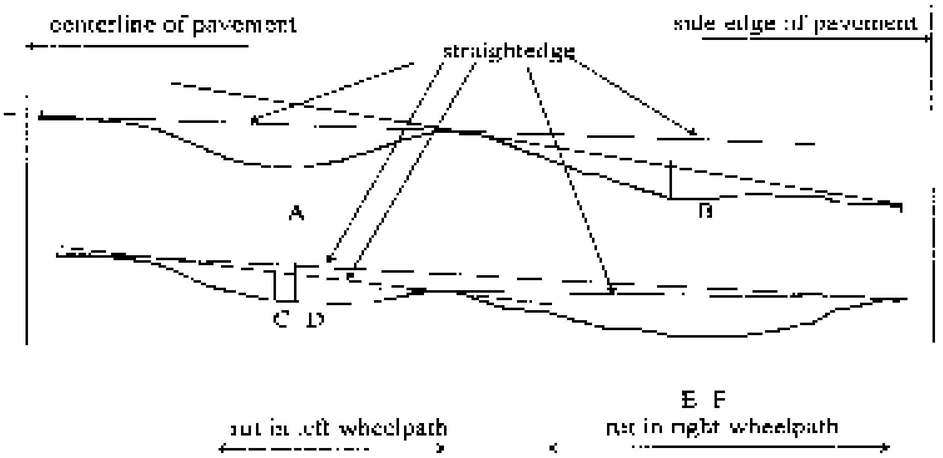


*Figure 6 shows measurement of rutting using the straightedge method. The results vary from A to F depending on the shape of the profile and the straightedge length.(ref2)*

When measuring rutting using a straightedge, the length of the straightedge is an important parameter, which influences the determination of the depth of the rutting. Also the shape of the transverse profile can have a significant influence on the result obtained by using the straightedge as shown in figure 6.

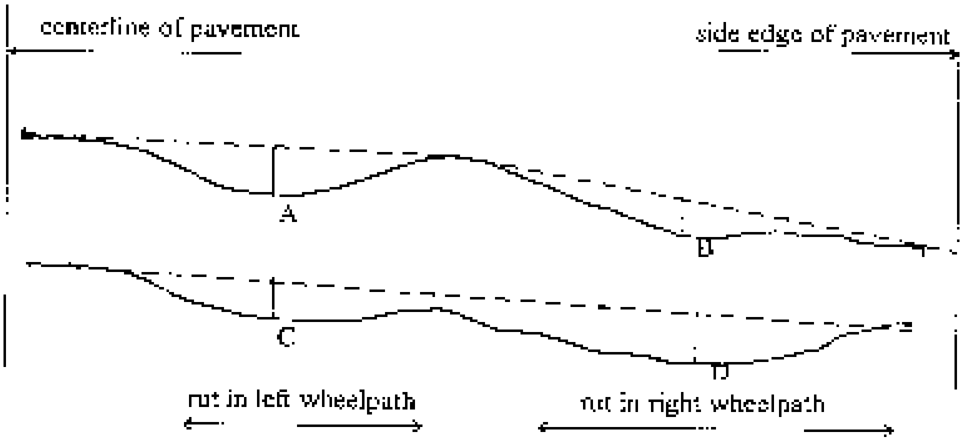


*Figure 7, Rutting determined by using the tensioned wire method. (ref2)*

An alternative to the straightedge method is the tensioned wire method. The method relates the actual pavement surface to a straight line given by an ideal tensioned wire which touches the highest points in the cross profile. With this line as a basis, it is possible to calculate the rutting as the distance between the line and the profile. This method removes some of the variables introduced when using a straightedge.

# 2.0 Experimental Design

## 2.1 Test sites

### 2.1.1 Test sites in USA

The test sites in the experiment in USA were located in the state of Arizona in the area of Phoenix and Tucson (Map Appendix 1). The test sites were located on in-service roads on both interstate and state roads. The test sections were chosen to cover a broad spectrum of service levels in relation to evenness and rutting in correspondence with the core document. Each test site was 1 mile long (1.6 km) and the actual test section was determined to 330 meter in accordance with ASTM draft 'standard test method for determining the precision and bias of equipment used to measure longitudinal profile of a pavement surface' (September 1998)

In total twenty sites were established on in-service roads together with special test sites at Williams Gateway Airport and Sky Harbor Airport in Phoenix and at Tucson Airport in Tucson. The location for the test sections on the in-service roads are shown in table 1.

| **Interstate roads** | **State roads** | **Local roads** | **Special tests** |
|---|---|---|---|
| I10; mp 107 - 106 (westbound) | S83; mp 25.5 - 26.5 (southbound) | Kinney Rd (near Desert Museum) | Williams Gateway Airport |
| I10; mp 106-107 (eastbound) | S83; mp 30 - 31 (southbound) | Sandario Rd (near Manville Rd) | Sky Harbor Airport |
| I10; mp 131-132 (eastbound) | S83; mp 31 - 30 (northbound) | | Tucson Airport |
| I10; mp 174 - 175 (eastbound) | S83; mp 40 - 41 (southbound) | | |
| I10; mp 176 - 177 (eastbound) | S86; mp 131 - 132 (eastbound) | | |
| I10; mp 180-181 (eastbound) | S86; 134 - 135 (eastbound) | | |
| I10; mp 270 - 271 (eastbound) | S86; mp 139 - 140 (eastbound) | | |
| I10; mp 274 - 275 (westbound) | | | |
| I19; mp 57 - 58 (northbound) | | | |
| I19; mp 90 - 91 (northbound) | | | |

Table 1; Location of test sites in the experiment in USA

The test matrix for the test sections in Arizona included test sections with IRI values ranking from approximately 0.5 m/km to 4.5 m/km. The test sections therefore covered road standards ranking from airport runways to older pavements, in according with the world bank specification in figure 3. The matrix for the selected test sections are shown in table 2.

Each test section was marked with reflecting tape to indicate start and stop of measurements. This gave the participating devices the ability to have automatic start and stop of data collection.

| **Test Sections In Arizona** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Target Test Matrix** | | | | | | **SELECTED TEST SECTIONS** | | | |
| Evenness Iri M/Km | MEGA TEXTURE | MACRO TEXTURE | FEATURES | RUTTING | No | ROAD ID | IRI (l/m) | RUT (mm) | MTD (mm) |
| 4.0<Iri<5.0 | LOW | LOW | LOW | LOW | 1 | | | | |
| 4.0<Iri<5.0 | HIGH | HIGH | LOW | LOW | 2 | | | | |
| 4.0<Iri<5.0 | - | - | YES | HIGH | 3 | | | | |
| 4.0<Iri<5.0 | - | - | LOW | MEDIUM | 4 | | | | |
| 2.5<Iri<4.0 | LOW | LOW | LOW | LOW | 5 | | | | |
| 2.5<Iri<4.0 | HIGH | HIGH | LOW | LOW | 6 | | | | |
| 2.5<Iri<4.0 | - | - | YES | HIGH | 7 | | | | |
| 2.5<Iri<4.0 | - | - | LOW | MEDIUM | 8 | | | | |
| 1.5<Iri<2.5 | LOW | LOW | LOW | LOW | 9 | | | | |
| 1.5<Iri<2.5 | HIGH | HIGH | LOW | LOW | 10 | | | | |
| 1.5<Iri<2.5 | - | - | YES | HIGH | 11 | | | | |
| 1.5<Iri<2.5 | - | - | LOW | MEDIUM | 12 | | | | |
| 1<Iri<1.5 | LOW | LOW | LOW | LOW | 13 | | | | |
| 1<Iri<1.5 | HIGH | HIGH | LOW | LOW | 14 | | | | |
| 1<Iri<1.5 | - | - | YES | HIGH | 15 | | | | |
| 1<Iri<1.5 | - | - | LOW | MEDIUM | 16 | | | | |
| Iri<1 | LOW | LOW | LOW | LOW | 17 | | | | |
| Iri<1 | HIGH | HIGH | LOW | LOW | 18 | | | | |
| Iri<1 | - | - | YES | HIGH | 19 | | | | |
| Iri<1 | - | - | LOW | MEDIUM | 20 | | | | |

Table 2; Test Sections in Arizona

### 2.1.2 Test sites in Japan

The test sites for the Japanese experiment were located in the central part of Hokkaido around Sapporo (Appendix 2) to accommodate a variety of surfaces and to ensure that measurements would be carried out on in-service roads. The test sites were selected in accordance with the experimental core document, and consideration was taken towards traffic conditions and the environment in which the measuring equipment performed. Each test site was almost 1 km long with a 500 meter test section used for the measurements. Totally fifteen test sites were established with the location shown in table 3.

| **National Highway (12 sections)** | | **Prefectural Road (1 section)** | | **Expressway (2 sections)** | |
|---|---|---|---|---|---|
| Route 36 | 1 | Kamiatsuma-Tomakomai Route | 1 | Douo Expressway (Eniwa IC - Kitahiroshima IC) | 2 |
| Route 234 | 4 | | | | |
| Route 275 | 1 | | | | |
| Route 276 | 1 | | | | |
| Route 337 | 2 | | | | |
| Route 451 | 1 | | | | |
| Fukagawa-Rumoi Fully-access-controled Highway | 2 | | | | |

Table 3; Location of test sites in the Japanese experiment

The test sites in Japan consisted of a 500 meter test section with 300 meter acceleration section before the test section and a 200 meter deceleration section following the actual test section.

Each test section was carefully marked in order for the test vehicle operator to be able to locate the test sections and where to perform the measurement. A special feature for the experiment in Japan was that the test of the high-speed devices were performed at night time due to traffic control regulations and because several makes of equipment are constructed to perform tests at night time. In order to fulfil the requirement of satisfactory information regarding start and end of the test sections illuminated cone-shaped signs were placed on the sites. Figure 8 illustrates a measurement performed at night.

*Figure 8, High-speed tests performed at night time*

The layout of the 500 metre test section and the position of the different tests are shown in Appendix 3 and 4. This shows the layout of the information signs on the test sections which should secure the accuracy for the measurements.

The test matrix for the test sections in Japan included test section with IRI values ranking from 2.4 to 5.0 m/km and therefore included test sections in the higher end of the test matrix. The test matrix did not include test sections with low and very even test sections with IRI below 2.4. The matrix for the selected test sections is shown in table 4 where it is compared to the target test matrix of the core document.

| TABLE 1 TARGET TEST MATRIX | | | | | | SELECTED TEST SECTIONS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| EVENNESS IRI m/km | Mega Texture | Macro Texture | Features | Rutting | No | Road Id | K.P. | | Iri (?/M) | Rut (Mm) | Mtd (Mm) | Air (?) | Pave (?) | Date (1997) | Surface Potentially |
| | | | | | | | B.P. | E.P. | | | | | | | |
| 4.0<IRI<5.0 | Low | Low | Low | Low | 1 | N.H.36 | 47.8 | 47.3 | 5.00 | 5.0 | 0.43 | 10 | 10 | 9/9 | Wave |
| 4.0<IRI<5.0 | High | High | Low | Low | 2 | N.H.276 | 82.4 | 82.9 | 4.02 | 5.1 | 1.01 | 10 | 11 | 9/11 | Porous |
| 4.0<IRI<5.0 | - | - | YES | High | 3 | N.H.234 | 65.2 | 65.7 | 4.21 | 21.2 | 0.22 | 16 | 18 | 9/9 | Ruts |
| 4.0<IRI<5.0 | - | - | LOW | Medium | 4 | N.H.451 | 71.8 | 71.3 | 4.15 | 15.7 | 0.28 | 11 | 13 | 9/10 | Wave |
| 2.5<IRI<4.0 | Low | Low | Low | Low | 5 | N.E. | 23.8 | 23.3 | 2.83 | 4.5 | 0.52 | 22 | 23 | 9/9 | Porous |
| 2.5<IRI<4.0 | High | High | Low | Low | 6 | H.P.R.259 | 0.8 | 1.3 | 3.06 | 4.6 | 0.54 | 11 | 13 | 9/8 | Ccp |
| 2.5<IRI<4.0 | - | - | YES | High | 7 | N.H.337 | 90.1 | 89.6 | 2.71 | 21.0 | 0.22 | 16 | 18 | 9/8 | - |
| 2.5<IRI<4.0 | - | - | LOW | Medium | 8 | N.H.275 | 72.7 | 73.2 | 2.52 | 9.3 | 0.26 | 16 | 18 | 9/10 | - |
| 1.5<IRI<2.5 | LOW | LOW | LOW | LOW | 9 | N.H.234 | 34.0 | 35.0 | 2.33 | 4.5 | 0.28 | 16 | 18 | 9/9 | - |
| 1.5<IRI<2.5 | High | High | Low | Low | 10 | N.H.234 | 34.7 | 35.2 | 2.47 | 3.4 | 0.31 | 16 | 18 | 9/9 | - |
| 1.5<IRI<2.5 | - | - | Yes | High | 11 | N.H.337 | 93.9 | 93.4 | 2.29 | 15.7 | 0.26 | 16 | 18 | 9/8 | - |
| 1.5<IRI<2.5 | - | - | Low | Medium | 12 | N.E. | 22.8 | 22.3 | 2.40 | 6.7 | 0.21 | 22 | 23 | 9/9 | - |
| 1<IRI<1.5 | Low | Low | Low | Low | 13 | N.E. | 9.5 | 10.0 | | | | | | | New |
| 1<IRI<1.5 | High | High | Low | Low | 14 | N.H.234 | 47.5 | 48.0 | | | | | | | New |
| 1<IRI<1.5 | - | - | Yes | High | 15 | - | | | | | | | | | New |
| 1<IRI<1.5 | - | - | Low | Medium | 16 | - | | | | | | | | | |
| IRI<1 | Low | Low | Low | Low | 17 | N.E. | 6.5 | 7.0 | | | | | | | |
| IRI<1 | High | High | Low | Low | 18 | - | | | | | | | | | |
| IRI<1 | - | - | Yes | High | 19 | - | | | | | | | | | |
| IRI<1 | - | - | Low | Medium | 20 | - | | | | | | | | | |

Table 4: Matrix for selected test sections in Japan compared to the target test matrix in the core document

### 2.1.3 Test sites in Europe

The test sites for the European experiment were located in the Netherlands and Germany between Eindhoven and Duisburg, as shown in Appendix 5. A total of 12 test sections was established and 127 test measurements were conducted. These were divided into test sections on in-service roads and at a special test facility owned by the DAF company.

The distribution of test sections and measurements are shown in table 5.

| **Test location**<br>**Road Number/ Country** | **Number of test sections** | **Number of tests** |
|---|---|---|
| E34/A67, Holland | 2 | 21 |
| DAF test facility, Holland | 5 | 45 |
| DAF test facility, Holland<br>Special tests | - | 16 |
| E34/A40, Germany | 5 | 46 |

Table 5: Test location and number of tests performed at the European experiment

The measurements were conducted by performing standard measurements at 60, 75 and 90 km/ h on well-defined test sections on in-service roads. The actual test sections were 500 metres long and had a run-in and run-off section as guidance to the actual test section. The layout of the test sections is shown in Appendix 6.

The test sections on the in-service roads were open to traffic during the tests, whereas the test section on the DAF facility was in a closed environment.

Figures 9 and 10 show the view of the operator of the Profilograph during measurement on one of the in-service test sections and one of the DAF test sections.

*Figure 9 In-service test section*

*Figure 10 Test section from DAF-test track*

As seen from figures 9 and 10, guidelines were painted on the surfaces in order for the operators to follow the same path through the different repeated runs. The guidelines were established to optimise the possibility of the different vehicles to measure the same longitudinal profile on the test sections.

| Evenness (IRI) | | Rutting (Inches) | | Location |
|---|---|---|---|---|
| Good | <1.0 | L | <10 mm | Site no 3, 4, 5, 9, 19, 11, R01 |
| Moderate | 1.0 - 2.5 | L | <10 mm | Site no 6, 7, 8, 13 |
| Severe | >2.5 | L | <10 mm | Site no R02, R03, R23, R050 |
| Good | <1.0 | M | 10-20 mm | Site no 2, R067 |
| Moderate | 1.0 - 2.5 | H | >20 mm | Site no 1 |
| Severe | >2.5 | H | > 20 mm | Site no 12, R22 |

Table 6: Test matrix for the European experiment

The test sites in the European experiment included test sections with IRI values from approximately 0.6 to 9.9. The test sections with the highest IRI were measured at the DAF test facility where the special test sections has been build to accommodate for testing of trucks on very uneven roads. The tests sections at the DAF test track had IRI values from 0.8 to 9.9 and the in-service test sections on the roads in Holland and Germany had IRI values from 0.6 to approximately 2.5.

## 2.2 Reference measurements

### 2.2.1 Devices used for reference measurements

In order to ensure a link between the experiments, reference measurements were conducted in each region using the same device and operators.

In October 1996, a special trial was held at the Federal Highway Administrations Turner Fairbanks facility in United States, to analyse and compare suitable reference devices to be used in the experiment. The result of the test was that three devices were chosen to be used as reference devices as they performed well and because they were easy to transport to the different experiments without significant shipping costs. The devices chosen for linking the three regional experiments together were the Static Dipstick, the Rolling Dipstick and the ARRB Walking Profiler. Each of these devices records the pavement profile by means of an inclinometer. All the devices are operated at walking speed (Fig. 11, 12, 13)

### 2.2.2 Measurement procedures

At each site a rod and level reading has been made every 30 meters for the test section. A static inclinometer has measured every 0.25 meters along with the rod and level measurement. A rolling inclinometer has been used to obtain a continuous profile and the measurements have been adjusted with the rod and level and static inclinometer measurements. The rod and level measurements have been used to ensure that there has been no drift in the static inclinometer and has been used to correct the continuous measurement. The final continuous profile will be used as a reference profile for the measurements performed by the high-speed devices, by comparing the profiles by a point to point comparison. By establishing a continuous profile by the rolling inclinometer it is possible to compare profiles from any profilometer no matter what sample interval is used. For analysis of the transverse profile, reference measurements were performed using the same techniques as described for the reference measurements in the longitudinal direction.

### 2.2.3 Reference equipment

Rod and Level

The rod and level measurements were performed as standard rod and level surveying measurements. The measurements were performed for each 30 meters

Static Dipstick

The Static Dipstick device was designed by the FACE company in USA. The original purpose of the device was to evaluate the flatness of concrete floors. The device consists of an inclinometer to determine the difference in elevation between the feet of the dipstick. This inclinometer works as an electronic pendulum which determines and displays the elevation differences. The accuracy specified by the manufacturer is ± 0.0015 in » to 0.04 mm per reading. The dipstick records the raw elevation data and by a set of application programmes by a PC it is possible to process the data into roughness statistics whereof one is IRI. The dipstick is operated by walking the device down a wheelpath. The operator rotates the dipstick from one elevation location to the next, leaving the front foot of the dipstick on the pavement surface while the back foot is rotated forward. If the front foot is lifted from the pavement, the reference elevation will be lost and the procedure must be started over. The operator waits until the display has settled and then calls out the reading.

*Figure 11, Static Dipstick*

Rolling Dipstick

The Rolling Dipstick operates in the same principle way although this device is continuously rolled down the wheelpath and continuously collects the elevation data. Also this device gives the opportunity to calculate roughness statistics.

*Figure 12, Rolling dipstick*

ARRB Walking profiler

The Walking Profilometer is a manually operated device for measuring the profile of the paved surfaces at walking speed. The measurements are performed by a walking beam that measures the true gravitational slope between front and back feet, 241.3 mm apart. When the foot of the device moves the back foot lands where the front foot was positioned. Data are displayed graphically on an onboard laptop computer and can be set up to include standard roughness statistics. The accuracy of relative height measurements from one point to the next in sequence is of the order of ± 0.005 mm, corresponding to an expected final height accuracy of about ± 1 mm over a 50 metre profile run.

Figure 13, ARRB Profiler

## 2.3 Measurement procedure

### 2.3.1 Test procedure in Arizona

Each high-speed device performed tests at 60 and 90 km/h and the minimum speed of the device specified by the manufacturer. Special tests were performed by requiring the devices measure from dead stop and then accelerating up to 90 km/h and decelerating down to a complete stop.

### 2.3.2 Test procedure in Japan

In Japan, the measuring speed of the vehicle depended on the speed regulation on the tests sites with the following procedure:

- Test sections with speed limits of 50 km/h, measuring speeds of 50 km/h and 30 km/h were used
- Test sections with speed limits of 60 km/h, measuring speeds of 60 km/h and 30 km/h were used.
- Test sections with speed limit of 90 km/h, measuring speeds of 90 and 60 km/h were used.
- Test section located on a non in-service site, measuring speeds of 90 km/h, 60 km/h and 30 km/h were used

### 2.3.3 Test procedure in Europe

In Europe, the measuring speed of the vehicles in the European experiment were divided in a standard and special measuring mode as follows:

- Standard test mode on DAF test facility and on in-service test sections:
  60 km/h, 90 km/h and the optimum speed for the device
- Special test mode on DAF test facility only:
  Slow speed in the range of 5 - 25 km/h
  Variable speed deceleration and acceleration from 50 to 75 to 50 km/h.

## 2.4 Test schedule

Dates of testing in the three experiments are shown in table 7.

| Region | Location | Date of execution | Number of participants |
|---|---|---|---|
| USA | Arizona | April 15 - May 1, 1998 | 6 |
| Japan | Hokkaido | July 6 - July 17,1998 | 8 |
| Europe | Holland and Germany | September 15 - September 25 | 30 |

### 2.4.1 Test schedule for the experiment in USA

The participants met on April 15, 1998 for a pre-meeting at the Arizona Department of Transportation Office.

On the following day, April 16, 1998, special tests began on the Williams Gateway Airport. These tests continued on the following day. On April 18, 1998 evening tests were performed at Sky Harbor Airport.

From April 19 to April 21, 1998 tests on the in-service test sections were performed on those test sections located in the Phoenix area. The low speed measurements, including reference measurements were performed on the test sections on 19 and 20 April covering 6 test sections. The high speed devices performed measurements on April 20 and 21. This meant that the high-speed measurements were performed the day after the reference measurements.

For the test sections located in the Tucson area these were measured from April 21 to April 28, 1998. As for the Phoenix area sites, the Tucson area sites were first measured with the reference devices and then followed by measurements of the high-speed devices. In the evening of April 24, 1998, special tests were performed at the Tucson Airport.

Following the end of the measurements a wrap-up meeting was held in Tucson.

### 2.4.2 Test schedule for the experiment in Japan

The experiments in Japan were initiated by an opening ceremony on July 6, 1998. On the evening of July 6, 1998 special tests were performed on the fully access controlled highway, where all measuring devices performed low speed operation and speed fluctuation tests. On the following days, measurements were performed on the in-service test sections in Hokkaido. The reference and the low-speed measurements were performed in the daytime and the high-speed measurements were performed at nighttime from approximately 8 pm to 3 am.

The experiment in Japan were closed on July 17, 1998, with a successful execution of the measurements which were finished in due time.

### 2.4.3 Test schedule for the experiment in Europe

The experiment in Europe was opened on September 14, 1998 starting with a participants' meeting followed by an opening ceremony and a presentation of the participating devices in Eindhoven in Holland.

The test sections in the European experiment were located both in Holland and Germany, hence the organisation of conducting the experiment was the responsibility of DWW in Holland and BASt in Germany respectively.

The opening day ended with a free training session at the DAF test facility.

Each testing day started with a daily briefing for the participants. The tests in Holland were carried out from September 15 until September 18, where September 17 was assigned to perform special tests on the DAF test facility. All tests in Holland were completed by September 18, 1998.

On Monday 21, the second part started with a short briefing at the AM Rheinberg Highway Department after which all participants left to perform their measurements on the German Highway Test sites. Most participants finished their measurements on the September 22, 1998 and all measurements were completed in due time before the closing of the experiment on September 25, 1998. The experiment were closed by a debriefing and a farewell reception at the AM Rheinberg in Germany.

# 3.0 Conclusion and Recommendation

The PIARC World Road Association, International Experiment to Harmonise Longitudinal and Transverse Profile Measurement and Reporting Procedures, completed the data collection phase in 1998 in the three different locations Arizona USA, Hokkaido Japan, and Holland/Germany,Europe.

The experiment included a significant amount of the high-speed profiling equipment available today. Many of these devices are used as routine devices in connection with monitoring the evenness of a road network in relation to pavement management and pavement rehabilitation strategies. As a road network often includes roads with large differences in evenness it is important that an investigation of such devices' repeatability and reproducability in relation to a reference are tested on number of test sections with a large variety of IRI.

The PIARC experiment, overall, included IRI values from approximately 0.5 m/km to 9.9 m/km, which in accordance with the World Bank classification shown in figure 3 ranks the test section from airport runways and super highways to rough unpaved roads.

The highest IRI-values were found at the special DAF test track, which gave the possibility for the devices participating in this experiment to be tested at this IRI level. In the experiment in USA and Japan the test sections had IRI values ranging from 0.5 to 5.0, meaning that the devices participating in these experiment were tested on pavement surfaces which in accordance with figure 3 are classified to be from airport runways and superhighways to maintained unpaved roads and damaged pavements.

The experiment has provided reference measurements from all three experimental locations. The reference measurements were conducted by the same two devices in all three locations with the Dipstick and Rolling Dipstick. The reference measurements were carried out by the same operator in all cases.

One of the major problems for the experiment was to assure that the devices were measuring the same profile line and that the devices in their repeated runs were measuring the same line every time. Therefore, test sections were marked with the line which should be measured by the devices. It was realised that driving at speeds up to 90 km/h creates difficulties of measuring exactly the same line. Therefore it will be taken into account that although the same device or two devices are not able to record the same profile and evenness is not an necessarily an indication of errors.

# 4. References

1. The little book of Profiling. Basic Information about Measuring and Interpreting Road Profiles, October 1997, by Michael W. Sayers, Steven M. Karamikas

2. CEN/TC 227/WG5 N89E, wi 00227-133, ex. 509, Surface Characteristics, Transverse Evenness, Method of Measurement