REPORT OF COMMITTEE ON ANTISKID PROPERTIES OF ROAD SURFACES

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APPARATUS FOR DETERMINING SKID RESISTANCE OF PAVEMENTS

SYNOPSIS

Two general types of apparatus have been used in the measurement of the slipperiness of pavements—trailers and single wheels attached at an angle to the propelling vehicle Description of types of apparatus includes that used by Moyer at Iowa, Stinson and Roberts in Ohio, the Ministry of Transport in England, and Boutteville, Bouly and the Syndicat S.F E R B in France Danger spots in a road system can be readily detected by routine testing of highways for the determination of the coefficient of friction between the tires and road The trailer type of testing apparatus possesses several advantages for this work Either the longitudinal coefficient or the sideways force coefficient is a satisfactory determinant It is pointed out that tires used should be smooth and kept inflated to a uniform pressure, that tests should be run at the highest practical speed—certainly not less than 30 m p h and that the pavement should be wet Tests of surface types are not sufficient, each individual section of road requires investigation Although no tests have been run over the same piece of road by the various kinds of testing apparatus, a comparison of results indicates a fairly close check

Slippery pavements still continue to take their toll of the motorist Present practice on the part of highway officials is to wait until several accidents occur on a stretch of road and then do something about it Routine regular testing of the road surfaces for their skid-resistant properties would make it possible to correct dangerous conditions before life and limb are sacrificed in determining that they are dangerous The City of St Louis has taken the lead in work of this sort The St Louis officials are using an apparatus similar to that developed by Professor Moyer Other responsible highway officials could profitably follow the St Louis procedure and test their road surfaces for skid resistance

Two general methods of measurement of skid-resistance have been used One a laboratory, and the other a field method The laboratory method has the advantage that the various factors can be controlled, but it cannot be applied to existing road surfaces New road surfaces tested under laboratory conditions do not always give the same results as when tested in the field Laboratory tests of a pavement type may be quite accurate, but tests of various examples of a type as built may give greater variation in results than tests of different pavement types The real question is whether a particular stretch of road is dangerously slippery or not Laboratory tests of types are of value but do not necessarily give this information The laboratory method of investigation is valuable as a research tool, but cannot be depended upon as a source of information for locating dangerous road conditions

In operating a motor car on the road, three forms of skidding may be encountered They are—(1) skidding straight ahead with the wheels locked with the brakes, (2) skidding straight ahead as the brakes are applied and the wheels are at the point of locking and sliding, and (3) skidding sideways on a curve without the use of brakes In practice, most skidding accidents are a combination of (1) or (2) with (3) This sideways skid will often occur on a straightaway as well as a curve

Machines have been devised which will measure the coefficient of friction between the tires and the road surface under these three conditions However, (2) is very hard to control, and most investigators have confined their efforts to the measurement of (1) or (3) or both

Two investigations have been carried on in the United States, one by Moyer in Iowa, and one by Stinson and Roberts in Ohio Both were reported at the 1933 and 1934 meetings of the Highway Research Board Trailers were used in both investigations

Two general types of apparatus have been used for measurement of the slipperiness of pavements—trailers and single wheels attached at an angle to the propelling vehicle The trailer type of testing apparatus seems to have some advantages in that its action is similar to that of automobiles and automobile tires may be used on it The apparatus can be used to measure the direct longitudinal coefficient or the sideways force coefficient The towing vehicle may carry a water tank so that the road can be sprinkled at the time of the test

The single wheel attached to the propelling vehicle is generally used only for measuring the sideways force coefficient This apparatus has a longer record of use than any of the others since it was developed for the Ministry of Transport in England, where more work of this kind has been done than in any other part of the world

The sideways force coefficient would seem to be the most simple form of comparison for routine testing of road surfaces The difficulties of braking action are eliminated, and only three factors need to be recorded, namely speed, wheel load, and sideways force The coefficient is the direct relation between the wheel load and the sideways force

A brief description of the commonly used types of apparatus will now be given

APPARATUS USED BY MOYER, IOWA STATE COLLEGE

This apparatus has been fully described in Vol 13, Proceedings, Highway Research Board and in Bulletin No 120 of Iowa State College from which the following has been abstracted

"The trailer was so constructed that it could be used interchangeably for the three forms of skidding Provision was made to vary the total load on the trailer from 630 to 1,630 pounds However, as a result of a study of the effect of variations in the weight of the trailer on the coefficient of friction and because of the ease of operation of the trailer using a light load, a standard gross load of 830 pounds was adopted With this load, it was possible to run tests satisfactorily and safely at speeds from 3 to 40 miles per hour

"For sprinkling the surfaces and to provide the power necessary to run tests at high speeds, a Graham truck, 2½ ton capacity, was equipped to tow the trailer The surface was sprinkled directly in front of the test trailer during each test Whenever the occasion presented itself, tests were run during and following rains

"To measure the skidding forces in the line of travel, the trailer was connected directly behind the towing truck (Figs 1 and 3) The tongue of the trailer was supported in a rocker arm maintained in a vertical position during the tests to eliminate the possibility of transmitting the horizontal pulling force from the truck to the trailer in any way except through the dynamometer The trailer was equipped with self-energizing mechanical brakes which were operated manually by means of a long brake lever conveniently located near the observer's seat on the truck Provision was made for a quick and easy method of adjusting the brakes and no difficulty was experienced in locking the wheels However, when first running tests for impending skidding, it was found that uniform braking distribution could not be maintained between the two wheels because of the inequality in the braking force on each wheel and partly because of the difference in the line of motion of the towing truck The 15-degree angle was selected on the basis of angle variation tests in which it was found that the coefficient reached a maximum value at an angle of about 12 degrees and remained constant for angles of inclination up to 30 degrees, the

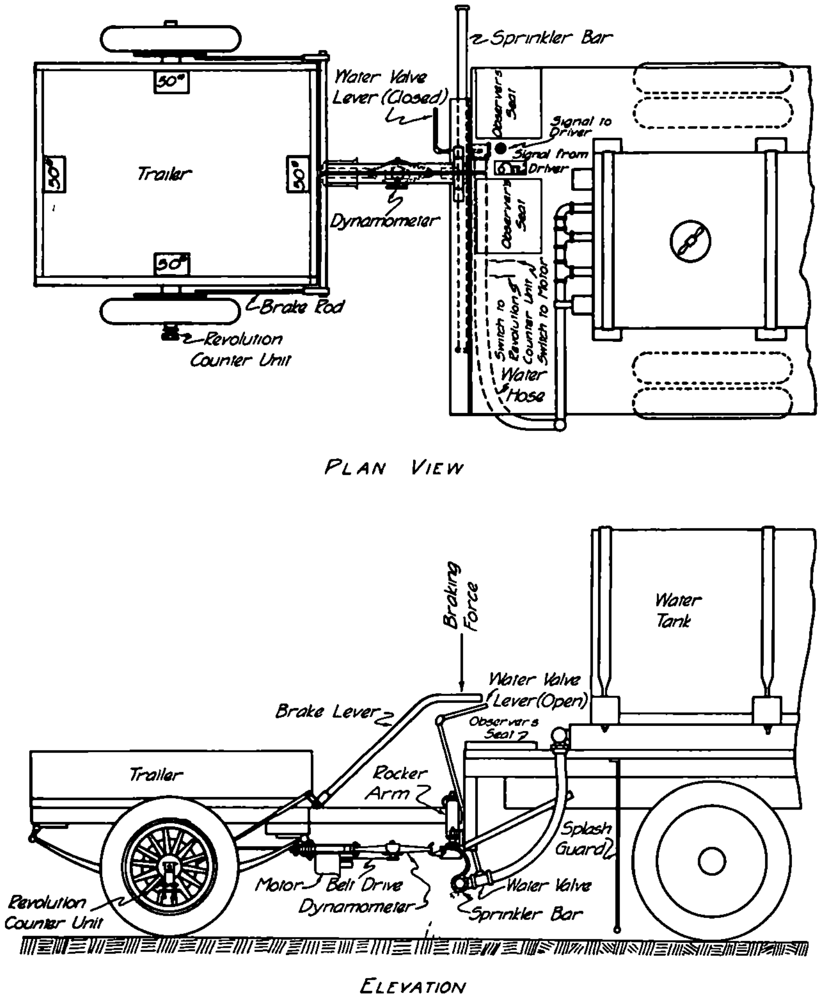

Figure 1 Arrangement of Test Equipment for Determining the Coefficient of Friction of Tires on Road Surfaces when Skidding Straight Ahead

the tire treads and road surface conditions To obviate this difficulty, the gears in the differential housing were cut square and a locking device inserted forming, in effect, a single axle

"In measuring the side skid forces, the trailer was connected to the towing truck in a position (Fig 2) such that the longitudinal axis of the trailer made an angle of about 15 degrees with the maximum angle at which tests were run The integrating dynamometer was connected in line with the axle of the trailer and measured the force which caused the wheels to skid sideways As the towing truck moved forward, the trailer tended to swing into the direction of travel of the tow truck, thus simulating the action of a car skidding on a curve

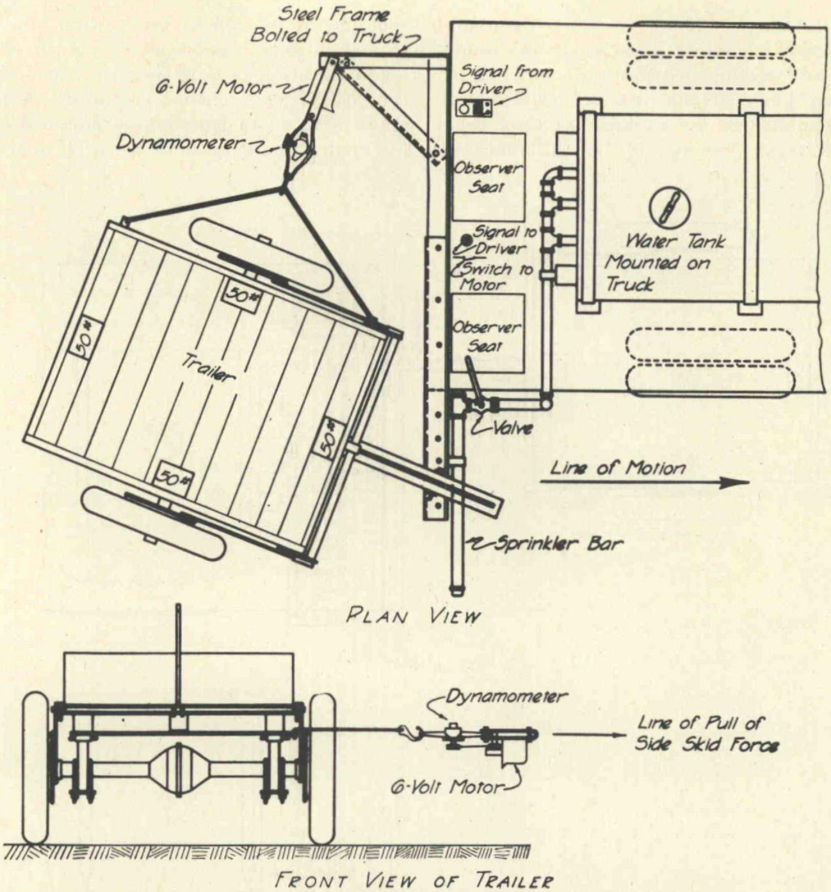

Figure 2. Arrangement of Test Equipment for Determining the Coefficient of Friction of Tires on Road Surfaces when Skidding Sideways

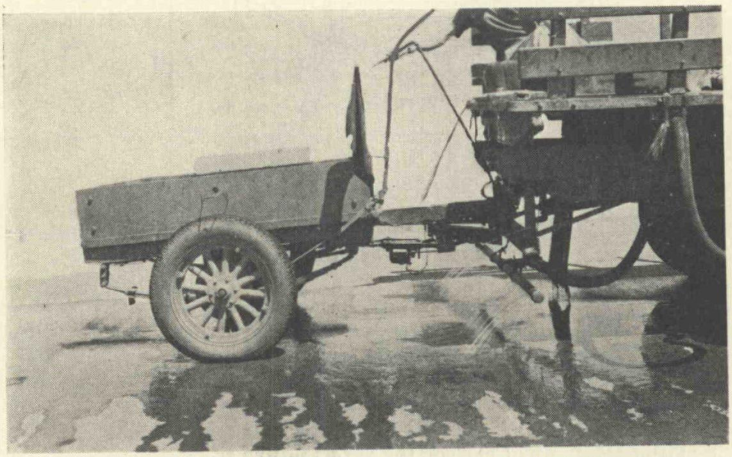

Figure 3. Equipment for Straight Skid Tests with Sprinkler in Operation

"The most important piece of equipment developed in this investigation was the integrating dynamometer (Fig. 4). Considerations governing its design were that: (1) The dynamometer should be simple and rugged in construction, capable of withstanding considerable abuse, and easy to attach to the trailer and tow car; (2) the human equation in reading or measuring the forces should be eliminated; (3) it should measure accurately to within 10 pounds forces ranging from 100 to 2,000 pounds; (4) the forces should be measured directly to eliminate the possibility of lag or the setting up of inertia forces in any part of the dynamometer; (5) it should be possible to calibrate the dynamometer under conditions of loading similar to that obtained during field tests; and (6) frequent field checks of the calibration should be easily made.

"In the search for a dynamometer meeting these requirements, preliminary testing was carried out with several dynamometers. The Kohlbusch dynamometer with maximum indicating hand measured only the maximum skidding force and this accurately only to the nearest 25 pounds. Calibrations of the Kohlbusch dynamometer spring with a Federal dial mounted in the frame indicated that an accuracy within 5 pounds could be obtained. Tests with a heavy duty integrating traction dynamometer developed by the Agricultural Engineering Department of Iowa State College indicated that there was considerable lag in the spiral spring and the levers of the recording and integrating mechanism. However, it was recognized that a dynamometer meeting all the requirements set forth could be made by mounting on the Kohlbusch dynamometer spring an integrating device of the same general type used in the traction dynamometer.

"The integrating device (Fig. 4) designed for this purpose consisted of a rotating fiber disk and two revolution counters. The fiber disk was mounted at a fixed distance from one side of the dynamometer spring. The inside revolution counters were geared to the disk and recorded its revolutions to the nearest tenth of a revolution. The disk was rotated at a constant speed by a motor drive. Another revolution counter, which served as the force-distance integrator, was fastened to the other side of the dynamometer spring and recorded the revolutions of a small steel wheel driven by friction on the fiber disk. When pull was applied to the dynamometer, the steel wheel moved toward the center of the disk, and turned with fewer revolutions in proportion to the number of revolutions made by the fiber disk. The quotient obtained by dividing the number of revolutions of the disk by the number of revolutions

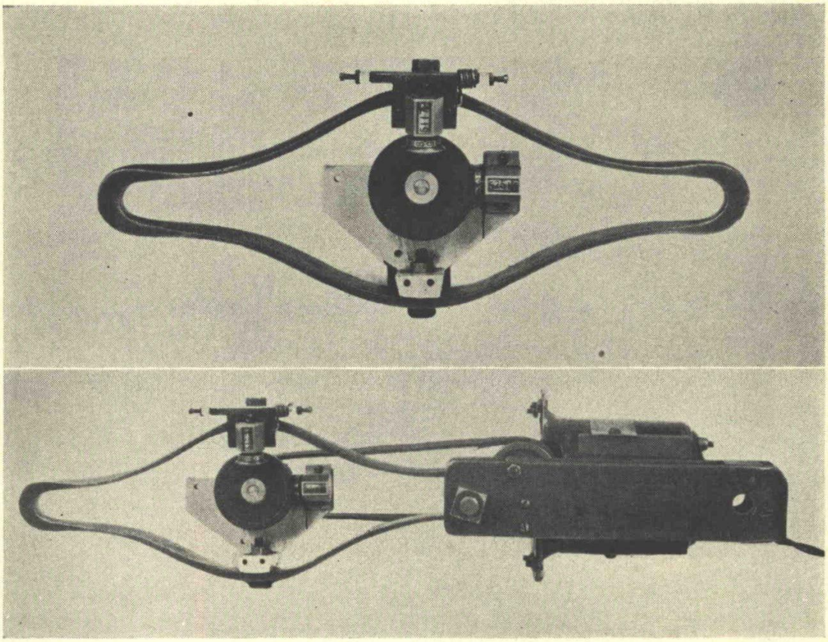

Figure 4. Integrating Dynamometer and Dynamometer with Motor Drive

of the steel wheel was a measure of the pull transmitted by the dynamometer.

"A useful field check on the calibration of the dynamometer was obtained by checking the quotient for zero pull after each series of tests and as frequently as six times a day. Slightly roughening the edges of the steel wheel kept it from slipping on the disk. The field calibration for zero load served as a means for detecting slippage at this point. Laboratory calibrations were made at least once every two weeks during the period when tests were run. The remarkable consistency of calibration and field results indicate the ruggedness and dependability of the dynamometer.

"Although it is desirable to know the maximum and minimum skidding forces, the most satisfactory basis for comparing the skidding characteristics of road surfaces is on the basis of the average coefficients of friction. In tests by Agg the vibrations set up in the trailer during the tests were generally responsible for fairly large variations in the magnitude of the skidding forces. The average pull measured by the integrating dynamometer eliminated, for all practical purposes, the effect of these vibrations."

APPARATUS USED BY STINSON AND ROBERTS, OHIO STATE UNIVERSITY

This apparatus has been fully described in Vol. 13, Proceedings of the Highway Research Board from which the following has been abstracted and brought up to date by Professor Stinson:

"The apparatus consisted of: a trailer (Figs. 5 and 6), a hydraulic dynamometer (Fig. 7), a recording and controlling mechanism (Fig. 8), and a towing car.

"The trailer was made from the rear end of an automobile chassis and carries a conventional load for the tires used. Only the left wheel of the trailer is equipped with a brake. This eliminates the need of equalization and permits the determination of both rolling and sliding coefficients of friction in the line of travel. The draw bar is attached in line with

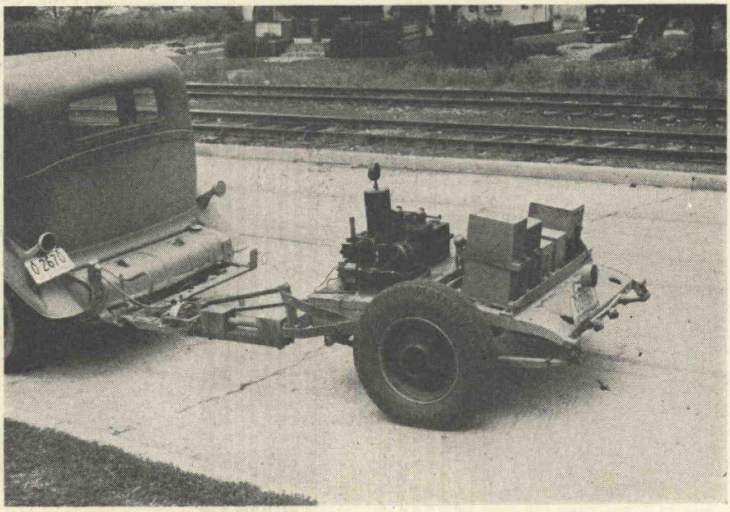

Figure 5. Test Car and Trailer

the left wheel so as to obtain a direct pull on the test wheel. When the trailer is coupled to the towing car, the trailer wheels are offset about eight inches from those of the towing car, so that the test wheel does not follow the track of the towing car. A hydraulic brake was used on the wheel and was operated by a constant oil pressure maintained in a tank on the trailer. The brake was applied and released by electrical control from the towing car.

"The test wheel operates a centrifugal slide indicator which gives a record, through a solenoid, of the instant the wheel is locked.

"The hydraulic dynamometer is mounted on the trailer draw bar and connects with the rear of the towing car. The dynamometer consists of two units—the dynamometer diaphragm and plunger, and the roller-bearing support. The rubber diaphragm has an active area of approximately ten square inches. The dynamometer liquid is a 50 per cent mixture of glycerine and alcohol. The roller bearing support for the dynamometer cylinder fits around the trailer draw bar shaft.

"The diaphragm type dynamometer has been installed recently in place of a two-inch cylinder and lapped piston. This has eliminated the possibility of any sticking or leakage, and the performance is much more consistent.

"The recording and controlling mechanism is mounted in the rear of the towing car. The brake is controlled through electric switches and a solenoid which operates the adjustable brake valve. The recording mechanism consists of an electrically operated recording drum over which sensitized paper is passed at approximately two inches per second and is rerolled after leaving the drum. Two records are made on this paper, the unit pressure in the hydraulic dynamometer, which is recorded by a conventional engine indicator unit, and the instant of sliding, which is recorded by a separate stylus operated by the slide indicator on the test wheel shaft. A base line is drawn by a third stylus for use in analyzing the record."

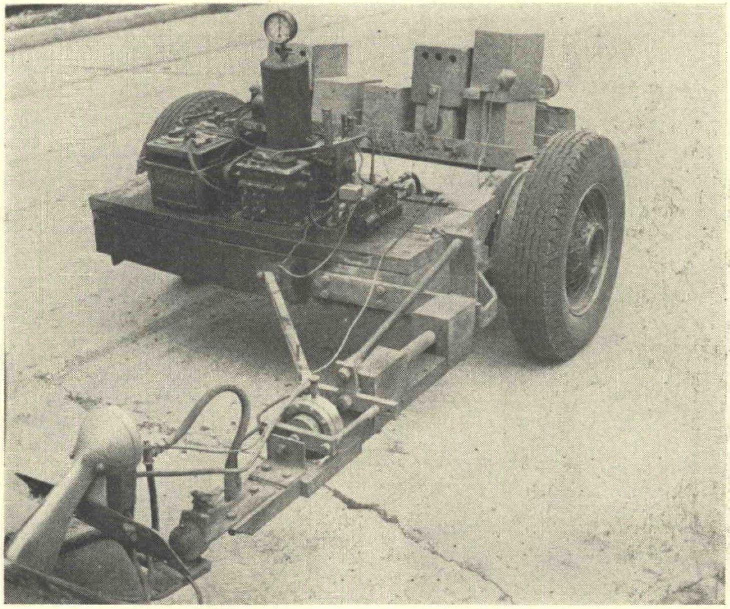

Figure 6. Trailer

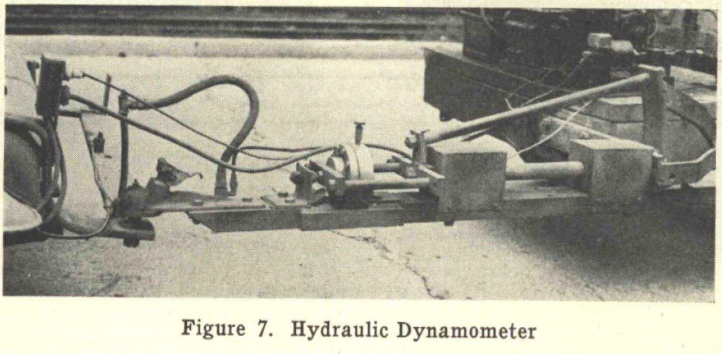

Figure 7. Hydraulic Dynamometer

Side Skid Apparatus: A description of apparatus for measuring side skid friction is given by Professor Stinson as follows:

"During the past winter, we have constructed a new trailer with which we are able to measure the side skid coefficient of friction. I am enclosing some photographs (Figs. 9, 10, and 11)

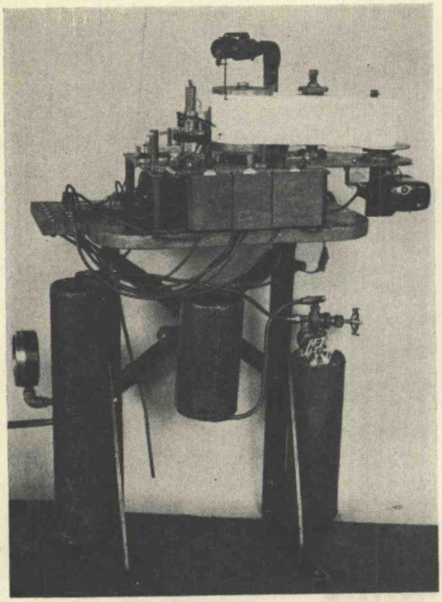

Figure 8. Recording Mechanism

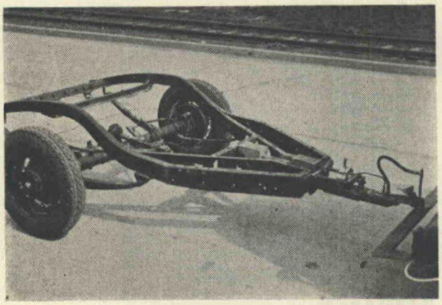

Figure 9. Trailer

of the equipment which were taken before the load was mounted. A normal tire load is placed on the frame while testing. The trailer is connected to the towing car through the hydraulic dynamometer used in our previous testing work. Both wheels are swivelled to the axle and can be turned to point toward each other in order to create a side skid action. These wheels are turned while in motion by a conventional starting motor to the desired angle. With the same recording mechanism that we have used in our other work, we can first record the tare force of drawing the trailer with the wheels parallel, and then can turn the wheels to the desired angle and take a record of the force required to overcome the skidding of the wheels.

"This apparatus has been used for comparative tests of several tires and road surfaces using normal tire loads and inflation pressures, although none of the results have as yet been published. The results are much more consis-

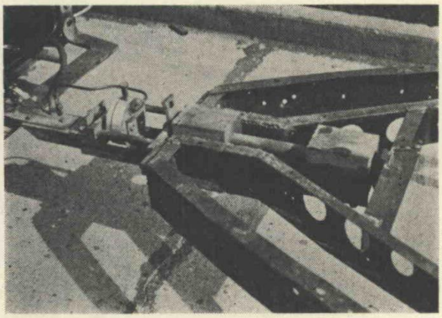

Figure 10. Hydraulic Dynamometer

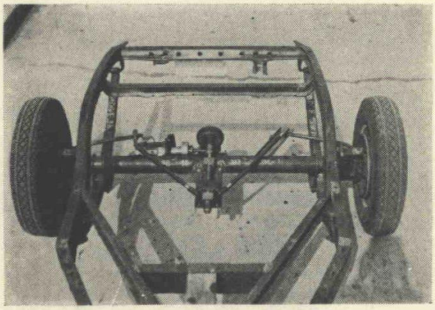

Figure 11. Device for Turning Wheels

tent than those obtained with the straight skid apparatus and can be made much quicker. Tests can be made with any angle of tow-in up to 15 degrees. The critical angle of modern tires carrying normal load is between 7 and 8 degrees. Any angle greater than this is satisfactory for test, and angles from 9 to 12 degrees have been used. Angles of 12 degrees or more have been found unsatisfactory due to (a) the abnormal scuffing of the tires even under short tests on wet surfaces, and (b) the great amount of power required to maintain uniform speed, particularly at high speed.

"All testing, either straight or side skid, is done with practically new stock tires. Consistent results can be obtained for 1,000 tests in straight skid with most tires, while in side skid they are used until the edges are well rounded over "The rolling or impending coefficient of a smooth tire is from 10 to 40 per cent less than a corresponding stock tire, and the variation on two roads will be much less, making comparative tests more difficult Smooth tires, unless free of all non-skid on the edges, will give variable results depending upon the amount of non skid present, and are going to be critical to small variations of tire pressure We feel that it is inadvisable to attempt to make comparisons of road surfaces with anything other than a comparatively new standard tire

"The side skid coefficients have been found to be about 30 per cent higher than the straight rolling coefficients on the same surface at speeds of 20 m p h and over This is thought to be due to the slow rate of relative sliding, and makes the values approach those of slow speed sliding"

APPARATUS USED BY THE MINISTRY OF TRANSPORT IN ENGLAND

This apparatus is fully described in Road Research Bulletin No 1 of the Department of Scientific and Industrial Research and Ministry of Transport, from which the following is abstracted

The apparatus at present in use consists of a motorcycle and sidecar, of which the sidecar wheel is mounted in a separate frame pivoted from the main chassis about a vertical axis, thus forming a castor arrangement as shown diagrammatically in Figure 12

"When testing a road surface, the motorcycle is driven along the road with the wheel fixed at an angle to the direction of motion, and both the normal force tending to restore it, and the load on the wheel, are measured The more slippery the road surface, the less is the force tending to push the wheel back into line The method of comparing the frictional properties of road surfaces therefore resolves itself into a comparison of the sideway restoring forces It is not this force alone, however, but the ratio of sideway force to the load on the wheel which has been selected as being the most suitable quantity for the comparison The resistance to slipping in a direction at right angles to the plane of the wheel is measured by this ratio, which is analogous to that generally known as the 'coefficient of friction,' but is called the 'sideway force coefficient' to denote its special nature

"Although the present design of machine is not perfect in all details, and while perhaps a motorcycle and sidecar will not necessarily remain the best form of instrument, the description of the machine now in use provides information regarding a satisfactory testing machine, with five years of practical experience behind it

Choice of Sidecar Wheel Angle "The sideway force coefficient is independent of the angle at which the sidecar wheel is set, provided the latter exceeds a certain critical value which depends upon tire characteristics

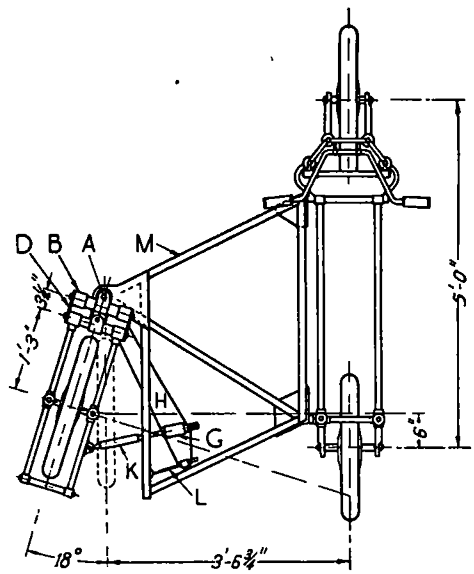

Figure 12 Diagrammatic Plan of Motor-Cycle and Sidecar Used by Ministry of Transport, England

"It was found from preliminary experiments that for comparative measurements on road surfaces, this angle should be 20° or more Actually an angle of 18° has been adopted throughout, as it was found that any increase in this value made the machine somewhat difficult to handle, and it was not considered expedient on the grounds of general safety to exceed it This compromise, however, only affects the highest values of the coefficient, and as these are the least interesting from the point of view of skidding, the small reduction from their true values is of no significance

Tyres "Since the machine is used to compare road surfaces, the tyre tread on the test wheel has to be of standard form It has been found that the usual tread patterns affect the results according to the amount of wear, and tyres with smooth treads are therefore used. These could not be obtained commercially, and a compromise was eventually found possible in the use of tyres of standard manufacture with the tread ground smooth. The form of tread is best shown on the left-hand wheel seen in Figure 14. Such tyres have been used for all routine skidding tests with satisfactory results; their only disadvantage being their short life due to the small amount of rubber on the tread. A sidecar tyre lasts, on the average, for about 30 miles of testing on wet surfaces, or

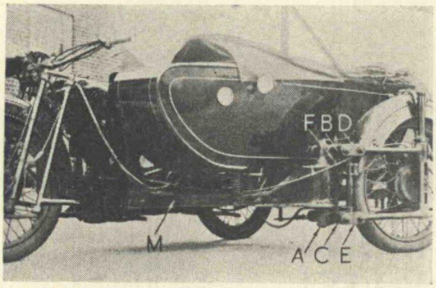

Figure 13. Motor-Cycle and Sidecar, Ministry of Transport, England

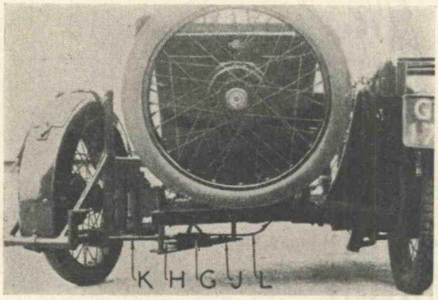

Figure 14. Motor-Cycle and Sidecar, Ministry of Transport, England

12 to 15 miles on dry surfaces. Wear when running normally as an ordinary motorcycle and sidecar is negligible by comparison. The inflation pressure adopted as standard was 50 pounds per square inch. The tyres used have so far been of the beaded-edge type, size 26 inches by 3 inches, fitted with security bolts. Arrangements have now been made with a tyre manufacturer for the production and supply of special wired tyres of the above size with a completely smooth tread of normal thickness to give increased life. A tyre with a smooth tread gives coefficients which are lower than would be obtained with tyres having treads in good condition. Since, however, tyres are often used until they are smooth, the results indicate the coefficients which are effective under the most disadvantageous conditions as regards tyre equipment in use on roads.

Disposition of Wheels: "The relation between wheel track, wheel base, and forward position of the sidecar wheel should be substantially as shown in Fig. 12.

Wheel Load: "When testing, the wheel loads of the machine now in use are approximately as follows: Front, 440 pounds; rear, 700 pounds; sidecar, 360 pounds. (These loads are for sidecar wheel in its testing position and with the driver in the saddle and the observer on the pillion.)

"It is apparent that the method of use described imposes a severe and complex loading upon the chassis of the machine. A chassis of usual design is insufficiently rigid to withstand this loading, and unless attention is paid to this point, severe oscillation of the machine is apt to arise, and chassis members are liable to break.

Sidecar Wheel Mounting: "The construction of the wheel mounting is best shown in Figures 13 and 14. It is free to pivot about the vertical spindle A, carried on the main chassis; at the top and bottom of the vertical spindle are horizontal lugs B and C, to which are pivoted links D and E supporting the sidecar framework. The load on the wheel is supported by the dynamometer F, consisting of a plunger $\frac{7}{8}$ inches in diameter working in a cylinder and transmitting the load by oil pressure to the recording apparatus. Similarly, the sideway force acting on the wheel when the machine is travelling forward with the wheel swung out, as shown in Figure 12, is measured by a second dynamometer of the same size, G (Fig. 14). The sideway force dynamometer G is carried on a plate H attached to the sidecar wheel pivot, the plate being supported by a second plate J bracketed to the main chassis. The sideway thrust on the sidecar wheel is transmitted to the dynamometer by a strut bar K, and the reaction on the dynamometer is taken by a Bowden cable L attached at its other end to a lever mounted between the motorcycle and sidecar which allows the angle of inclination of the wheel to be adjusted. The lever is provided with a trip which can be released from the handlebars of the machine in case of emergency. It has never been found necessary to use this safety device, but it is thought advisable to have it available.

Dynamometers and Recording Apparatus: "The variations in oil pressure, due to variations in load and sideway force while the machine is in operation, are transmitted through flexible metallic pressure tubing from the dynamometers to recording plungers, $\frac{1}{4}$ inches in diameter, controlled by springs which have a rate of about 45 pounds per inch. They extend as the oil pressure is increased, and this extension is recorded by mechanism described later. The complete apparatus is shown at N, Figure 15. The sideway force coefficient obtained from these spring extensions is continuously recorded on a paper roll, $8\frac{3}{4}$ inches wide, driven by clockwork. Synchronously, (a) time in $\frac{1}{2}$ seconds, (b) revolutions of the front wheel, and (c) signals as required by the observer, such as when passing from one type of surface to another, are recorded on the same roll by electromagnets supplied with current from the 6-volt lighting battery.

"Since, in order to obtain the least possible frictional lag, no packing of any sort is permissible between the dynamometer and recording plungers and their cylinders, great care is required in their manufacture in order to ensure free movement without loss of oil. The plungers are of mild steel, case-hardened, carefully annealed to remove internal strains before final hardening, grinding, and polishing to make their bearing surfaces parallel, and truly circular to give a maximum clearance of 0.001 inches and a minimum clearance of 0.0005 inches. Three shallow oil grooves are provided on the plungers. The cylinders are of phosphor bronze machined to the above limits.

"Since a small amount of oil leakage is necessary, the losses are made good by means of an oil gun having a screwed connection to lubricating nipples; these are isolated from the flexible pipe by means of a cock, which is opened only when charging the system with oil. A small, screw-down needle-valve is connected in each pipe to the recording plungers for the purpose of adjusting the damping according to the viscosity of the oil. By this means, large and sudden variations in the recorded pressure are smoothed out, while the comparatively slow changes due to variations in the surface are recorded.

"As already stated, it is the ratio of sideway force/load, called the sideway force coefficient, which is taken as the quantity by means of which the frictional properties of the road surface are compared. For convenience in evaluating records, the recording mechanism is designed to combine the two measurements of sideway force and load, so as to record the sideway force coefficient direct on the chart.

"The construction of this mechanism is shown in Figure 16. The oil pipe from the load dynamometer is connected at A, and the load measured by the extension of spring C; similarly the sideway force dynamometer is connected at B, and the force measured by spring D. The end of the load-measuring spring is connected through a link to E, which slides in guides F: similarly the end of the spring for measuring the sideway force is connected to part G. Part E is forked and G slides within it, being guided by slots in the same guides F. Parts E and G are arranged to slide in directions at right-angles to each other, and each is provided with a slot cut at right-angles to its direction of travel. Pin H passes through both slots where

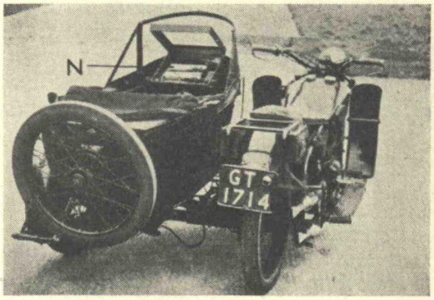

Figure 15. Motor-Cycle and Sidecar, Ministry of Transport, England

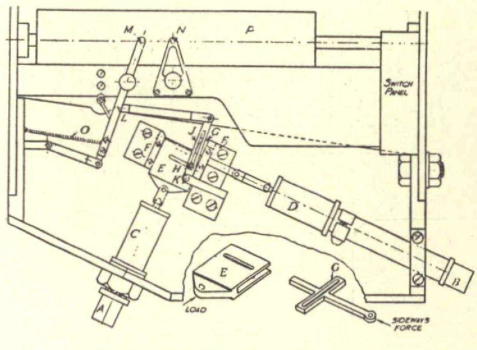

Figure 16. Coefficient Recorder, Ministry of Transport, England

their centre-lines intersect, and through a third slot in forked link J, pivoted at K.

"Link J is attached to the pen arm L carrying the pen M, by means of a straight-line linkage. A light spring O serves to take up the slack, while N is the fixed datum pen, and P is the drum over which the recording paper passes.

"It will therefore be seen that the displacement of M follows the angular movement of link J, which is in turn determined by the displacements of H in two directions at right angles, one proportional to the load, and the other to the sideway force Provided K coincides with the position of H for zero load and zero sideway force, a simple geometrical analysis shows that the displacement of the end of link J (and therefore also of the pen M) de-

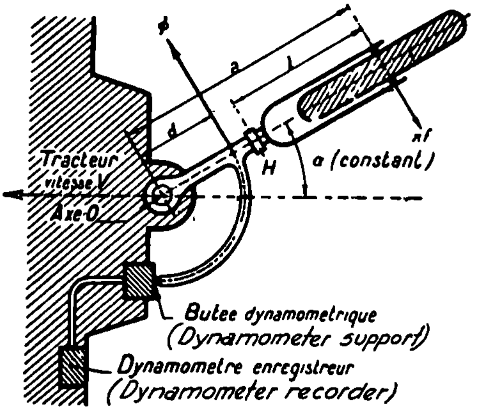

Figure 17 Diagram of the Boutteville Apparatus

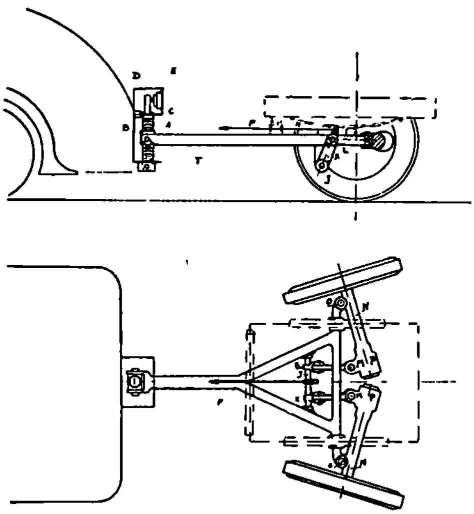

Figure 18 Diagram of the Bouly Apparatus

pends upon the ratio sideway force load or sideway force coefficient

"For a value of coefficient of l, pen M moves to the extreme left, and, provided the loads per unit extension of the springs C and D are approximately the same, as they should be, link J takes up a position at 45° to the axes through K parallel to those of E and G"

APPARATUS USED BY BOUTTEVILLE IN FRANCE

This and the succeeding two types of apparatus are fully described in La Glissance Des Routes Et Sa Mesure published by the Syndicat Des Fabricants D'Emulsions Routieres De Bitume in Paris, France, from which the brief descriptions have been adapted

This apparatus is of the single wheel trailer type set at an angle to the line of travel The illustration, Figure 17, shows its construction

APPARATUS USED BY BOULY IN FRANCE

This apparatus is of the trailer type with two wheels set at an angle to the direction of travel Figure 18 shows an outline of the arrangement of the apparatus

STRADOGRAPHE DEVELOPED BY THE SYNDICAT S F E R B IN FRANCE

This apparatus is of the trailer type with two wheels set at an angle to the line of travel Figure 19 shows the arrangement of the apparatus

OPERATION OF SKID TESTING APPARATUS

Tires Tread design of tires has a definite effect on the test results Tires with non-skid treads wear down during the testing period and give varying results Some investigators correct this difficulty by using new tires and discarding them as soon as they become worn, while others use a special type of smooth tread tire

Condition of Surface Tests of dry surfaces are of little value Almost any pavement which has no loose material on its surface is skidsafe when dry

During a rain is the best time for testing

English results as reported in Road Research Technical Paper No 1 for tests on a concrete surface at 20 miles per hour are as follows:

	Coefficient
Road dry	0.85
Rain just starting	0.71
Surface first wet	0.49
Raining heavily	0.55–0.61
Road drying	0.51–0.61–0.76–0.85

The road may be sprinkled at the time of testing and a wet surface artificially produced. The coefficient obtained on a surface of this sort will be somewhat less than that for the same surface during a hard rain. This is not objectionable, since the worst conditions are being looked for.

English investigations indicate that about two and one-half Imperial gallons of water per square yard is needed properly to wet the road surface. This is three U. S. gallons. Professor Stinson comments as follows:

"When tests are made on wet surfaces with either trailer, it is always during a hard rain or with the test road continuously flushed and sprinkled by a street flusher. A strip of road surface approximately ¼ mile in length, where possible, is selected for test. It has been found that the condition of the surface is variable during the initial wetting. As a result, it has been found necessary to wash the surface several times in the spring and sometimes in the autumn, even half a day in order to get uniform conditions. This requires from 10,000 to 20,000 gallons of water per day. Our experience has led us to believe that it is practically impossible to obtain results of value by simply wetting the road ahead of the test tire."

Seasonal Effect: Road Research Technical Paper No. 1 states that there is a distinct drop in the value of the coefficients recorded during the summer months over those obtained during the winter months in England. Professor Stinson reports:

"For four years we have tested one section of a portland cement concrete road each April and September. Two conclusions have been that the coefficient of friction (a) decreases from year to year, and (b) is less in the autumn than in the spring. The later agrees with tests made in England, but we find that if the road is flushed for several hours, a large part of this decrease is eliminated."

Speed: Results obtained at low speeds are of little value. All investigators agree that the coefficients decrease as the speed increases. It would seem, therefore, that the testing apparatus should be operated

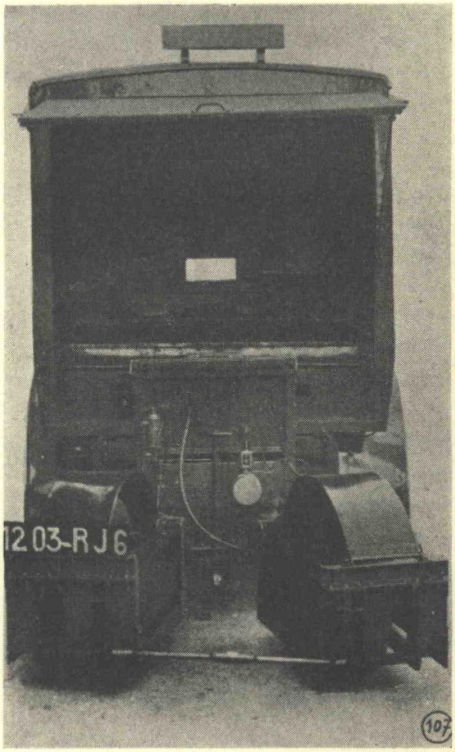

Figure 19. The Stradographe of the S.F.R.B. Syndicate Ready for Use (the Transverse Shock Absorber Has Been Placed in the Rear).

at as high a rate of speed as possible. This will probably be from 30 to 40 miles per hour.

CONCLUSIONS

Danger spots in a road system can be readily detected by the routine testing of highways for the determination of the coefficient of friction between the tires and the road.

The trailer type of testing apparatus possesses several advantages for this work.

Several satisfactory pieces of apparatus have been designed and tested sufficiently to insure satisfactory results

Either the longitudinal coefficient or the sideways force coefficient is satisfactory for the determination of the relative slipperiness of road surfaces

No check tests have ever been run over the same piece of road by the various kinds of testing apparatus However, a comparison of published results seems to show a fairly close check

Tests of types are not sufficient Each individual section of road must be tested

Tires used should be of uniform tread design and composition, and should be kept inflated to a uniform pressure

Tests should be run at the highest practicable speed, certainly not less than thirty miles per hour

Pavements should be tested when wet

Bird and Scott, in Road Research Bulletin No 1, speaking of conditions in England, say the following concerning the sideways force coefficient

"Values of 0 5 or more at 30 m p.h may be regarded as safe, whilst a value of 0.2 or less indicates a surface needing alteration According to conditions of traffic and location, values between these limits may be safe or dangerous"

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DISCUSSION ON MEASUREMENT OF SKID RESISTANCE

MR J H SWANBERG, *Minnesota Highway Department* It is apparent that skid resistance cannot be definitely correlated with type of surface The tests seem to confirm the conclusion that the surface types can be grouped only in a general way with respect to skidding coefficients Apparently any given section of road is dependent more upon the job control of the proportions and the ingredients than on the general type

Assuming the validity of the above conclusion, one can appreciate the need for established methods and apparatus for the making of friction tests on road surfaces If sideway skidding can be used for the basis of comparison, the problem of apparatus will be simplified, since it requires lighter and less complicated equipment and therefore greater mileage can be covered at less cost

Some argument has been presented that a driven wheel would give a different brake action than a non-powered wheel Would it be possible to have a driven wheel arrangement in addition to sideway adjustment, and would such an arrangement be practicable?

From the statements made concerning the results of wetting the road surface in the English investigation and in the comments of Professor Stinson, there would appear to be some question concerning the effect of sprinkling the surface immediately ahead of the test trailer as was done in the Iowa experiments We all know that a road surface at the beginning of a light rain is usually more slippery than after it has been rained upon for some time This is probably due to the presence of dust, which upon being wetted becomes slippery but is subsequently washed off

Has any work been done to show the probable errors of test results in order to arrive at the number of tests which should be made to yield a reliable average? Because of the small range of variation in skid coefficients, it would appear that a large number of test determinations should be made

It was shown by Moyer in his report "Skidding Characteristics of Road Surfaces" at the 13th Annual Meeting of the Highway Research Board that the majority of cars are not able to take advantage of available braking resistance when the coefficient is above a certain value, therefore it would appear that there should be an optimum skidding coefficient beyond which it would not be desirable to go because of the greatly increased tractive resistance and high tire wear

If a simple apparatus can be designed so that a large number of Highway Departments could avail themselves of the equipment, a comprehensive cooperative research project could be undertaken Such a research project would appear to be very desirable Any skid resistance policy will certainly have an effect on many industries in the highway field and highway engineers should have comprehensive data to justify any changes in highway surfacing types from the standpoint of skid resistance

MR GEORGE E MARTIN, *The Barrett Company* The Committee did not feel that it was in position to design a specific piece of apparatus as suggested by Mr Swanberg but did feel that several types of apparatus were available and that there was no reason why individual organizations should not go ahead with the routine testing of existing pavements

It would, of course, be desirable from a research standpoint to have all of the pieces of apparatus the same, but it is not necessary to wait for that before starting to collect test data From our experience with engineering organizations in the past, we doubt that it would be possible to get any great number to adopt one specific type or piece of apparatus

I agree with Mr Swanberg that a skidding coefficient which is too high may increase tire wear and be objectionable from that standpoint, but I do not believe that it would increase tractive resistance