APPENDIX E

MEASURING PAVEMENT ROUGHNESS

INTRODUCTION

In order to provide a measure of pavement surface condition that has nationwide consistency and comparability and is as realistic and practical as possible, a uniform, calibrated roughness measurement for paved roadways is required by the HPMS.

Roughness is defined in accordance with ASTM E867 as “The deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality.” After a detailed study of various methodologies and road profiling statistics, the International Roughness Index (IRI) was chosen as the HPMS standard reference roughness index. The summary numeric (HPMS data reporting unit) is the IRI in meters/kilometer (inches/mile). The primary advantages of the IRI are:

1. It is a time-stable, reproducible mathematical processing of the known profile.
2. It is broadly representative of the effects of roughness on vehicle response and user’s perception over the range of wavelengths of interest, and is thus relevant to the definition of roughness.
3. It is a zero-origin scale consistent with the roughness definition.
4. It is compatible with profile measuring equipment available in the U.S. market.
5. It is independent of section length and amenable to simple averaging.
6. It is consistent with established international standards and able to be related to other roughness measures.

EQUIPMENT

The different methods of collecting profile and roughness data can be grouped into four classes of equipment:

- Class I — Includes all manual profiling techniques such as rod and level.
- Class II — Includes direct profile measuring equipment. This group also includes noncontact devices that make use of laser, infrared, or ultrasonic sensors.
- Class III — Includes Response Type Road Roughness Meters (RTRRMs). The RTRRM systems measure the dynamic response of a mechanical device as it travels over the roadway surface at a constant speed. These devices use a variety of displacement technologies including the use of axle/body displacement transducers and accelerometers mounted on axles and/or bodies. Response devices must be calibrated to known profiles; they measure average rectified slope (ARS) values that can be correlated to IRI.
- Class IV — Subjective estimations of roughness made by an observer using a descriptive scale that approximates the IRI for different road conditions and ride sensations.

The preferred method of obtaining IRI data for the HPMS can be found in AASHTO Provisional Standard PP37-99. This provisional standard calls for the use of a measured longitudinal profile as a basis for estimating IRI. Consequently, Class III and IV devices are unsuitable for HPMS purposes. AASHTO Provisional Standard PP37-99 is reproduced in this appendix with the written consent of AASHTO.

HPMS Roughness Measurement Procedure

Roughness is reported for HPMS in IRI units converted to either m/km or in/mi (1 m/km = 63.36 in/mi). When Class I or II equipment is used for roughness measurements, the procedure is reduced to reporting the units required by HPMS. Class III equipment (commonly referred to as an RTRRM) should not be used.

To the maximum practical extent, HPMS roughness data should be obtained from ongoing State or local Pavement Management System (PMS), Long Term Pavement Performance (LTPP) and Strategic Highway Research Program (SHRP) activities. HPMS data should be collected in accordance with AASHTO Provisional Standard PP37-99. The goal of HPMS is to ensure nationwide consistency and repeatability of roughness measurements over time and the avoidance of duplicative State data collection efforts. All equipment must be operated within manufacturer's specifications; quality assurance specifications outlined in AASHTO Provisional Standard PP37-99, Section 5, must be followed.

Each State should document and retain records of its quality assurance procedures; FHWA field offices should monitor adherence to these procedures as part of roughness data process reviews.

Roughness data should be reported in IRI units for all sections in accordance with Table IV-1 in Chapter IV. The lower functional systems (rural and urban collector and urban minor arterial) have been placed in the "recommended" category since there are situations where it may not be possible to obtain meaningful roughness measurements with profiling equipment. Major obstacles include:

- Speed restrictions
- Section lengths
- Traffic signals
- Congestion
- Pavement treatments
- Intersection treatments

However, some of these obstacles can be overcome by collecting roughness data during non-peak hours or at night, where speed, traffic, and safety are less of a problem. There are situations where it also may not be possible to obtain meaningful roughness measurements on some urban other principal arterial sections. In these cases, a value of "0" may be reported.

Verification sites require periodic remeasurement to ensure that the profile has remained stable. Heavily traveled roadways and those subjected to severe weather conditions will require remeasurement more often to reestablish the known profile. To ensure that an accurate known profile is being used for verification activities, remeasurement should be performed once per year at a minimum, just prior to data collection activities. Year-round data collection activities may require more frequent remeasurements of verification sites. Any time maintenance or resurfacing is performed on a verification section, the known profile must be reestablished.

Additional Recommendations for Collection of Roughness Data

The following field survey guidelines are recommended for State use in addition to the AASHTO Provisional Standards:

- Where roughness data are collected in both directions, the State should select one direction for each HPMS sample section to be reported and should use this same direction for that sample section in all future applications. It would be useful to choose one direction statewide, and use that for all sample sections (i.e., east to west, south to north).

- For multi-lane facilities, roughness data for the outside (right) lane should be reported. However, if this is not practical, whichever lane is measured should be used for all future HPMS reporting.
- Roughness data collection should be performed when the pavement is in stable condition. Data should not be collected during winter (frost/freeze or freeze/thaw) or wet base conditions. Data collection should be performed during good weather conditions. All manufacturer's recommended procedures should be observed. Good general practice rules include:
  - Temperature: Between 4 and 38° C (40 and 100 degrees F).
  - Wind: Data collection should not be performed when wind conditions affect the stability of the equipment/vehicle.
  - Surface: Data collection should preferably be performed when the roadway surface is dry.
- Data should only be collected at the speeds that correspond to the manufacturer's recommended speed range; speeds should also be consistent with the posted speed limit. Constant speeds should be maintained for all measurements within manufacturer's specified ranges.
- Exclude the impacts of bridge approaches and railroad crossings (or other localized discontinuities) from the roughness measurement for the roadway. Bridge decks should not be included; the objective is to obtain a measure of pavement not bridge roughness.
- Roughness measurements should be taken over a whole HPMS sample section and converted to units per kilometer (mile). However, in order to achieve equipment and speed stability, a minimum length, consistent with the manufacturer's specification, is required prior to the beginning of the measurement area. If this minimum cannot be met prior to the start of the sample section, a shorter portion of the HPMS section may be measured, but that same portion should always be measured in future roughness data collection activities. Short HPMS sections may be included in longer roughness test sections for measurement and reporting purposes. However, the same longer sections should always be measured in future data collections.

COORDINATION WITH OTHER ACTIVITIES

One of the goals of HPMS is to avoid duplicate data collection efforts. States are encouraged to coordinate roughness measuring activities, where possible, such that the same equipment, verification sites, and measurements are used for multiple purposes. Therefore, HPMS activities should be coordinated with other State activities such as the Strategic Highway Research Program/Long Term Pavement Performance and the State Pavement Management Systems.

The LTPP activities monitor pavement performance and use in detail for approximately 1,500 pavement sections nationwide as part of SHRP. Attempts should be made to ensure that as many LTPP sections as possible are also HPMS standard sample sections or at least representative (i.e., in close proximity) of HPMS samples. The pavement and traffic monitoring data collected on LTPP sections should be used for the HPMS universe or standard sample sections, where possible.

Efforts should be made to utilize the LTPP established sections/profiles as multiple use verification sections in each State.

Many State and some local transportation agencies have operational or are developing a PMS to guide program development, improve life-cycle costs, and help select the most effective pavement improvement strategies. The HPMS pavement data reporting should make full use of existing PMS data and collection activities.

STANDARD PRACTICE FOR DETERMINING ROUGHNESS OF PAVEMENTS

AASHTO DESIGNATION: PP37-99[1]

1. Scope

1.1 This practice describes a method for estimating roughness for a pavement section. An International Roughness Index (IRI) statistic is calculated from a single longitudinal profile measured with a road profiler in both the inside and outside wheelpaths of the pavement. The average of these two IRI statistics are reported as the roughness of the pavement section.

1.2 The practice recognizes the need for a quality assurance (QA) plan and proposes guidelines for the development of a QA plan.

1.3 Measurements of profile are made in accordance with ASTM Designation E 950, "Test for Measuring the Longitudinal Profile of Vehicular Traveled Surfaces with an Inertial Profilometer." If this practice is at anytime in conflict with references made, such as ASTM Standards, this practice takes precedence for its purpose.

1.4 *This practice does not purport to address all of the safety issues, if any, associated with its use. It is the responsibility of the user of this practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations related to and prior to its use.*

2. Reference Documents

2.1 ASTM Standards

E1166	Guide for Network Level Pavement Management.
E867	Terminology Relating to Traveled Surface Characteristics.
E950	Test for Measuring the Longitudinal Profile of Vehicular Traveled Surfaces with an Inertial Profilometer.

2.2 Other References

2.2.1 Sayers, Michael W., "On the Calculation of IRI from Longitudinal Road Profile," the University of Michigan, Transportation Research Institute, Preprint TRB, 74th Annual Meeting, Washington, D.C., January 1995.

2.2.2 Sayers, Michael W., T. D. Gillespie, and W.D.O. Paterson, "Guidelines for Conducting and Calibrating Road Roughness Measurements," The World Bank Technical Paper Number 46, The World Bank, 1986.

3. Significance and Use

3.1 This practice outlines standard procedures for measuring longitudinal profile and calculating the International Roughness Index (IRI) for highway pavement surfaces to help produce consistent estimations of IRI for network level pavement management.

4. Terminology

4.1 Definitions

4.1.1 Roughness - According to ASTM E867, roughness on a traveled surface is defined as the deviation of a surface from a true planar surface with characteristic dimensions that affect vehicle dynamics and ride quality.

In this practice, the term roughness is the average of two IRI statistics calculated from longitudinal profile measurements, one in each pavement wheelpath.

4.1.2 Longitudinal Profile - A longitudinal profile is the set of perpendicular deviations of the

[1] This standard is based on SHRP Product P338

pavement surface from an established horizontal reference plane to the lane direction.

4.1.3 International Roughness Index (IRI) - The IRI is a statistic used to estimate the amount of roughness in a measured longitudinal profile. The IRI is computed from a single longitudinal profile using a quarter-car simulation as described in the report, "On the Calculation of IRI from Longitudinal Road Profile." [Sayers 95] A FORTRAN program is provided in Appendix X1 of this procedure to calculate the IRI statistic from a longitudinal profile.

5. Quality Assurance

5.1 Agencies using this practice are required to develop a satisfactory quality assurance plan. At a minimum, the plan shall include the requirements listed in the following sections.

5.1.1 Certification and training record of individuals conducting the survey.

5.1.2 Accuracy and calibration records of equipment used in the survey.

5.1.3 Periodic and ongoing quality control program and the content of the program.

> Note 1 - The estimate of roughness of pavements can be used both at network and project level pavement management. Guidelines for network level are included in ASTM E1166, which can be used as a source for the development of a QA plan.

> Note 2 - The guidelines that can be used for the development of a quality assurance program are given in Appendix X2.

6. Recording of Data

6.1 Agencies using this practice are expected to designate the lane(s), direction(s) of travel to be surveyed based on sound engineering principles, and management needs within the agency.

6.2 Locate (place) the two sensors, separated approximately 1.6 to 1.8 meters (63" to 71") in the wheelpaths. The longitudinal profile points used for calculating the IRI shall have a longitudinal spacing not greater than 150 mm (5.9"). Long wavelength filters are used to remove all wavelengths exceeding 60 m (197').

> Note 3 - The use of anti-aliasing filters and averaging to remove small wavelength content from the profile is left to the agency and equipment manufacturers.

7. Calculations

7.1 Calculate IRI values for each 0.1 km (0.62 mi) for both wheelpaths. Compute an average of the two IRI values to determine roughness.

> Note 4 - The tenth of a kilometer values are needed to calculate average values for each data collection section.

8. Report

8.1 Report IRI to the nearest one-tenth meter per kilometer (0.1 m/km), no English units are applicable. This does not preclude more accurate recording of the IRI.

8.2 Report the roughness calculated in Section 7.1 to the nearest one-tenth meter per kilometer (0.1m/km).

8.3 Use the length of the data summary interval of 0.1 km (0.062 mi.).

8.4 The minimum data recorded and stored for each section shall include:

8.4.1 Section Identification - List all available information necessary to locate the section using agency's current referencing system.

8.4.2 IRI for each of the two wheelpaths. (m/km).

8.4.3 <u>Average</u> of both IRI's calculated for the section. (m/km).

8.4.4 Date of data collection. (month/day/year).

8.4.5 Length of section in meters for which the data is collected.

8.4.6 Profile sampling interval.

8.4.7 Long wave length filter setting.

8.4.8 Pavement surface temperature.

APPENDIX X1

FORTRAN Program to Calculate IRI from Profile

(Nonmandatory Information)

[FHWA Note: For discussion of IRI, including Fortran and RoadRuf programs, go to Internet website: http://www.umtri.umich.edu/erd/roughness/iri.html.]

The Fortran program was developed by Sayers in 1995 at the University of Michigan. [Sayers 95] and complies with requirements of PP37.

Note 1 - Practice requires IRI to be reported in units of meters per kilometer (m/km), the profile elevations (Variable PROF in subroutine IRI) are measured in millimeters, and input distance between elevation points (variable dx in subroutine IRI) is measured in meters. Consequently, the UNITSC value in the program should be set to one (1.0).

Note 2 - Another software program is available from the University of Michigan Transportation Research Institute (UMTRI), named RoadRuf. This Microsoft Windows C based software contains procedures for calculating IRI and many other profile analysis capabilities. The software can be made to comply with the requirements of this protocol. It is public domain and can be downloaded from the Internet at http://www.umtri.umich.edu. Setup options are discussed in the accompanying documentation.

APPENDIX X2

Guidelines - Quality Assurance Plan

(Nonmandatory information)

X2.1 Quality Assurance Plan - Each agency shall develop a quality assurance plan. The plan shall include survey personnel certification training records, accuracy of equipment, daily quality control procedures, and periodic and on-going quality control. The following guidelines can be used for developing such a plan.

X2.2 Certification and Training - Agencies are individually responsible for training and/or certifying their data collection personnel and contractors for proficiency in using the profile measuring equipment according to this practice and other applicable agency procedures.

X2.3 Equipment Calibration - Equipment Calibration (accelerometers and non-contact sensors) is done in accordance with specific manufacturer recommendations. The equipment must operate within the manufacturer's specifications. A regular maintenance and testing program is established for the equipment in accordance with the manufacturer's recommendations.

X2.4 Verifications Sections - Verifications sections are selected with known IRI statistic for both wheelpaths. These sections are measured by equipment operators on a regular basis. Evaluations of these measurements can provide information about the accuracy of field measurements and give insight into needed equipment calibration. Verification sections are rotated on a regular basis in order to assure that the operators are not repeating previously known IRI statistics during the verification. An alternate to verification sections might be to re-measure and compare up to 5% of the data as a daily or weekly quality check.

X2.5 Quality Checks - Additional quality checks can be made by comparing last year's IRI statistics with current measurements. At locations where large changes occur, the pavement manager may require additional checks of the data.