Skid Testing

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INRODUCTION

It is probable that man has been concerned about the tractive capabilities of his roadway surfaces for almost as long as he has had roads. With the current emphasis on highway safety, the problem of skid resistance of pavement surfaces is a timely subject indeed.

A rather cursory review of the literature reveals that formal studies of this problem have been made at least since the late eighteen hundreds. Byrne[1]** described in 1896 observations made in this county by a Captain Greene and in London by a Colonel Haywood concerning the slipperiness of various types of pavements. Working at about the same time, and apparently without knowledge of each others activities, both used essentially the same technique for evaluating pavement slipperiness. In both investigations the parameter measured was the distance which a horse towing a cart could travel over a given surface before he slipped and fell. The investigators apparently recognized that there were varying degrees of slipperiness, and attempted to take this into account by describing each fall as a fall upon the knees, a fall upon the haunches, or a complete fall. Falls resulting from stumbles were discounted as being associated with pavement roughness rather than with pavement slipperiness. Observations were made of horses drawing both two-wheel and four-wheel carts.

Although in the light of today's activities these early investigations would be considered very crude indeed, it is interesting to note that both investigators rated a variety of pavement surfaces used at that time in very much the same order, with respect to slipperiness, that they would be expected to be rated using today's far more sophisticated techniques.

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** Superscript numbers in parentheses refer to references at end of paper.

Studies of the slipperiness of pavements as it affects motor vehicle traffic began in the United States at least as early as the 1920's. In 1924, Agg[2] reported the results of a series of experiments conducted at the Iowa Experiment Station in which the skid coefficients of various pavement surfaces were determined by towing an automobile, applying the brake to lock the rear wheels, and measuring the pull against the towing vehicle on a dynomometer. The vehicle was towed at a uniform speed of from 3 to 5 mph and the brake on the towed vehicle applied gradually, to eliminate impact, until the rear wheels started sliding.

Agg's early investigations were continued by Moyer,[3] and similar investigations have continued with periods of greater or lesser activity until the present day.

EQUIPMENT AND TECHNIQUES

During the period since 1920 a wide variety of equipment and techniques has been developed for use in evaluation of pavement slipperiness. This paper does not include consideration of the numerous small devices, often referred to as laboratory test devices, which may be used on pavement surfaces to give a measure of coefficient of friction at very low speeds. It is limited to discussion of those techniques which provide a measure of pavement coefficient of friction at speeds at least in the order of those at which motor vehicles normally travel over the pavement tested. These techniques fall principally into three caetegories. The first involves measurement of the distance which a vehicle will slide with all wheels locked in coming to a stop from a selected initial speed. The second involves measurement of the rate of deceleration of a vehicle when the brakes are locked at a preselected speed. The measurement may be made for only a brief interval after brake lock-up, after which the brakes may be released and the vehicle permitted to travel along it original course, or throughout the entire interval while the vehicle is sliding to a complete stop. The third method involves the use of a towed vehicle, usually a two-wheeled trailer, which is towed across the selected test site at some predetermined speed. One or more wheels on the test trailer are locked and one of a variety of possible measurements is made from which the coefficient of friction between the tire and surface may be determined.

Each of these methods of test have certain distinct advantages, and certain accompanying disadvantages.

Lock-Wheeled Stopping Distance Method

The principal advantage of the lock-wheeled stopping distance method is the relatively low initial cost of equipment and the ease with which the equipment can be assembled for use. The basic test vehicle is normally a conventional passenger car. To this vehicle must be added appropriate apparatus to permit the measurement of its stopping distance. In the simplest form, this may be a gun which fires a chalk bullet against the pavement surface when the brakes of the vehicle are applied. The distance from the chalk mark on the surface to a point on the surface immediately under the gun after the vehicle has come to a rest is then measured with a tape or by any other appropriate or convenient means. Most investigators who intend to conduct any appreciable number of such tests have found it expedient to make use of a fifth wheel attached to the rear bumper of the test vehicle. This wheel, properly instrumented, will give a very accurate readout of vehicle speed to assist the driver in controlling his speed at the beginning of tests and will measure the distance which the vehicle travels after the brakes have been applied, giving a direct readout available to the driver. The cost of the installation, in addition to that of the basic vehicle, may vary from as little as $50 for a chalk gun installation to as much as $2000 for a well-instrumented fifth wheel.

The principal disadvantage of this method of test is that it is inherently somewhat dangerous. When a vehicle slides with all wheels locked the driver no longer has any steering capability. If the vehicle begins to deviate from its original direction of motion, either into an adjacent pavement lane or off the road, the driver must release his brakes in order to recover steerability and then take such corrective action as is indicated. The time interval available to him to make the decision and take the action may be only a fraction of a second. Thus, the risk to the driver and to the vehicle in this method of test is appreciable.

Because of the certainty of the loss of steering control of the vehicle and the possibility of its subsequently following a most erratic path, it is essential that no traffic be permitted to operate in an adjacent lane. On two-lane pavements, or multilane pavements where there is no intermediate median strip, traffic in both directions must be stopped while a test is in progress. On divided highways it is frequently possible to divert traffic from the lanes being tested into lanes on the other side of the median. In either event considerable traffic congestion and delays to the public using the roadway invariably results.

It is now generally agreed that few if any pavements are slippery when they are dry. Problems occur only when the pavement surface is wet. It seems reasonable to expect, therefore, that most tests will be conducted with the pavement wet.

If many tests of this nature are to be performed, the provision of water to wet the pavement surface becomes a demanding job. At least the full width of one traffic lane must be watered for any test of this nature. For a test conducted at 40 mph or higher speed several hundred feet of such pavement must be covered. A number of tests must be performed at any speed to provide a dependable average stopping distance. If there is any appreciable cross drainage to the roadway surface the water will run from the surface rapidly and must be frequently replaced, perhaps before each individual test. This involves hauling large quantities of water to the test site, frequently over rather considerable distances.

Finally, although the initial cost of equipment for this type of test is relatively small, the average cost per test is quite high. Flagmen must be provided to control traffic on the highway being tested. Drivers must be available to haul and spread water on the test site. One or more individuals are required to make the actual measurements. The Tennessee Highway Research Program has normally found that a crew of six men is a minimum to safely conduct such tests. Because of the problems of traffic control and difficulties of providing adequate water, the number of tests which can be performed in a day's time is quite limited. The large payroll associated with a test crew such as that described above, in combination with the small number of tests possible for a day, accounts for the large cost per test associated with this type of operation.

Decelerometer Method of Test

The deceleration method retains to some degree both the advantages and disadvantages of the stopping distance method. Equipment may vary from a Tapley Decelerometer, which has been very popular in some states, to highly sophisticated decelerometers with appropriate recording devices for permanent record. The basic vehicle is again usually a passenger car. The cost of the test apparatus to be added to the car may vary from less than $500 for the first case cited above to as much as several thousands of dollars. If the deceleration measurement is limited to a short interval just after brake application and the vehicle is then permitted to continue on its normal course, and if the tests can be conducted during periods of rainfall so that no prewatering of the pavement surface is required, the tests can be conducted with little hazard or delay to adjacent traffic. Many tests have, in fact, been made in this manner with no traffic control exercised. If, on the other hand, deceleration measurements are to be made throughout the length of a skid from an initial speed to complete stop the method is subject to all of the same limitations of lack of steerability, traffic control, water supply and cost as is the stopping distance method.

Skid Trailer Method

The principal disadvantage of the skid trailer method of test is the relatively large initial expense of equipment. Most trailers now in use have been built as experimental equipment. Many contain features which would not be necessary, or perhaps desirable, for trailers which were to be used in routine pavement testing. Consequently few accurate cost estimates are available. The Tennessee Highway Research Program is now building a trailer and equipping a towing vehicle to permit the conduct of tests to speeds of at least 80 mph. It is believed that the final cost of this apparatus will be in the order of $20,000. The writer is familiar with other recent cost estimates of trailers ranging from $60,000 to $100,000.

The principal advantage of the skid trailer method is probably that of safety. During more than 15 years of over the road testing, the Tennessee Highway Research Program trailer has never been involved in an accident nor has the crew reported a near accident while the vehicle was being used for test purposes. The use of the equipment involves little if any inconvenience to traffic on the highway, since no deceleration of the vehicle occurs during testing. Such equipment can be, and is, frequently used for testing while traveling in relatively heavy traffic. A two-man crew, driver and technician, is ample for essentially all testing of this nature. With certain installations the crew can be reduced to one, with the driver also manipulating the few necessary controls to conduct the skid test. The problem of water supply is evry much minimized. The towing vehicle can carry a water supply varying from perhaps 200 to 500 gallons. Since the water is applied to the pavement only in front of the test wheel or wheels and for a distance only slightly longer than that through which the wheel actually slides, relatively small amounts of water are required per test. Consequently a considerable number of tests can normally be performed through use of the supply available on the towing vehicle. Finally, in spite of the high initial cost of equipment, the cost per test is quite modest. The reduction in crew from six or more to two and the tremendous increase in number of tests which can be conducted per day of work makes the cost per test with a skid trailer as little as perhaps one tenth that per test by the stopping distance technique.

EXTENT OF USE OF THE TECHNIQUES

All of the methods described above have been used to greater or lesser degree in the United States. The General Motors Proving Ground is known to have conducted stopping distance tests on dry pavements in 1937.[4] In 1939 Rudd reported on such tests on wet pavements in the City of Cleveland.[5] Moyer conducted similar tests on a relatively wide scale in Iowa in 1941 and 1942[6] and in California in 1949.[7, 8] Shelburne and Sheppe[9] reported in 1948 on the results of more than 1000 measurements of skidding distances in Virginia. The test program in Virginia has continued until the present time.[10] Indiana initiated a program of research on skid resistance in 1950 in which measurements of stopping distance were employed.[11] These tests have continued. The Tennessee Highway Research Program conducted a number of such tests from 1953 to 1955[12] and continues to conduct them on rare occasions. Other states known to have conducted similar tests from time to time include Louisiana, Mississippi, North Carolina and Washington. Many tests, including some from relatively high speeds, have been conductd by the U.S. Bureau of Public Roads.[13]

The decelerometer method has been used much less broadly than has the stopping distance method. The use of the Tapley Decelerometer has been investigated by Virginia[10] and Tennessee[12] as well as others. Extensive use of the device has been made by the State of Florida. Moyer, in his 1949 test program, measured rate of deceleration throughout the stopping interval. Kentucky has conducted similar tests more recently.

Of the three methods of tests described, the method most widely used at the present time is probably that of the towed trailer. As previously stated, Moyer[3] is believed to have used the first two-wheel towed trailer similar to those in present use in the early 1930's. There is a report[14] that at about the same time the City of St. Louis used similar apparatus for evaluating street surfaces with respect to slipperiness. Shortly thereafter a skid trailer was constructed and used in Ohio.[15] In 1939 the Oregon State Highway Department[16] reported on construction and use of a two-wheel trailer in which only the left wheel was braked. Also in 1939 a report[17] was published of towed trailer tests conducted by the B. F. Goodrich Company.

By 1949 Moyer[7] had constructed a towed trailer in California which was widely used and is still believed to be in use. In 1951 the Tennessee

Highway Research Program commenced construction of a trailer which has been in continual use, with some subsequent revisions, since early 1952.[18, 19]

A marked increase in interest in towed trailer testing of pavement slipperiness occurred in the late 1950's and has continued to the present time. The General Motors Proving Ground designed and built a trailer in 1957.[20] At the same time an essentially identical trailer was built by the Michigan State Highway Department.[21] At about the same time the Cornell Aeronautical Research Laboratory undertook development of a skid trailer for the Portland Cement Association.[22] This trailer has been in use since 1958. Essentially identical trailers were subsequently built by the New York Department of Highways and the U.S. Bureau of Public Roads. The Bureau had previously made use of a one-wheel trailer.

A second increase in interest in this field has occurred within the past two years. During recent months trailers containing some of the attributes of the General Motors, PCA, or Tennessee trailers have been built by Virginia, Maryland, Florida, New Jersey and Louisiana. A trailer has recently been constructed by the Ford Motor Company and the trailer of the General Motors Proving Ground has been completely redesigned. Several tire manufacturing companies are known to be operating skid trailers.

RECOMMENDATIONS FOR HIGHWAY DEPARTMENT EQUIPMENT

The Federal Highway Safety Act of 1966 requires that after a given date all departments of highways will be required to conduct a continuing inventory of the skid resistance of their pavement surfaces. To date no definition has been given of what will constitute such an inventory, not even of what is meant by continuing. This poses a great many problems.

As perhaps a minimum inventory one might assume that one skid test at one speed every ten miles along the highway system might be considered adequate. At the other extreme, it is possible that the inventory should consist of the development of a curve of coefficient of friction versus speed for at least one location within every contract section of pavement surface within the state. To be considered a "continuing" inventory, testing might have to be repeated once a year. Perhaps some longer interval of time between tests would be considered satisfactory. In any event, it is obvious that even with the loosest interpretation of a "continuing inventory," the highway departments will be faced with the necessity for conducting a program of skid testing far more comprehensive than any known to date.

It is the opinion of the writer that the only feasible approach to this problem is through the use of towed trailers. The use of such equipment will minimize water problems, minimize crew requirements, minimize interference with traffic, and maximize the amount of testing which may be accomplished within a given period of time.

Within the group of trailers presently in use, a wide variety of options are available to one who is faced with the necessity for making decisions about a new trailer. The following comments represent the writer's recommendations to a highway department which undertakes acquisition of a trailer for survey rather than research purposes.

The trailer itself should be mechanically as simple as possible. It should be so designed as to require a minimum of maintenance. It should be so designed that the truck driver, if he has minimal automotive repair skills, may be expected to take care of most emergencies which might arise on the road.

A number of approaches to strain measurement are available. One should be selected which gives a reading indicative of the torque on the sliding wheel or wheels. The strain measuring unit should be simple, preferably precalibrated, and so located that it may easily be changed on the road should failure in the unit occur.

The trailer should be equipped with wheels to carry a 7.50 x 14 tire in order that ASTM standard skid test tires may be used. It is recommended that only one wheel be locked during testing. This provides a very stable operation, permitting skids even on curves, and reduces tire wear. Particular care must be taken to provide a braking system adequate to provide rapid lock-up of the test wheel in the repeated skids which will be required of the apparatus. Some recent experiences with electric brakes have not been altogether satisfactory. Perhaps this matter can be rectified. A system of air over hydraulic is known to have worked well for a number of years.

The electronic system for detecting, amplifying, and recording strain measurements should also be as simple as possible. Advantage should be taken of plug-in units where available, in order that spare units may be carried with the vehicle and substituted in the event of equipment difficulties.

A wide variety of opinion exists at the present time as to the towing vehicle. These have ranged from station wagons to 2½-ton trucks. It is recommended that for survey purposes the largest practical truck, within the limitations of available power, be employed. This will permit ample room for instrumentation and crew and for carrying the largest possible amount of water. The Tennessee Highway Research Program makes use of a 2½-ton International truck with a six-man cab. A bucket seat is provided for the driver. The instrument console is positioned where the right front seat would normally be located. The operator sits on the right side of the rear seat to operate the controls. This makes the remainder of the rear compartment available for luggage. This truck carries a 500-gallon water supply. It is believed that for continual testing purposes any smaller supply will prove to be inadequate. Upon some occasions when a great deal of testing was being undertaken it has been necessary to refill the 500-gallon tank as many as five times during a day's work.

A two-man crew is recommended for operations of this nature. It is certainly not difficult to instrument the towing vehicle in such a way that a single individual can drive the truck and operate the test controls. This does however put a considerable burden on that individual, as he must watch out for other traffic, get his vehicle properly positioned for the test, attain and maintain the specified test speed, and operate the controls for testing. It has also been the experience in Tennessee that on many occasions on the road circumstances will essentially require the presence of two individuals.

SUMMARY

Although investigations of pavement slipperiness, and measurement of such slipperiness, have been in progress in the United States for many years it is only during the recent past that a considerable amount of attention has been given to it. It seems certain that activities in this field will multiply many fold within the next two years. Those coming into the field in the near future will find a considerable amount of past experience available as a guide to their efforts.

Several sizeable skid correlation studies have been held in the United States, the most recent in Florida in November, 1967. Although these studies have invariably shown that those with new trailers and only partially trained crews experienced some difficulties, they have also shown that those with experienced crews and well tested equipment could correlate their results quite well. Some aspects of such testing have been standardized (tires, wheel load, etc.). Many important operational features of the test equipment itself have not been standardized.

Those now coming or soon to come into the field are urged to first give serious consideration to what they desire and expect from such testing equipment and then to carefully review the available information on existing equipment in order that they may profit from the experience which has been obtained through many years of testing of this nature.

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