STATE OF ILLINOIS

DEPARTMENT OF PUBLIC WORKS AND BUILDINGS

DIVISION OF HIGHWAYS

RESEARCH AND DEVELOPMENT REPORT NO. 23

SELECTION AND DESIGN OF A SKID TESTER

(IHR-86)

State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

INTERIM REPORT
IHR-86
SKID RESISTANCE OF PAVEMENT SURFACES

SELECTION AND DESIGN OF A SKID TESTER

by

Edward J. Kubiak

A Research Project Conducted by
Illinois Division of Highways
in Cooperation with
U.S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

March 1970

State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

SELECTION AND DESIGN OF A SKID TESTER

INTRODUCTION

In recent years, increased vehicle speeds, greater traffic densities, and better accident data have helped to focus more attention on the degree of involvement of slippery pavements in accidents.

The Illinois Division of Highways, to improve its knowledge of the factors that influence skid resistance and to devise means for improving the skid resistance of Illinois pavements, has entered upon a research undertaking that will involve a considerable amount of skid testing of pavements.

The Illinois study is divided into five separate phases of work: (1) development and calibration of skid-testing equipment; (2) evaluation of skid resistance of existing pavement surfaces; (3) determination of polishing characteristics of aggregates; (4) development of procedures for improving skid resistance of existing pavements; and (5) establishment of criteria for the skid resistance of pavements.

This report covers the equipment development portion of the project. It presents a review that was made of existing skid-testing devices, describes the considerations that went into the selection of a device for the present project, outlines the design criteria established for the selected equipment, and describes the device designed and constructed to meet these criteria. The needs of the remaining phases of the project, as well as future anticipated operational needs, were prime considerations in the ultimate selection of the test equipment.

EXISTING SKID TESTING DEVICES

The survey of existing pavement skid testers showed a variety to be in use. Devices that were found to be acceptable for one kind of usage were found to be unacceptable for another. No all-purpose device, and no device that could be said to furnish all of the frictional information that could be desired, was found to have been developed; nor did it appear likely that such devices would be developed within the foreseeable future.

Three general types of skid-testing devices came under investigation: (1) the portable hand-operated device; (2) the stopping-distance vehicles; and (3) the skid trailer.

The portable devices appeared to offer the advantages of mobility, simplicity, low purchase price, and low maintenance cost. Disadvantages seemed to be the small sampling area, poor repeatability, and danger to the operator when sampling busy highways. Also, some authorities claim the coefficients of friction determined with these devices do not correlate well with those that test at ordinary road speeds.[5/]

The main advantages of the full-size vehicle and the trailer-type testers appeared to be their capability for simulating a skidding of an actual automobile wheel, a capability for sampling large areas, a high test rate, low traffic interference, low cost of operation per test, and ease of testing. Of the two types, the trailer appeared to offer a higher degree of productivity and greater safety. The major disadvantages appeared to be a high initial cost and a high maintenance cost. Skid trailers meeting the criteria established by ASTM Committee E-17 and described in the ASTM Designation: E 274-65T, "Tentative Method of Test for Skid Resistance of Highway Pavements Using a Two-Wheel

Note: Superscript numbers refer to references listed at end of report.

Trailer," appeared to have the additional advantage of standardization that permits correlative exchanges between a growing group of users.

SELECTION OF TESTING DEVICE

In selecting a skid-test device for the Illinois study, two planned uses were given special recognition:

(1) Tests at as many as 2000 locations in all parts of the State in the research study.

(2) Survey-type testing on a Statewide basis subsequent to the research study.

These uses were considered to emphasize the need for a device that would be reasonably mobile, capable of high production, and with a capacity for producing reliable and reproducible data over a long period of time. These needs, together with a desire to provide the highest possible degree of safety to both the operator and the traveling public, were considered to establish the skid trailer as the type of tester most suitable for Illinois.

The fact that standardization was developing in the design of skid trailers to the extent that correlations of the outputs of such a device in Illinois with those of a number of other agencies were possible, added to the attractiveness of this kind of a device for the Illinois study.

After a review of published information on skid trailers, and after correspondence and discussion with many of the people who have been involved in the development of skid trailers, a decision was made that those design features which the experience of others had proven to be satisfactory would be included, insofar as possible, in the Illinois trailer. A further decision was made that whenever improvements seemed appropriate and possible, they would be incorporated.

The reported experiences of others indicated that a minimum of complexity would be a desirable goal in an effort to achieve dependability. Therefore, simplicity of design and operation was stressed in the development of the plans and specifications for the Illinois device.

DESIGN CRITERIA

Plans, specifications, and available literature (included in the list of references) on skid-test systems of several agencies were studied, and formed the basis for the development of the design criteria and ultimate design of the system described in this report. The skid-test system belonging to the Portland Cement Association was examined and road-tested. Literature on systems belonging to the Bureau of Public Roads, Florida, Texas, New York, Tennessee, Virginia, Ontario, Canada, and General Motors, was also studied.

The design of the skid-test system was divided into three major sections: (1) the tow truck and water tank; (2) the skid-test trailer and water nozzles; and (3) the electrical system. Design criteria were established for each section as follows:

(1) <u>Tow Truck and Water Tank</u>

(a) The tow truck and water tank should meet ASTM requirements.

(b) The water tank should be mounted on the tow truck to provide a relatively low center of gravity.

(c) The water tank should be securely fastened to the truck framework to protect the driver in case of an accident.

(d) The water tank should carry an ample supply of water for one day of testing.

(2) <u>Skid-Test Trailer and Water Nozzles</u>

(a) The skid-test trailer should conform to ASTM requirements.

(b) Proven design features of other skid trailers should be incorporated as much as possible.

(c) The trailer should be a two-wheel type of rugged construction.

(d) The water system should conform to ASTM requirements.

(e) A control mechanism should be provided for varying the water flow rate in relation to test speed.

(3) The Electrical System

(a) The electrical system should conform to the ASTM recommendations.

(b) A standard lighting system should be used on the trailer (stop and tail lights, turn signal, etc.) and function with the lighting system of the tow truck.

(c) The skid-test system should operate automatically and be pre-programmed. For safety, a method should be provided for discontinuing a test cycle.

(d) The programming of the test cycle should be susceptible to easy alteration.

(e) During the test cycle, the velocity of the tow truck should be controlled by a governor.

(f) The recording equipment should be selected for transistor operation and minimum power requirements, and if possible, should operate off of the truck's 12-volt electrical system.

(g) The control panel and recording equipment should be located in such a position as to allow the driver to operate the complete system as a one-man operation.

(h) A means should be provided to abort the test cycle in the event water fails to flow to the wheel or wheels being used in the test.

SELECTION OF TOW VEHICLE AND DESIGN OF WATER TANK

Vehicles being used for towing two-wheel skid-test trailers were found to vary from light station wagons to heavy trucks. Because some investigators[11/] reported experiencing an undesirable swaying effect when testing with a light tow vehicle, only heavier vehicles were given consideration for the test system being designed. Heavier vehicles also have the advantage of providing greater mass to resist slowdown when braking during the test process. Both flat-bed trucks and chassis-cab trucks were given consideration before making the final selection of a chassis-cab truck. A principal consideration leading to the final selection of the chassis-cab truck was the opportunity to mount the water tank on this type of truck in a manner to provide a lower center of gravity.

The truck style selected was a standard two-man-cab truck with a straight single-channel frame. This truck style allows a rectangular water tank to be mounted on the frame. The arrangement appeared to offer a reasonably low center of gravity and a minimum of problems when truck replacement becomes necessary. A two-axle, two-ton truck powered with the highest horsepower motor available as standard equipment was specified.

The amount of water needed for a full day's testing was estimated to be about 400 gallons. The water tank was designed to accommodate a volume of approximately 60 cubic feet (450 gallons). Baffle plates were provided to minimize the inertial effect of the water.

The water pump system selected was in accord with ASTM recommendations, and designed to be mounted on the underside of the water tank behind the rear axle of the truck. This location was selected because of the mechanical protection offered by the rear axle and the minimum amount of plumbing required. The tow truck, water tank, and water pump are shown schematically in Figure 1.

DESIGN OF THE SKID TEST TRAILER AND WATER NOZZLES

Of the skid trailers that were investigated, four were very similar in design and all were reported to have good performance records.[10/] These trailers belonged to the New York and Texas highway departments, the Bureau of Public Roads, and the Portland Cement Association. Certain features were selected from each for inclusion in the final trailer design that is shown in Figure 2. The frames of the four trailers were found to differ mainly in the length and location of the cross members and the methods of fabrication (bolting versus welding). A frame very similar to that of the PCA trailer was selected for the Illinois device, principally because it appeared to offer some fabrication and repair advantages. The Portland Cement Association design was modified by lowering the trailer hitch to conform to ASTM requirements.

None of the skid trailers investigated appeared to have an axle assembly that conformed completely with tentative ASTM requirements. The ASTM test method recommends that the skid resistance force be measured as a function of the rotational torque produced in the braking assembly and that the centerline of the axle be higher than the centerline of the trailer hitch. An axle assembly was designed to fulfill this requirement. This assembly consists of an axle shaft, a spring system, and two electrical brake units.

Electric brakes were chosen because of their positive action and ease of control. Brake drum sizes used on other skid trailers were found to range from a 10 x 2-in. to a 15 x 3-in. The 10 x 2-in. brake drum would nest into the recommended 14-inch rim but the brake manufacturer expressed doubt as to the ability of this size of brake to lock under the specified ASTM test conditions. To assure that the brakes would lock when testing, a 12 x 2-in. brake assembly was selected. The hub assembly was designed to allow the use of the larger brake with a 14-inch rim.

In selecting a torque-measuring system, both Method One and Method Two of the ASTM requirements were initially considered. In Method One, torque is measured by strain gauges which are installed on the brake shoe anchor pins. In Method Two, the brake backing plate is mounted on bearings so as to be free to rotate. The force required to resist this rotation is measured by strain gauges. Some agencies using Method One reported problems with the transducer post shearing off and with errors due to the shifting of the brake shoes. Those who use Method Two reported problems in backing plate alignment and in transducer failure. These problems led to the choice of a different type of measuring system. The selected torque-measuring system utilized strain-gauge torque-tube transducers. The torque tube is mounted between the brake backing plate and a flange which is welded to the axle. Each torque tube is instrumented with two two-gauge rosettes and is wired as a full bridge to null out all forces except torque. A sketch of the system is shown in Figure 3.

The ASTM Tentative Method specifies that water is to be applied in front of the locked test wheel at a film thickness of 0.020 $\pm$ 0.005 inch. Unfortunately, no positive method of measuring the water film thickness seems to have been developed. Furthermore, of the several existing water application systems that were investigated, none seemed to offer a design which would meet fully the ASTM specifications. Maintaining a uniform thickness of water both transversely and longitudinally throughout a test appears to be a problem. Some trailer designs use a trough to lay the water on the pavement. One system uses a brush, nine inches wide, with the water flowing through the bristles. This arrangement permits the water path to be held to a nine-inch width. Some of the test trailers use different sizes of nozzle for each test speed.

The water system selected for the Illinois trailer was a modified version of the system used by Texas, consisting of a water pump, piping, two solenoids, and two nozzles. It was designed to conform as closely as possible to the ASTM specifications. The intent was to control the water thickness by the use of different nozzles for different test speeds.

After receiving the fabricated skid-test system, preliminary testing showed that the water application system was inadequate. The major problems were: (1) the output rate varied with battery condition; (2) the proper flow rate could not be maintained when switching from a one-wheel test to a two-wheel test; (3) the flow rate was not easily adjustable for different test speeds; and (4) the water, when applied to the pavement, tended to splash and scatter far beyond the width of the tread path.

To overcome these difficulties, the original electric motor and water pump were removed from the tow truck, and an auxiliary shaft mounted parallel to the truck drive shaft. The auxiliary shaft is driven by the drive shaft by means of pulleys and a belt. Two water pumps were mounted under the truck and these pumps are, in turn, driven by belts from the auxiliary shaft. All the pulleys and belts are of the chain-belt type so that no slippage occurs. The pulleys on the water pumps were equipped with magnetic clutches. Thus, by energizing one or both of the clutches, water is supplied to the selected test wheel at a rate which is proportional to the speed of the truck.

ELECTRICAL SYSTEM

The electrical system of the skid trailer consists of three parts: (1) operational lighting; (2) test programmer; and (3) recording system.

The operational lighting for the trailer includes such equipment as tail lights, turn signals, stop lights and license plate lights, as required in Article XV, Equipment of the Uniform Act Regulating Traffic on Highways in Illinois. The trailer lights operate in conjunction with the lighting system of the tow vehicle.

In most of the skid-test systems that were investigated, the operator is required to perform a series of tasks to start and to conduct individual tests. It appeared that variations between operators, or even in the procedure followed by the same operator, could very likely affect the quality and repeatability of test results. To overcome what appeared to be an undesirable feature, a method was devised whereby the complete test cycle could be controlled automatically by an electrical timing device. The complete cycle takes place following activation of a single switch. The operator need only select from among three switch positions to determine whether the test is to be made with the left wheel, the right wheel, or both wheels of the skid trailer. Another switch is mounted on the control panel for use in discontinuing testing at any point in the cycle if an emergency should arise. The switches are mounted in such a position that they can be operated either by the vehicle driver or by a second man, depending on whether the equipment is to be operated by one man or two.

The electrical timing device is a modified version of a similar device used in the Texas skid-test system. The programming of the testing period is controlled by an adjustable timing mechanism which activates five switches. Each switch can be adjusted to open or close at any time within the testing period. The braking period, the water flow period, the recorder period, the latching period, and the calibration period are each controlled by a switch. One additional switch is included as a spare in the Illinois system for possible future use. A block diagram of the electrical control system is shown in Figure 4.

The braking period is the time required to lock the wheels initially and during which they are locked for the test. The actual time the wheels are locked can be varied from less than one second to the major portion of the entire time cycle. This allows flexibility in setting the duration of each operation of the test cycle. Three seconds presently seems to be appropriate for the braking period.

The water flow period must begin before the braking period since the water must flow long enough to insure that the wheel and pavement have had sufficient time to be wetted, and must continue until the braking period is complete. A lead of about one-half second has been established for the Illinois device.

After the brakes have released, a calibration pulse is applied automatically to the system. This calibration pulse represents a known skid value and is used to check the reliability of the equipment. This pulse will appear on each skid test recording.

The recording period must start before the brakes are applied and end after the skid-test wheels have returned to their normal speeds.

The latching period begins with the closure of a latching switch about a half second after the "Press to Test" switch has been closed, and continues through the entire test period (seven seconds). A typical programmed skid test is shown in Figure 5.

The length of time needed for each operation will not be known exactly until tests of the completed device are made at various speeds to determine proper settings. The time controlling each operation of the test cycle is fully adjustable and the test cycle can be programmed to any desired sequence.

ASTM Committee E-17 has recommended that three different functions be recorded for each test: right-wheel torque, left-wheel torque, and speed of the test vehicle. Because of the lack of availability of three-channel recorders and the high cost of four-channel recorders, the possibility of making use of a two-channel recorder to record all of the desired information was investigated and found to be feasible.

To make use of the two-channel recorder, each of the two pens is assigned to record the torque of one wheel. The drive motor of the recorder is modified to allow the recording chart to be driven by an auxiliary speedometer cable so that the speed of the chart is proportional to the speed of the truck. Using an event marker at the edge of the recording paper, to make at one-second intervals measurements of the spaces between successive marks, provides sufficient information for calculating speed.

The recording equipment is mounted in a console at the right of the driver (between two bucket seats), allowing room for a passenger or alternate operator. This arrangement is shown in Figure 6.

The completed test system is shown in the photograph of Figure 7; the trailer alone is shown in the photograph of Figure 8.

REFERENCES

1. "Comparative Motor Vehicle Traffic Accident Statistics," Illinois Division of Highways, Bureau of Traffic, 1966.

2. "Illinois Motor Vehicle Traffic Accident Facts," Illinois Division of Highways, Bureau of Traffic, 1966.

3. ASTM E-17 Committee, Tentative ASTM Standard, issued 1965.

4. "Tentative Skid-Resistance Requirements for Main Rural Highways," National Cooperative Highway Research Program Report No. 37, 1967.

5. Whitehurst, E. A., "Skid Resistance," The National Limestone Institute, January 1966.

6. "Brakes and Stopping of Motor Vehicles," Public Safety Memo No. 22, National Safety Council, April 1956.

7. Dancy, W. H., Jr., "The Development of an Instrument and Control System for the Virginia Council of Highway Investigation and Research Skid Resistance Measurement Trailer," Proposal No. IDG-VCHIR-240-66U, June 1966.

8. Cook, Larry, "Modification and Evaluation of the Virginia Skid Test Trailer," WP 66-3, October 1965.

9. Oetzel, J. G., "When are Brakes Adequate?," Warner Electric Brake and Clutch Co.

10. "Florida Designs Skid-Test Machine," <u>Better Roads</u>, September 1966.

11. Dillard, J. H. and Mahone, D. C., "Measuring Road Surface Slipperiness," ASTM Special Technical Publication No. 366.

12. McCullough, B. F. and Hankins, K. D., "Development of a Skid-Test Trailer," Texas Highway Department, Report No. 45-1.

13. Normann, O. K., "Braking Distance of Vehicles from High Speeds," Highway Research Board, Vol. 32, 1953.

14. Csathy, T. I., "Skidding and Skid Resistance," Department of Highways, Ontario, Report No. 46, March 1964.

15. Stover, V. G., "Locating Slippery Highway Surfaces Through Accident Report Analysis," <u>Traffic Engineering</u>, November 1962.

16. Balmer, Glenn, "Three Instruments for the Measurements of Pavement Skid Resistance," <u>Journal of the P.C.A. Research and Development Laboratories</u>, Vol. 7, No. 2, May 1965.