Field Test and Evaluation Center Program and Skid Trailer Standardization

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Efforts to measure the skid resistance of highway pavement surfaces through the use of some form of towed vehicle have been reported for at least 50 years. The towed vehicle began to take the form of a two-wheel trailer at least 40 years ago. A sharp increase in interest in and concern over pavement skid resistence began in the 1950s, and during the ensuing years there has been considerable proliferation of two-wheel trailers and some one-wheel trailers operating under generally similar principles. Early reports by developers and users of such equipment quickly revealed that, in spite of the best efforts of investigators, different skid trailers could not be expected to give similar results when used in testing the same pavement under the same conditions within the same time framework. This observation has led to several efforts during the years to effect a correlation between trailers.

The first effort of significance occurred in 1958 as a preliminary to the first International Conference on Skid Resistance. This correlation study, performed on five typical pavements in the Virginia highway system, revealed that, when a number of skid trailers were used to evaluate the condition of these pavements (with the tests performed under identical watering conditions at speeds as nearly identical as possible and within a few minutes of each other), the various units tended to rate the pavements in the same relative order of performance but reported widely differing values of coefficient of friction. Subsequent correlations held in Tappahannock, Virginia, in 1962 and in Okala, Florida, in 1967 revealed that there had been little change in this circumstance. These results were disappointing in view of the efforts of various investigators during the intervals between the correlations to identify and eliminate or minimize the causes of the variations in performance among similar skid measurement systems.

The most recent major correlation, conducted at the Pennsylvania State University in 1972, revealed that significantly different results were still being obtained on the same pavements under the same test conditions by different skid measurement systems all of which were presumed to be measuring the same phenomenon. The data collected during this correlation study were analyzed in far greater depth than those collected during any previous study in an effort to identify the causes for differences in the performance of different skid measurement systems and to assess the magnitude of difference that might be expected between systems because of specific variations in system design or operation.

The broadest effort yet undertaken toward eliminating variations and establishing correlation among skid measurement systems is that which constitutes the field test and evaluation center program at the Federal Highway Administration (FHWA). The fundamental purpose and form of that program have been described by Watson and Cook and will not be elaborated on here. In brief, the program involves FHWA contracts that have resulted in the creation and operation of three field test and evaluation centers having as their purpose the evaluation and correlation of skid measurement systems owned and operated by state departments of transportation and other agencies and a contract with the National Bureau of Standards to provide for calibration and correlation of the equipment used at the centers with a national standard system.

Although this paper deals with the facilities and operation of the Field Test and Evaluation Center for Eastern States (EFTC), operated by the Ohio State University, the facilities available and the procedures employed are identical or substantially identical to those at the Field Test and Evaluation Center for Central States, operated by the Texas Transportation Institute at College Station, Texas, and the Field Test and Evaluation Center for Western States, operated by the Ford Motor Company at its Desert Proving Ground near Kingman, Arizona.

FACILITIES AND PROCEDURES

EFTC is located about 72 km (45 miles) northeast of Columbus, Ohio, at East Liberty, Ohio, among the facilities of the Transportation Research Center of Ohio. In addition to support facilities such as offices, a conference room, a maintenance shop, and tire storage and

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tire mounting and balancing facilities, the principal facilities at EFTC fall into three catagories: facilities involved with water calibration and evaluation, facilities involved with force measurement calibration, and facilities involved with dynamic correlation. Facilities are also available for speed calibration and calibration of tire pressure gauges.

Before water subsystem calibration and evaluation, the angle and location of the nozzle with respect to the pavement and wheel must be determined to fall within the requirements of ASTM E 274. If they do not, appropriate adjustments are made if it is reasonably possible to do so.

The calibration of water delivery subsystems, as well as most of the evaluation of the performance of such subsystems, is accomplished while the trailer sits over a specially constructed pit located in the garage area. Movable ramps permit the trailer to be positioned over the pit and provide a support for associated test equipment. When the trailer is properly positioned on the ramps, the towing vehicle is sitting with its rear wheels on a set of dynamometer rollers that permit it to be operated with the transmission engaged to simulate speeds of 32, 64, and 97 km/h (20, 40, and 60 mph). The trailer wheel for which the water delivery subsystem is being evaluated (usually the left wheel) is removed, and the axle height is adjusted to be at the same height above the ramp as if the wheel were still in place. Water is then pumped through the nozzle into the pit at simulated speeds of 32, 64, and 97 km/h (20, 40, and 60 mph) while the resulting trace widths are measured. The policy at the centers is to measure the trace width at the elevation at which the water would normally strike the pavement but with the water in free-fall into the pit. This does not take into effect any spreading action of the water during the brief period of time between its contacting the pavement and reaching the test tire, but, on the basis of considerable experimentation, this was the only trace width that could be measured with reliably repeatable results.

After trace widths have been determined for the three test speeds, water flow is calibrated. This is accomplished by pumping water through the nozzle at the three simulated speeds and collecting the discharge for a measured period of time in a Q-tank. This tank is calibrated so that the collected discharge may be measured to the nearest 0.4 liter (0.1 gallon). If, on the basis of the previously measured trace widths, the water delivery rate does not fall within the specification limits of ASTM E 274, an attempt is made to bring it into compliance with that specification. This attempt may involve replacement of drive shaft or water pump pulleys, addition of gate valves, or repair or replacement of the water pump, or all of these things. If adjustments of flow rate are required, trace widths are rechecked and changes in the subsystem are accomplished until the combination of trace width and flow provides the most acceptable results throughout the speed range involved.

After the flow rate has been appropriately calibrated, and adjusted if required, the delivery of water in front of the test wheel is evaluated for uniformity and lateral positioning on the static distribution gauge (SDG). The SDG consists of a segmented receiver that splits the water in sections of equal width at the level of the roadway surface. The water from each segment of the container is collected in a separate reservoir, and each reservoir is connected to a sight tube. The sight tubes for all reservoirs are mounted in a rack so that the heights of the columns of water in the adjacent sight tubes represent, in effect, a histogram of the water delivery at the roadway surface. The test is performed at simulated speeds of 32, 64, and 97 km/h (20, 40, and 60 mph), and a photograph is taken of the sight tubes containing water at the end of each test. Adjustable tabs at the bottom of the tubes define the position of the outer edges of the test tire. If the delivered water is not laterally centered on the test tire, the nozzle position is adjusted to correct this problem.

The force measurement subsystems of visiting skid measurement systems are evaluated through the use of an air-bearing force plate. This force plate, calibrated by the National Bureau of Standards, is recessed in the garage floor so that its height is even with that of the floor, thus eliminating any need for blocking up the trailer and towing vehicle. The test wheel to be calibrated is positioned on the force plate; the brake is applied to lock the test wheel; and horizontal force is induced through a chain and air cylinder. The output from the force plate and the conditioned signal output of the system being calibrated are fed into an X-Y plotter, and the resulting plot is evaluated for linearity and hysteresis. In addition, both signals are read on a digital voltmeter, and the results are given to the visiting organization in a form usable for constructing a calibration curve if necessary or desired. If the system being calibrated has the capability of measuring dynamic vertical load, the vertical load transducer is also calibrated on the force plate by jacking up on the trailer to reduce the load below static and by loading the trailer with bags of lead shot to increase the load. As a portion of the force plate calibration procedure, the test wheel is weighed, as is the load on the tongue, and adjustments are made if necessary.

Throughout the horizontal force calibration, the actual vertical load on the test wheel is measured. Thus the incrementally observed load transfer can be used to determine an effective value of h/l. This value rarely agrees perfectly with the value based on individual physical measurements of h and l. The effective value is reported to each state together with a recommendation that it be used in calculating skid numbers (SNs).

The third principle area of investigation involves dynamic correlations between the inventory system under examination and the center's area reference system (ARS). Two such correlations are performed: An initial correlation is performed at the beginning of the inventory system visit before any changes are made in the system, and a final correlation is performed after all appropriate modifications and adjustments have been completed.

Correlations are performed on the center's primary reference surfaces. Five such surfaces were built at each of the three centers. Every effort was made to achieve the same surfaces at each center, including the use of an epoxy binder produced in one lot and shipped to all three centers and construction by the same commercial crew using the same equipment at all three centers. The original objective was to achieve five surfaces that would have a range of SN_{40} of approximately 20 to 70; two of these five surfaces were to have similar SN values but different speed gradients. The objective was partially achieved, but after final construction it was found that all five pads had SN values approximately 10 higher than those originally desired. Pad 5 was found to have an SN of about 85 and to be extremely damaging to tires. After some period of use, it was decided that pad 5 should be eliminated and that an additional pad (pad 0) constructed of Jennite should be placed on the existing base. Approximate current SN_{40} values for EFTC pads are as follows:

Pad	Value	Pad	Value
0	20	3	51
1	35	4	63
2	53		

On the basis of the two correlations just described, each visiting organization is provided with two sets of correlation equations: (a) one relating their system to the center's ARS in the as-arrived condition, which may be used to adjust SN values measured prior to the visit to the center, and (b) one relating inventory values to those of the center's ARS after calibration, modification, and adjustment, which may be used to relate values measured in the future to the ARS level.

OBSERVATIONS AND ACCOMPLISHMENTS

In the course of the evaluations of 23 systems at the Eastern Center to date, some circumstances have arisen frequently enough to indicate inherent problems associated with certain types of skid measurement systems. The most common has been in achieving required water delivery from the nozzle or nozzles.

Center personnel have yet to find on any skid measurement system nozzles that adequately deliver a proper amount of water at all speeds to the test wheel. Typically, nozzles are fundamentally too narrow for use with the ASTM E 501 38-cm (15-in) test tire [which is approximately 2.54 cm (1 in) wider in tread width than the discontinued ASTM E 249 36-cm (14-in) tire]. Some nozzles deliver water in such a manner that the flow tends to converge, producing a trace width narrower than the nozzle orifice width. Some diverge so rapidly that attempts to pump the required amount of water through the nozzle result in trace widths on the order of 46 cm (18 in).

In an effort to standardize nozzles and minimize variations attributable to them, the centers often replace the existing system nozzle with a Penn State type of nozzle. One of the problems associated with nozzles of the Penn State type is the divergent flow of water that produces trace widths (as measured at the center) that do not remain constant as flow rate is increased but increase with increased flow. This causes some difficulty in adjusting flow rate per wetted centimeter to be within the ASTM E 274 specifications for those units in which the pump is driven by the vehicle drive shaft because the tendency of such systems is to deliver a gross flow rate that is essentially proportional with respect to speed. As a consequence, a flow rate per wetted centimeter is delivered that is not essentially proportional with respect to speed. Therefore, if the flow rate per wetted centimeter is properly trimmed at 64 km/h (40 mph) for such nozzles and water delivery systems, a slightly excessive flow is usually found to be produced at the lower speeds, and a somewhat inadequate flow is usually found to be produced at higher speeds.

A number of skid measurement systems make use of a flow control concept in which some of the pumped flow is recirculated back to pump suction. In such a case, the pump may be drive-shaft-driven and the gross pump output is proportional to speed, but the nozzle output becomes very nonlinear with speed. An additional problem with this type of system is that the flow diverted back to the tank is typically adjusted by use of a relief valve that is not designed as a continuously operating flow-control valve and accordingly is a poor performer in this mode.

Calibration of force (and load) transducers to date has shown most to be remarkably linear and free from significant hysteresis. However, the calibration pulse value commonly represents force different from that which the inventory crew believes it to represent.

Although speed calibrations have generally shown the inventory systems to be measuring and recording speed within 0.8 km/h (0.5 mph) of true ground speed, some instances have been noted in which the measured and recorded speed differed from true speed by as much as 10 percent. Although it may be a matter of small importance, very few visiting crews have been found to have tire pressure gauges that accurately measure gauge pressure at 165 kPa (24 lbf/in^2); the difference in one case was as great as 27.6 kPa (4 lbf/in^2). In work with a number of state skid measurement systems, it has become evident that in some cases the procedures used in data reduction (defined as conversion of transducer output signal to SN) can cause some difficulty through the recording of erroneous SN values. The most common such procedure is an attempt to relate chart lines on the system recorder directly to SN.

The relationship between horizontal measured force and SN is clearly not a linear relationship because of the unloading of the test wheel. For those systems in which both the horizontal force and the vertical load are measured and the force is divided by the load electronically to obtain SN, a linear relationship between chart lines and SN results. For those systems in which only the horizontal force (or something representing this force) is measured, the linear relationship does not exist and an effort to force it results in error. In some cases, the users of the system involved have acknowledged the lack of linearity in the fundamental relationship and have attempted to minimize the error throughout the range of SNs in which they are most interested, perhaps 35 to 45, by such techniques as setting artificial zero values. In other cases, the users have simply assumed that the load on the test wheel remains constant and have scaled their recorder chart directly in SN values. In each case, the center gives the user sufficient information to permit development and use of a true calibration curve if desired as well as an indication of the magnitude of error introduced in the user's reported values of SN through failing to do so.

During operation, a principal problem that is being observed in many units is the difficulty of setting or confirming the zero signal. It is becoming increasingly popular to use disk brakes on skid measurement system test wheels. Typically, such brakes do not fully retract when released, and some drag remains on the disk. This makes it essentially impossible to confirm the zero setting of the instrumentation without stopping the vehicle and jacking up the test wheel. In a few cases, the residual drag has been observed to be sufficient to cause highly excessive heat buildup in the test wheel system (perhaps sufficient to affect transducer calibration and readout). A solution to this problem, which involves replacement of two valves, appears to be at hand.

The center operations are currently felt to be accomplishing two functions that are expected to have a primary effect on skid measurement system operation:

1. Standardization of water subsystem delivery rates and distribution and
2. Calibration on an air-bearing force plate relatable to the National Bureau of Standards.

If these and other procedures are, in fact, affecting the results of inventory skid measurement system testing, the effect should be apparent as differences between the as-arrived performance of the system and that when the systems are ready to depart from the center.

One such demonstration is seen in the elimination of speed effect on calibration. Typically the as-arrived correlation will result in a distinct correlation equation for each of the three speeds, and the departing correlation will result in no significant difference and a slope of essential unity in the three equations [that is, SN_{ALL} (REF) = -2.21 + 1.011 SN_{ALL} (Inventory)].

Another possible measure of the effectiveness of the calibration and correlation procedures is the standard

deviation of the visiting inventory system during the initial and final correlations. Of the 16 systems for which such data are now available, 11 showed reductions in standard deviation of SN between the two correlations; the average reduction in standard deviation for the 11 systems was 1.0 SN. In the case of the poorest performance noted to date, one system had an initial standard deviation of 6.8 SN that was reduced to 3.8 SN on the final correlation (a replacement brake hydraulic valve has since been found that should make a further step improvement in this system). The average standard deviation for all 16 systems was 3.2 SN as they arrived at the center and 2.6 SN as they departed the center.

SUMMARY

On the basis of one and a half seasons of operation involving 23 skid measurement systems, we believe that the procedures followed at the field test and evaluation centers result in significantly improved uniformity of operations among a variety of skid measurement systems and provide a procedure through which skid numbers measured over a wide area may be transformed to reference values. Operation of the centers to date has clearly shown the need for certain system improvements, notably the need for development of a nondivergent nozzle of suitable dimensions that will deliver an adequately uniform flow of water, adherence in system design to pump systems that deliver flow at the nozzle proportional to speed, development of fully retracting brakes to make possible frequent checks and adjustments to signal zero levels, and refinements in data reduction procedures.

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