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Skid Resistance Measurement Test Procedures for Intercomparing FHWA National and Regional Reference Systems

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ABSTRACT

The measurement of the skid resistance of highways, under wet weather conditions, is part of the Federal Highway Administration (FHWA) skid-accident reduction program. A national reference system and regional reference systems are operated to improve the method of measurement, to reduce differences in results between systems and to include measurement assurance in the program. State highway measuring systems are intercompared with reference systems at FHWA regional field test centers. This document describes the objectives, the scope and the general procedures of the tests used to intercompare the regional reference systems with the national reference system operated by the National Bureau of Standards. Listings of the general equipment required are included.

Key Words: Friction, pavement; highway safety; measurement, skid resistance; pavement, skid resistance; test procedures, skid resistance measuring systems; tire-pavement interface forces.

1. INTRODUCTION

Most measurements of the skid resistance of highways are carried out using locked-wheel skid measurement systems. The measurement is based upon the steady state friction force developed by a locked test wheel as it is dragged over a wetted pavement under a constant load and at a constant speed. The test apparatus consists of an automotive vehicle with one or more test wheels incorporated into it or forming part of a suitable trailer towed by a vehicle. It includes force and velocity transducers and associated instrumentation, a water supply and dispensing system, and actuation controls for the brake of the test wheel. The test wheel is equipped with a standard ASTM tire for pavement tests.

In the measurement process, the test apparatus is brought to the desired test speed, water is delivered ahead of the test wheel and the braking system is actuated to lock the wheel. The friction force generated between the test tire and the pavement surface (or some other quantity that is directly related to this force) and the speed of the test vehicle are recorded with the aid of suitable instrumentation. The result is expressed as skid number, SN, which is determined from the force required to slide the locked test tire at a stated speed, divided by the effective wheel load and multiplied by 100.

Requirements for this type of locked-wheel skid measuring system have been set forth in ASTM Designation E274 [1]*, and most of the systems operated by state highway departments are reported to be in substantial compliance with these requirements. However, differences between various systems that comply with the requirements have been found to cause variabilities between measurements made with different systems. In order to reduce these measurement variabilities, and also to improve the precision of the measurements made with a given system, the Federal Highway Administration (FHWA) is developing a hierarchy for the measurement of pavement skid resistance [2]. This activity is being pursued as part of the FHWA's skid accident reduction program.

At the national level the hierarchy provides for an interim reference system (IRS) maintained by the National Bureau of Standards (NBS). At the regional level the hierarchy provides for area reference systems (ARS) maintained at FHWA Field Test Centers (FTC). The skid resistance measuring systems maintained by the states are used to inventory and rank the skid resistances of highways. The FHWA plan to assure consistency between state measurements includes the development and monitoring of test procedures and apparatus by NBS in order to relate the measurements made within the hierarchy to the national standards of measurement.

The IRS is a skid measuring system developed for FHWA by NBS. It was developed by analyzing and modifying a commercial, two-wheel skid trailer and a 3/4-ton (680-kg) crew-cab truck. The system, as modified, is shown in figure 1. The trailer incorporates a strain-gage-based, beam-type transducer mounted on the left wheel axle. This transducer is instrumented to measure vertical and horizontal wheel forces and the torque applied to the wheel. A layer of water is applied to the pavement just ahead of the left wheel by a flow channel water chute specially designed to have a non-divergent flow pattern and to minimize the effects of minor perturbations in the water flow. The water is delivered from a tank on the truck by a pump that is belt driven from the drive shaft. The flow rate is controlled by metering valves and measured with a turbine-type flow meter. The driver is assisted in controlling the vehicle speed during tests by visual and audio signals that indicate the deviation from

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*Numerals in brackets denote the literature references cited at the end of this report.

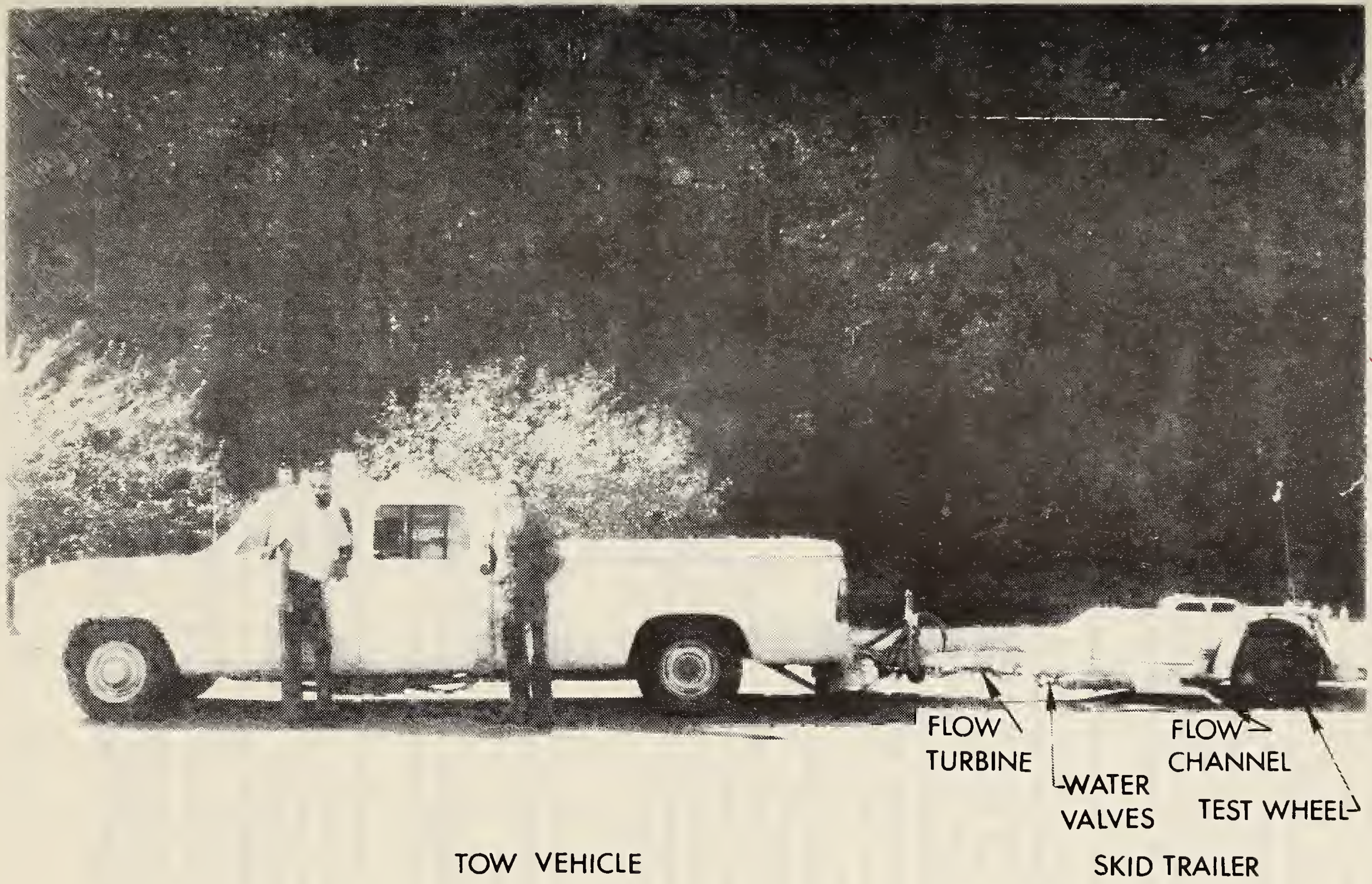

Figure 1. The interim reference skid resistance measurement system (IRS).

the specified test speed. The speed signal is derived from a fifth wheel attached to the truck. Speed is also measured and recorded by a stationary radar system. During a test the horizontal (traction) force, vertical (wheel load) force, water flow rate, and speed (as measured by the fifth wheel) are recorded in analog form in the tow vehicle. These same quantities, except speed, are also recorded in digital form by a transient recorder also located in the tow vehicle, and speed (as measured by the radar) is recorded at the ground station. At the conclusion of a test, the digital information is transferred to the ground station for processing. The ground station is a recording-calculating-plotting system designed to process the data to obtain the instantaneous measured skid number as a function of location on the test pavement.

This report outlines the test procedures which are used to elicit and to compare the performances of the IRS and the several ARS systems. The objective and the scope of each test procedure is given as well as a check list of the general equipment required. The report is addressed, primarily, to the FTC engineers who are responsible for comparing the state systems with the ARSs; to provide them with the opportunity to adopt, for their work, some or all of the outlined procedures. These engineers are already familiar with the IRS and its performance, and with the general nature of these test procedures. Therefore, the procedure outlines are intended to serve only as general guides and reminders, not as test method standards.

The preparations which should be carried out before testing begins are summarized in section 2.1 of this report. The calibrations of the speed measuring and force measuring equipments are outlined in sections 2.2 and 2.4, respectively. The needs for an improved water laying system, and for an improved test of its performance, are discussed in section 2.3.

In section 2.5, displacement measurements are summarized which identify the static motions due to the static traction forces applied at the tire-pavement interface. However, motions of the trailer during skid testing involve dynamic forces. Thus, while only a prelude to a dynamic force analysis, the static displacement results can be used to compare different trailer designs.

Skillful operation of the national and regional reference systems is required to achieve reliable and repeatable measurements. The test method is based upon skidding within designated lanes of the surface at designated longitudinal positions. The accomplishment of a constant speed during skidding mandates a close relationship between the driver and the power train. The instrumentation operator needs to know the timing of his system and be able to compensate for the time lags associated with the system response. The tests outlined in section 2.6 acknowledge the contribution of a skillful crew to the measurement process and suggest a means of quantifying the crew-system performance.

Non-uniformities in tires, pavement characteristics, and weather conditions contribute to data scatter. Test matrices can be designed to identify such conditions when the scatter exceeds the normal dispersion level of the measurements. A test matrix, or test program building block, is described in section 3.1.

Other parameters which can be controlled by the conditions of operation of the system have also been shown to affect the skid resistance measurement results. The tests summarized in section 3.2 can establish the various ranges of operational control needed to achieve the desired degree of measurement precision. Since different pavements are expected to exhibit different speed and water depth sensitivies, different degrees of operational control may be required on the different test surfaces to achieve the same precision of measurement.

The results of the tests conducted in sections 2 and 3 should be obtained prior to system correlation. If the sensitivity of SN to a particular operating variable is unknown, a constant value of the variable should be maintained during the correlation tests. To interrelate the measurements of the reference systems, a test program is designed using the previously mentioned procedures as building blocks. The desired elements of such a program are given in section 4.

The measurement assurance program for an FTC and its ARS includes the periodic evaluation of test facilities and procedures, determination of the performance characteristics of the ARS and its subsystems, measurement of selected reference surfaces maintained at the FTC with the IRS, and correlation of the measurements made by the ARS and the IRS. The program also includes the evaluation of new test equipment and procedures, and experimental studies for the development of numerical data, where appropriate, to identify and quantify sources of difference in the skid number measurements. As a result, improvements in procedure and equipments are expected as the program develops, with increased measurement capabilities being transferred to highway skid resistance measuring systems at the FTC.

These procedures were developed through a cooperative effort by personnel of NBS, FHWA and the Western, Central, and Eastern FTCs.

2. PREPARATION, MEASUREMENT, AND ADJUSTMENT OF SUBSYSTEMS

2.1 Test Preparations

2.1.1 Orientation of Personnel

a. Objective

The test personnel are to be prepared for the test program to be conducted.

b. Scope

(1) An introduction to the test program will be provided.

(2) The operational and safety procedures in effect at the test site and the proper channels through which requests for assistance should be processed will be determined.

c. General Procedures

(1) An inspection of the test equipment will be conducted.

(2) An orientation session will be held, consisting of discussions among the assembled test personnel. The test director will outline the test program, the preferred test sequence and schedule, and duties which may require supplementary test personnel.

(3) The notations required on the test records, the amount of preliminary data reduction, the contents of any preliminary letter reports, and the final report will be discussed.

(4) During the session, questions will be encouraged.

(5) Details of FTC operational and safety procedures will be solicited by the test director.

d. General Equipment Required

(1) Test plan and schedule.

(2) Lists of personnel duties and requirements.

2.1.2 Documentation and Description of the ARS

a. Objective

General information about the ARS and the testing facilities of the FTC is to be obtained.

b. Scope

The information can consist of photographs, general technical data and descriptions including mechanical dimensions, schematics and system block diagrams.

c. General Procedures

(1) Photograph each system tested.

(2) Photograph each test set up.

(3) Record pertinent dimensions of each system and test set up.

(4) Obtain or develop pertinent schematics or block diagram information.

d. General Equipment Required

(1) Camera with film.

(2) System manuals.

(3) Measuring equipment.

2.1.3 Test Tires

a. Objective

A set of tires sufficient for the test program is to be prepared.

b. Scope

(1) The tires will be conditioned for use.

(2) Test data will be obtained for the evaluation of engineering characteristics of the tires.

(3) The degree of uniformity will be investigated within and between tires, considering wheel radius, groove dimensions, rubber hardness, and spring rate.

c. General Procedures

(1) A sufficient number of standard test tires will be obtained, preferably from one production run.

(2) The tires will be mounted on appropriate wheels and balanced dynamically.

(3) The tires will be individually numbered on the outboard sidewall as a means of identification and a radial paint stripe will be applied as an index mark.

(4) A go/no go gage will be used to determine that groove width and depth are within tolerance.

(5) Each tire, inflated to 24 psi (165 kPa) will be run under load for 200 miles (320 km) near 40 mph (64 km/h).

(5) Each tire, inflated to 24 psi (165 kPa) will be run under load for 200 miles (320 km) near 40 mph (64 km/h).

The following procedures may be applied to a representative sample of the lot.

(6) Each tire will be stored for 24 hours or more at approximately 72 °F (22 °C). At 24 psi (165 kPa) inflation pressure, the tread hardness will be measured using a Type A-2 durometer with one kilogram total load.

(7) With a radial load of 1085 lbf (4825 N) applied to each tire in turn, the inflation pressure will be re-adjusted to 24 psi (165 kPa) and the tire radius will be measured at the point of load application.

(8) The radial load will be varied between 700 lbf (3100 N) and 1500 lbf (6700 N), and the corresponding changes in tire radius will be measured. The results will be used to calculate the radial spring rate. Tangential spring rate can be determined from traction displacement data (see section 2.5).

d. General Equipment Required

(1) Tire mounting and balancing equipment.
(2) Go/no go groove profile gage.
(3) Thermometer.
(4) Tire inflation pressure gage.
(5) Type A-2 durometer.
(6) Paint.
(7) Means of applying load and measuring displacement.

2.1.4 Tow Vehicles

a. Objective

The tow vehicles, in turn, will be prepared for the test program.

b. Scope

(1) The normal operating configurations of the tow vehicles will be determined.

(2) Test data will be obtained concerning the displacement of the hitch and the changes in radius of the tow vehicle tires as a function of occupant weight, tire inflation, and water dispensed.

c. General Procedures

(1) The crew complement and seating arrangement of the tow vehicle will be determined. Normal on-board storage of auxiliary equipment will be determined and implemented. Fuel and pavement-wetting tanks will be filled.

(2) Crew weight and trailer hitch loads will be simulated with weights.

(3) Hitch displacement and tow vehicle tire radius will be measured as occupant weights are modified, tire-inflation pressure is changed, and water is removed from the tow vehicle.

d. General Equipment Required

(1) Weights.
(2) Displacement gages.
(3) Inflation pressure gage.
(4) Means of removing water from tow vehicle tanks.
(5) Means of measuring volume or weight of water removed.

2.1.5 Force Measuring Instrumentation

a. Objectives

The skid-test systems, in turn, will be checked to determine the operational readiness of their on-board force measuring instrumentation.

b. Scope

(1) All on-board force measuring instrumentation necessary for the skid-test program will be checked to ensure that it is functional.

(2) Tests will be conducted to evaluate resolution, linearity, frequency response, stability, and other characteristics, as appropriate, to ensure the reliability of the instrumentation.

c. General Procedures

(1) Signal generators will be used to simulate force inputs within normal ranges of amplitude and frequency.

(2) Outputs will be observed for the normal range of instrumentation settings under operator control.

(3) Engine speed will be varied and the stability of excitation voltages, amplifier outputs, etc., will be observed.

(4) An oscilloscope will be used in a high-gain, a-c measuring mode to identify characteristics of noise.

(5) An auxiliary X-Y recorder will be used to expand the output signals for the determination of linearity and hysteresis.

(6) The cab heater/air conditioner or other means will be used to vary instrument compartment temperature. Temperature stability of each instrumentation channel will be observed.

(7) The wheel force transducer temperature will be varied by conductive heat transfer from the brake assembly. Several skid tests (brake applications) will be performed in succession as a means of heating the assembly. Transducer outputs will be monitored for temperature stability.

d. General Equipment Required

(1) Signal generators.
(2) Oscilloscope.
(3) Voltmeters.
(4) X-Y recorder.

2.1.6 Skid Trailers

a. Objective

The skid trailers, in turn, will be prepared for the test program.

b. Scope

(1) The desired trailer static weight distribution will be attained.

(2) Test data will be collected to enable the determination of engineering characteristics of the trailer suspension system, such as Coulomb friction, damping factors, suspension spring rates, and natural frequencies of the trailer.

c. General Procedures

(1) Normal values will be set for trailer operating variables, e.g., tire and shock absorber inflation pressure, hitch height, etc.

(2) The trailer will be weighed simultaneously at its three points of support, i.e., the hitch and the two tires.

(3) The total weight and its distribution will be trimmed such that each tire supports 1085 ± 5 lbf (4825 ± 20 N) and the hitch supports 150 ± 25 lbf (670 ± 100 N).

(4) The trailer body will be lifted slightly through its center of gravity and released abruptly. The transient time variations of the following quantities are to be recorded: body-to-axle displacement; body-to-pavement displacement; axle-to-pavement displacement; vertical load on the test wheel as measured by a force plate under the wheel; vertical load on the test wheel as measured by the wheel transducer.

(5) Step (4) will be repeated for a variety of lift forces, both with and without the trailer shock absorbers connected.

(6) The trailer will be lifted slightly through the axle and released abruptly. Again, the transient variations of the quantities listed in (4) are to be recorded.

(7) Step (6) will be repeated for a variety of lift forces both with and without the trailer shock absorbers connected.

d. General Equipment Required

(1) Force plate instrumented for vertical load.
(2) Vertical load transducers.
(3) Inflation pressure gage.
(4) Electrical displacement gages.
(5) X-Y recorder with time-base feature.
(6) Means of lifting and releasing the body and axle.

2.1.7 Force Plate Calibration

a. Objectives

A force plate with multiple sensitive axes is to be calibrated in a manner traceable to the national standards of force by a procedure that minimizes sources of error.

b. Scope

(1) The force plate is to be calibrated in a fixture that provides simultaneous combined loading of its sensitive axes. Loads applied are to be determined by load cells that have been directly compared with the national standards of force. Loading conditions will be designed to simulate conditions of actual use.

(2) Means are provided with the force plate to generate reference signals under specified conditions. These signals will be adjusted to provide force plate outputs equivalent to known loads. The signals can be used to adjust the gain and offset of readout instrumentation used with the force plate.

c. General Procedures [3]

(1) The orientation of the traction axis of the force plate with respect to its surface is to be determined.

(2) Combined loads are to be applied in accordance with the vertical force unloading-due-to-traction characteristic of the trailer design with which the force plate is to be used.

(3) Traction response of the force plate will be recorded under combined loading. Traction reference signals will be adjusted under 1085 lbf (4825 N) vertical loading.

(4) Vertical response of the force plate will be recorded under vertical loading. Vertical reference signals will be adjusted under no-load conditions.

d. General Equipment Required

(1) Multiaxial force loading fixture.
(2) Load cells traceable to the national standards of force.
(3) Readout electronics.
(4) Means for measuring angular displacement.

2.2 Speed Measuring Systems

2.2.1 Fifth Wheel

a. Objective

A fifth wheel speed measuring system is to be calibrated.

b. Scope

The fifth wheel readout is to be compared with known speed and distance quantities determined by timed operation over a measured course.

c. General Procedures

Use the procedure given in ASTM Designation F 457 [4].

d. General Equipment Required

(1) Measured mile.
(2) Stop watch.

2.2.2 Drive Train Tachometer

a. Objective

The relation between speed and drive train tachometer readings is to be established as an aid to water flow rate adjustments.

b. Scope

Tachometer readings will be obtained at the speeds designated for skid testing.

c. General Procedure

(1) The tow vehicle will be put in its normal operating configuration.

(2) Water and fuel tanks will be filled.

(3) Tires will be warmed up by a five-mile (8-km) drive at approximately 40 mph (64 km/h).

(4) Tow vehicle tires will be set at the desired inflation pressure for skid testing.

(5) The tow vehicle will be driven at a speed designated for skid testing and in the gear ratio to be used during skid testing.

(6) The corresponding drive train tachometer reading will be recorded.

(7) Steps (5) and (6) will be repeated at each designated speed.

d. General Equipment Required

(1) Inflation-pressure gage.

2.2.3 Radar Correlation and Determination of Fifth Wheel Sensitivity to Operating Parameters

a. Objectives

(1) Speed measurements made with the calibrated fifth wheel are to be correlated with radar speed measurements.

(2) Test data are to be obtained to determine the sensitivity of the fifth wheel to its operating parameters.

b. Scope

(1) Tow vehicle speed will be measured simultaneously by fifth wheel and radar techniques at each speed designated for skid testing.

(2) The tests will be repeated with variations of fifth wheel inflation pressure and vertical force.

c. General Procedures

(1) The fifth wheel is to be calibrated in accordance with section 2.2.1.

(2) The fifth wheel will be warmed up by a five-mile (8-km) drive at approximately 40 mph (64 km/h).

(3) The tow vehicle is to be driven directly toward the radar deviating only near the end of the run in order to avoid colliding with the radar equipment.

(4) The tow vehicle is to be driven with a speed variation of approximately ±2 mph (±3 km/h) about the speed specified by the radar operator.

(5) Simultaneous records are to be made of the fifth wheel and radar readouts, and synchronized by means of the speed peaks.

(6) The test will be repeated at each speed designated for skid testing.

(7) The test will be repeated with fifth wheel inflation pressure varied from normal by ±10 percent and ±20 percent.

(8) The test will be repeated with the fifth wheel vertical force varied from normal by ±10 percent and ±20 percent.

d. General Equipment Required

(1) Speed measuring radar system with 0.1 mph (0.2 km/h) resolution and a recorder output.

(3) Means for determining and adjusting the vertical force exerted against the pavement by the fifth wheel.

2.3 Water Laying System

The standard method of test for skid resistance, ASTM E274 requires that the pavement wetting system be suitably designed to ensure that the water layer encountered by the test tire has a uniform cross section at all test speeds, with a minimum of splash and over-spray. Thus, the cross section of water to be measured is located at the forward edge of the tire-pavement interface. While in transit from the nozzle to the interface, the water is subject to many disturbances.

At this time, a completely satisfactory pavement wetting system does not appear to be available, nor suitable equipment and procedures for measuring water laying system performance.

The static distribution gage (SDG) measures the distribution of water across the width of the stream, but not at the leading edge of the tire-pavement interface nor after the water trajectories are modified by impact with the pavement surface under dynamic conditions (i.e. with the trailer in motion). The dynamic distribution gage (DDG) is used under dynamic test conditions to meet the latter objection but is not a test of conditions at the leading edge of the interface. The DDG, as it is presently designed, collects extraneous water such as the spray which follows the trailer as well as the water ahead of the test tire.

The various ways of evaluating wetted width include using the SDG and DDG distribution widths, measuring the water trace on the pavement after the passage of the skid trailer, and photographing the pavement from the moving trailer to show the water trace width at the leading edge of the tire interface. These methods produce widely varying results.

Each measurement technique has known sources of error. Width readings of both distribution gages do not include the spreading that begins when the water contacts the pavement. The SDG reading does not include dynamic effects. Water traces laid down on pavement and measured after trailer passage contain an increment of width due to spreading which necessitates an assumption about the width at the time of passage. Measurements of photographs of the wetted width from the moving skid trailer require geometric calculations to account for changes in scale with distance from the camera. At this point, an optimal camera arrangement with proper lighting has not been established.

Consequently, no procedures for measuring water laying system performance are given here. Additional test descriptions and a discussion of measurement errors are given in reference 5.

2.4 Wheel Force Calibration

2.4.1 Transducer Orientation

a. Objective

The wheel transducer is to be oriented on the trailer such that large changes in vertical load produce only minimum changes in the traction force readings.

b. Scope

The adjustment is applicable to force transducers instrumented for traction force.

c. General Procedure

(1) The trailer is to be put in its normal operating position.

(2) The test wheel is to be supported on an air bearing.

(3) The transducer traction instrumentation is to be set on a sensitive range and the reading is to be zeroed.

(4) The test wheel is to be lifted into the air and any change in traction reading noted.

(5) Steps (2) to (4) are to be repeated while varying hitch height until there is a minimum change in the traction reading between loading conditions.

(6) On single test wheel trailers, operation at this hitch height is an alternative to rotating the transducer. On dual test wheel trailers at least one transducer will have to be rotated if the objective is not met initially.

d. General Equipment Required

(1) Air-bearing support for test wheel.
(2) Adjustable hitch on tow vehicle.

2.4.2 Vertical Load Channel Calibration

a. Objectives

(1) The vertical load measuring system is to be calibrated.

(2) The linearity and hysteresis of the system are to be determined.

b. Scope

The performance of the instrumentation is to be recorded externally using an expanded scale. The variation in vertical load is to be at least ± 400 lbf (± 1800 N) about the static load value.

c. General Procedure

(1) The trailer frame is to be pinned to a vertical air cylinder which can unload or load the frame. Alternatively, weights may be placed symmetrically on the trailer frame to increase the load. An hydraulic jack may be used to lift the trailer by the body to reduce the load.

(2) A force plate instrumented for vertical load is to be placed under the test wheel.

(3) Using an external X-Y recorder as readout, plot the on-board vertical load instrumentation channel output versus the force plate vertical load output. The plot is to cover an increasing and decreasing range of at least ± 400 lbf (± 1800 N). At the same time, a voltmeter is to be used to record numerical values.

(4) Under static vertical load, the output(s) of the on-board vertical load calibration signal generator is to be recorded.

(5) The data are to be examined to determine the equivalent force value of the on-board calibration signal(s) and to evaluate the linearity and hysteresis of the instrumentation channel.

d. General Equipment Required

(1) Force plate system.
(2) X-Y recorder with high resolution.
(3) Stable voltmeter with high resolution.

2.4.3 Traction Channel Calibration

a. Objectives

(1) The traction force measuring system is to be calibrated.

(2) The linearity and hysteresis of the system are to be determined.

b. Scope

The performance of the instrumentation under combined vertical and traction loading conditions is to be recorded externally using an expanded scale. The variation in traction load is to be from zero to at least 800 lbf (3600 N) and return.

c. General Procedure

(1) A force plate instrumented for traction is to be placed under the test wheel.

(2) Using an external X-Y recorder as readout, plot the on-board traction instrumentation channel output versus the force plate traction output. The plot is to cover increasing and decreasing traction forces from zero to at least 800 lbf (3600 N). At the same time, a voltmeter is to be used to record numerical values.

(3) Under zero traction force, the output(s) of the on-board traction calibration signal generator is to be recorded.

(4) The data are to examined to determine the equivalent force value of the on-board calibration signal(s) and to evaluate the linearity and hysteresis of the instrumentation channel.

d. General Equipment Required

(1) Force plate system.
(2) X-Y recorder with high resolution.
(3) Stable voltmeter with high resolution.

2.4.4 Determination of the Effective Vertical Unloading Constant

a. Objective

The effective value of the unloading constant H/L (geometrically, the ratio of hitch height to horizontal distance from hitch to trailer axle) is to be determined.

b. Scope

The constant is to be determined for the hitch height obtained in section 2.4.1 and also for this hitch height increased by one inch (2.5 cm).

c. General Procedure

(1) The wheel transducer traction signal is to be applied to the X-axis of an X-Y recorder.

(2) The wheel transducer vertical load signal is to be applied to the Y-axis of the X-Y recorder.

(3) The trailer test wheel is to be supported on the force plate.

(4) The hitch height is to be set to the value determined in section 2.4.1.

(5) Traction force is to be applied to the plate, increasing and decreasing the force over a range from zero to at least 800 lbf (3600 N).

(6) The data are to be recorded and a straight line is to be fitted to the plot. The slope of this line, measured from the X-axis, is the effective value of H/L for the trailer.

(7) Increase the hitch height by one inch (2.5 cm). Repeat steps (5) and (6). The slope of the plotted line is the effective value of (H + 1)/L for the trailer when H and L are expressed in inches.

d. General Equipment Required

(1) Force plate system.
(2) X-Y recorder with high resolution.

2.4.5 Sensitivity of Wheel Force Calibration to Variations in Operating Parameters

a. Objective

The change in offset and/or sensitivity of the wheel force transducer readings, due to variations in operating parameters, is to be measured.

b. Scope

The operating parameters to be varied may include:

(1) hitch height,
(2) test wheel radius,
(3) test tire inflation pressure,
(4) shock absorber inflation pressure,
(5) trailer static weight,
(6) lateral force at the tire-pavement interface, and
(7) transducer temperature.

c. General Procedure

(1) The transducer instrumentation is to be set up in the normal manner with the skid testing system in its normal operating configuration. The test wheel of the trailer is to be supported on a force plate.

(2) The value of one operating parameter is to be increased to the upper bound of the range expected during skid testing.

(3) Traction force is to be applied to the test wheel. The wheel transducer instrumentation output is to be plotted versus the force indicated by the force plate, using an X-Y recorder. At the same time, a voltmeter is to be used to record numerical values. Any difference from the results with the normal value of the operating parameter is to be noted.

(4) The value of the operating parameter is to be decreased to the lower bound of the range expected during skid testing.

(5) Step (3) is to be repeated for the decreased value.

(6) Steps (2) through (5) are to be repeated for each operating parameter to be investigated.

d. General Equipment Required

(1) Force plate system.
(2) X-Y recorder with high resolution.
(3) Stable voltmeter with high resolution.
(4) Means of varying the operating parameters.

2.5 Trailer Displacements

2.5.1 Displacements Under Static Traction Force

a. Objective

Translation and rotation of the skid trailer, in response to static traction force, are to be characterized.

b. Scope

(1) The trailer, hitched to the tow vehicle, is to be subjected to static traction forces comparable to the steady-state forces experienced in skid testing.

(2) Displacement measurements are to obtained over this range of forces to aid development of analytical representations of the skid testing system, and to permit comparisons with other trailer designs.

c. General Procedure

(1) The trailer and tow vehicle are to be hitched together, in line and on level pavement, and in the normal operating configuration. The test wheel of the trailer is to be supported on a force plate.

(2) Displacement measuring devices are to be positioned about the trailer to measure the following responses to traction force:

(a) trailer axle rotation in roll and yaw,

(b) trailer body rotation in roll, pitch, and yaw,

(c) trailer body translation along longitudinal, lateral, and vertical axes,

(d) hitch point translation along longitudinal, lateral, and vertical axes,

(e) change in radius of test tire, and

(f) motions of the trailer suspension.

(g) Tow vehicle tire longitudinal deflection may also be measured at this time by means of a displacement measurement at the tow vehicle rear axle.

(3) Traction force is to be applied through the force plate over a range from zero to 800 lbf (3600 N) and return. Displacements are to be measured over the full range of increasing and decreasing traction at increments of approximately 50 lbf (220 N).

(4) The results are to be plotted to show the motion characteristics of the trailer versus increasing and decreasing traction force.

d. General Equipment Required

(1) Force plate system.

(2) Displacement transducers such as dial gages or electrical linear potentiometers.

2.6 System - Crew Performance Tests

2.6.1 System-Driver Rating

a. Objective

A performance rating for the system-driver combination of a skid resistance measuring system is to be developed.

b. Scope

The rating is to include a measure of the driver's ability to stay within a specified lane of a surface and to maintain a specified speed throughout a skid test in a particular system.

c. General Procedure

(1) Instrumentation is to be placed at the entrance and exit of each lane of a surface to indicate passage of the test wheel.

(2) The driver is to be informed of the specified test speeds and lanes.

(3) System speed is to be continuously recorded during test wheel lock for three skid tests at each of three speeds; 20, 40, and 60 mph (32, 64, and 97 km/h). The entrance and exit lanes of each test are to be noted.

(4) A system-driver performance rating (DPR) is to be calculated for each skid test. Such a rating may take the form

$$DPR = \frac{L}{\frac{1}{T}\int_{o}^{T} D^2 dt}$$

where L = 1 if the test wheel entered and exited on the specified lane,

L = 1/2 if the test wheel entered on the specified lane but exited on an adjacent lane,

L = 0 if the test wheel entered on the wrong lane, or if it entered on the specified lane but exited two or more lanes away from the specified lane,

D = speed deviation, expressed in 0.1-mph units (0.1 mph = 0.16 km/h),

t = time, expressed in seconds, and

T = time duration of the skid, expressed in seconds.

d. General Equipment Required

(1) Lane instrumentation.

(2) Speed recording instrumentation.

(3) Means of indicating the duration of the skid on the speed record.

2.6.2 System-Operator Rating

a. Objective

A performance rating for the system-operator combination of a skid resistance measuring system is to be developed.

b. Scope

The rating is to include a measure of the operator's ability to start a locked wheel skid at a predetermined longitudinal position on the surface while operating a particular system.

c. General Procedure

(1) The driver and operator are to be informed of the desired starting position of the locked wheel skid.

(2) The operator may place reference pylons on the approach to the surface but shall not make a practice skid on the surface.

(3) The difference between the desired position and the actual position of the start of the locked wheel skid is to be measured in three skid tests conducted at each of three speeds; 20, 40, and 60 mph (32, 64, and 97 km/h).

(4) A system-operator performance rating (OPR) is to be calculated for each skid test. Such a rating may take the form

$$OPR = \frac{1}{d}$$

where d = distance in feet from the desired location (1 foot = 0.3 m).

d. General Equipment Required

(1) Highway pylons.
(2) Length scale.

3. SKID RESISTANCE MEASUREMENTS OF PAVEMENTS

3.1 The Test Matrix

The general method of test is described in ASTM Designation E 274. The measurement represents the steady-state friction force on a locked test wheel as it is dragged over a wetted pavement surface under known vertical load and at constant speed. The test is used to measure either the difference in skid resistance between various designs of tires or the difference in skid resistance between various pavements. In the latter case, a standardized, but special-purpose, full-scale automotive tire is mounted on the test wheel to direct the sensitivity of the measurement to differences in surface characteristics. However, variations in the test results occur which are not due to the measuring system since the tire is subject to wear, and the surface over which it is dragged has non-uniform skid resistance characteristics. To measure the effects of the different operating variables and to account for disagreement between measuring systems, the non-uniformities of standard tires and test surfaces need to be identified. Accordingly, the test program described here employs, as a building block, a test matrix which allows a measure of the differences between test tires and between the lanes comprising the test surface to be determined, while the significance of a given variable is being tested. A sample test matrix is shown in figure 2. Twenty-one skid resistance measurements are made in each test matrix with the tire, lane, and operating variable values indicated. The mean of the 21 skid resistance measurements is taken as the skid number of the surface measured during the indicated time period using the "average" tire at the indicated test speed. In addition, the matrix yields a skid number-test variable gradient for the surface, as well as an indication of the skid number dispersion due to lane and tire variabilities.

For example, if it is desired to compare the effect of making a measurement using tire A with measurements made using all of the other tires, it is desirable to eliminate any measurement deviations due to skidding in different lanes and with different values of the test variable.

Time Period ________
Surface ____________
Test Speed _________

Tires

Test Variable	A	B	C	D	E	F	G
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
V - ΔV	____	____	____	____	____	____	____
	(2)	(3)	(4) (Lane)	(5)	(6)	(7)	(1)
V	____	____	____	____	____	____	____
	(4)	(5)	(6)	(7)	(1)	(2)	(3)
V + ΔV	____	____	____	____	____	____	____

Figure 2. Test matrix.

Letters A through G designate seven tires while numbers 1 through 7 identify the seven lanes comprising the surface. The value of the test variable is V, and ΔV is an incremental change in the test variable.

Let a measurement result be represented by the notation

$$(SN + \varepsilon)_{LT(V - \Delta V)}$$

where SN = a nominal skid number measurement value

+ε = an increase in the SN value due to testing at a lower value of test variable

L = lane identification of the test

T = tire used in the test

V = nominal value of test variable

ΔV = incremental change in the value of the test variable.

From the test matrix, figure 2, tire A was used in lanes 1, 2, and 4 at three values of the test variable. Lane 1 was used with tires A, G, and E at three values of the test variable while lane 2 was used with tires B, A, and F at the three values of the test variable, and lane 4 was used with tires D, C, and A at the three values of the test variable.

An equation can be written for the measurement results from each lane.

$$2(SN + \varepsilon)_{1A(V - \Delta V)} - (SN)_{1G(V)} - (SN - \varepsilon)_{1E(V + \Delta V)} = \Delta_{AGE} + 3\varepsilon \quad (1)$$

$$2(SN)_{2A(V)} - (SN + \varepsilon)_{2B(V - \Delta V)} - (SN - \varepsilon)_{2F(V + \Delta V)} = \Delta_{ABF} \quad (2)$$

$$2(SN - \varepsilon)_{4A(V + \Delta V)} - (SN)_{4C(V)} - (SN + \varepsilon)_{4D(V - \Delta V)} = \Delta_{ACD} - 3\varepsilon \quad (3)$$

where Δ_{AGE} = twice the difference between using tire A and the average of using tires G and E in lane 1

Δ_{ABF} = twice the difference between using tire A and the average of using tires B and F in lane 2

Δ_{ACD} = twice the difference between using tire A and the average of using tires C and D in lane 4.

Note that equations (1), (2), and (3) are each independent of lane effects. Note also that the sum of the three equations is independent of any test variable effects (assuming ΔV is sufficiently small that the gradient is linear). Consequently, the sum is free of both lane and test variable effects. To simplify the notation then, eliminate the lane and test variable differences from the sum, and get [6]

$$6(SN)_A - (SN)_B - (SN)_C - (SN)_D - (SN)_E - (SN)_F - (SN)_G = \sum \Delta \quad (4)$$

To this equation add the equation

$$(SN)_A - (SN)_A = 0 \quad (5)$$

Then

$$7(SN)_A - \left\{ SN_A + SN_B + SN_C + SN_D + SN_E + SN_F + SN_G \right\} = \sum \Delta \quad (6)$$

Now, the measurement performance with tire A can be compared with the performance of all of the tires by writing

$$SN_A = \sum_{i=A}^{G} \frac{SN_i}{7} + \frac{\sum \Delta}{7}$$

$$= \text{mean of all measurements} + \frac{\sum \Delta}{7} \quad (7)$$

In a similar manner, the data from the test matrix can be re-arranged to yield, for example, the measurement performance on lane 1 compared with the performance on all of the other lanes. These results are a measure of surface uniformity.

A least-squares linear fit of the test matrix data versus the measured operating variables yields the skid number-operating variable gradient.

3.2 Variation of Measurement Results with Operating Parameters

a. Objectives

(1) The sensitivity of the measurement results on selected surfaces to changes in operating conditions is to be determined.

(2) The degrees-of-control required on certain operating parameters to achieve desired levels of precision are to be determined.

b. Scope

(1) Data are to be obtained for test matrices where the operating variable is a parameter such as:

(a) test speed,
(b) water depth,
(c) hitch height,
(d) test tire inflation pressure,
(e) test tire static load, or
(f) tow vehicle tire inflation pressure.

(2) Data are to be examined to determine the effect that the change in the variable has on the measurement results.

c. General Procedures

(1) A surface for test is to be selected.

(2) Nominal test conditions are to be specified.

(3) Data are to be gathered for the planned test matrix with incremental values of the operating variable covering the expected normal range of variation.

(4) Sufficient time is to be allowed between tests for the surface to dry.

(5) The data are to be examined as outlined in section 3.1.

c. General Eqipment Required

(1) Means to vary and measure operating variables.

4. INTERRELATION AND CORRELATION OF REFERENCE SYSTEM MEASUREMENTS

a. Objectives

(1) The difference in skid resistance measurements, obtained by the reference systems while operating under similar conditions on the same surface, is to be determined.

(2) The sensitivity of the skid resistance measurements to incremental changes in operating variables is to be measured.

(3) Dispersion in the measurements due to differences between test tires, between the lanes comprising the surface, and between time periods of test and climatic conditions is to be identified.

b. Scope

(1) The measurements are to be made on at least two surfaces providing a suitable range of skid resistance values.

(2) The reference systems are to make measurements over the same range of a particular operating variable while other variables are held constant.

c. General Procedures

(1) Each subsystem is to be prepared to confirm or adjust its performance within a desired range prior to starting the interrelation and correlation test program.

(2) Surfaces are to be selected for measurement.

(3) Test matrices are to be planned.

(4) Known operating variables are to be held under control where possible, such as:

(a) test speed,
(b) water depth,
(c) hitch height,
(d) test tire inflation pressure,
(e) test tire static load,
(f) tow vehicle tire inflation pressure,
(g) surface cleanliness, and
(h) surface degree-of-dryness prior to measurement.

(5) Known operating variables not subject to control are to be measured, such as:

(a) temperature of ambient air,

(b) temperature of the test surfaces,

(c) wind speed and direction near the test surfaces, and

(d) wear condition of the test tires.

(6) The test program is to be conducted.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The measurement of the skid resistance of highways, under wet weather conditions, is part of the Federal Highway Administration (FHWA) skid-accident reduction program. A national reference system and regional reference systems are operated to improve the method of measurement, to reduce differences in results between systems and to include measurement assurance in the program. State highway measuring systems are intercompared with reference systems at FHWA regional field test centers. This document describes the objectives, the scope and the general procedures of the tests used to intercompare the regional reference systems with the national reference system operated by the National Bureau of Standards. Listings of the general equipment required are included.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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