COEFFICIENT OF FRICTION BETWEEN TIRES AND ROAD SURFACES

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SYNOPSIS

Tests to determine the "Coefficient of Friction between Automobile Tires and Road Surfaces" were made using a two-wheel trailer connected to a towing car through a hydraulic dynamometer All runs were made during rainfall, the test speeds were maintained throughout the application of the brake, and data were obtained to determine the rolling and sliding coefficients of friction Smooth and nonskid tires were used and tests were made on portland cement concrete, brick and bituminous road surfaces at speeds of five to forty-five miles per hour

Two important trends shown by these tests are That the coefficients of friction on all road surfaces decrease with increase of speed, and that the difference between the rolling and sliding coefficients increases with increase of speed These relations are very significant from the standpoint of safety

In these tests the straight ahead sliding coefficients of friction between nonskid tread tires and the various wet road surfaces tested at thirty miles per hour ranged as follows Bituminous concrete 0 54 and 0 42, sheet asphalt 0 41, portland cement concrete 0 41, vertical fiber wire cut brick whitewashed before application of filler 0 52, vertical fiber wire cut brick partially covered with asphalt 0 23, repressed brick tar filler (none above surface of brick) 0 35, repressed brick partially covered with asphalt filler 0 24 The results quoted apply only to the specific surfaces tested and should not be assumed to be typical of all surfaces in the various classes

One of the main factors influencing safety in highway transportation is the ability of vehicles to stop. Many cities and states have codes specifying stopping distances that must be met In 1930 a project was undertaken by the Engineering Experiment Station of Ohio State University in conjunction with local police and automobile club officials to determine the minimum stopping distance of automobiles and trucks. These tests showed that if the brakes are properly adjusted, the car will stop well within the allowable limit, and that the stopping distance of any car is dependent upon the type and condition of the road surface as well as the condition and pressure of the tires After these conclusions had been reached, a second project was begun for the purpose of studying these variations with the hope of obtaining some information that would aid in decreasing highway hazards

Preliminary tests of the coefficient of friction between tires and road surfaces were made for an undergraduate thesis at the Ohio State

University by R G Kilgore and H N Veley in 1932 A Buick sedan was towed by a truck through a hydraulic dynamometer and the increase in tractive effort was measured when the brake was applied on one rear wheel as the car was towed along at a uniform speed The brake was applied gradually, and when the tire slid the brake was released Due to the limited power and speed of the truck, tests were made only at five and ten miles per hour The results of these tests showed the need of more extensive work on the subject, with equipment that could be operated at much higher speeds

SCOPE OF INVESTIGATION

The coefficient of friction between a tire and a road surface at any instant is dependent upon many variables, such as

(1) Road surface
  a type
  b construction
  c condition (oily, wet, dry)
(2) Speed of operation
(3) Tires
  a. tread design
  b smooth vs good nonskid surface
  c air pressure
  d contact area
  e material

The determination of the effects of all of these variables presents a rather extensive program This paper presents the results to date on a very small part of this outline, namely, the effects on coefficient of friction of different types of wet road surfaces and smooth and nonskid tires Some testing has been done on dry roads, but since wet roads present the real traffic hazard, the comparisons here have been limited to them Tests are in progress on the effects of different tread designs and air pressures, but sufficient data are not available for presentation at this time

The present program has been under way since June, 1932, as a project of the Ohio Engineering Experiment Station, with the assistance of R G. Kilgore, who was granted a two-year Robinson Fellowship on the basis of his undergraduate thesis. The scope of the work has been limited because of insufficient personnel, practically no financial assistance, due to a radical reduction in the University budget, and lack of rain at times when testing could be done It is still hoped that much future work may be carried out with portable and stationary sprinkling systems

APPARATUS

The apparatus consisted of: a trailer, a hydraulic dynamometer, a recording and controlling mechanism 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

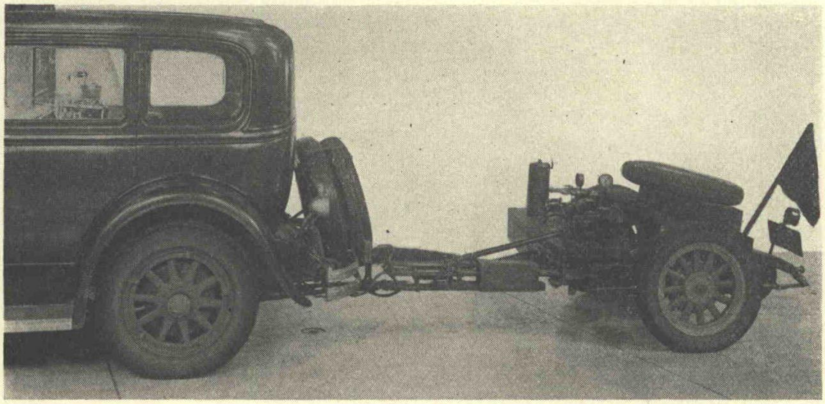

Figure 1. Test Car and Trailer

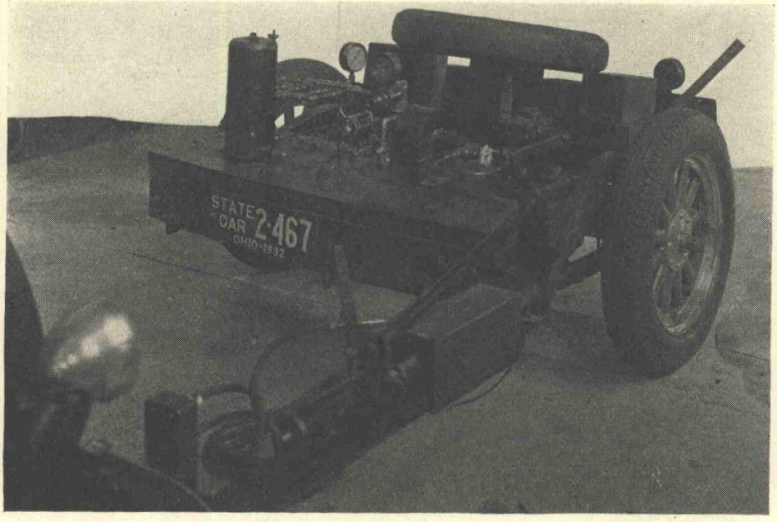

Figure 2. Trailer

line with 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. The original hydraulic brake was used on the wheel and was operated by an air booster

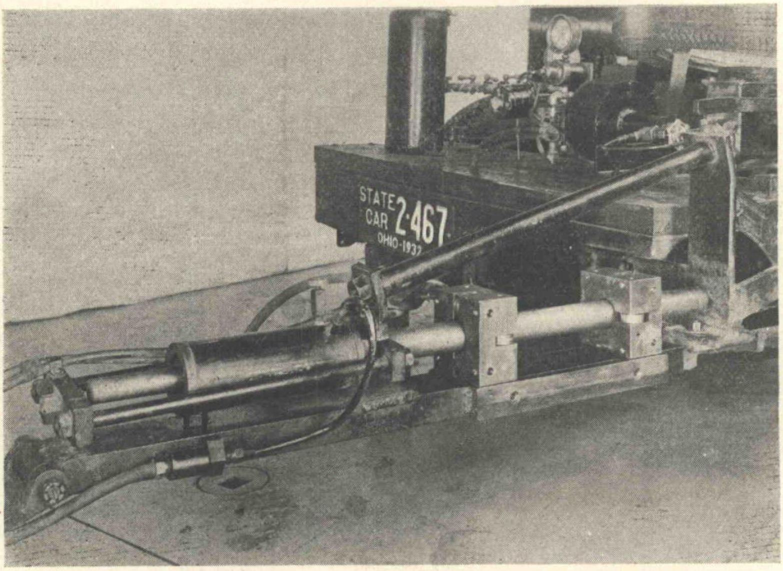

Figure 3. Hydraulic Dynamometer

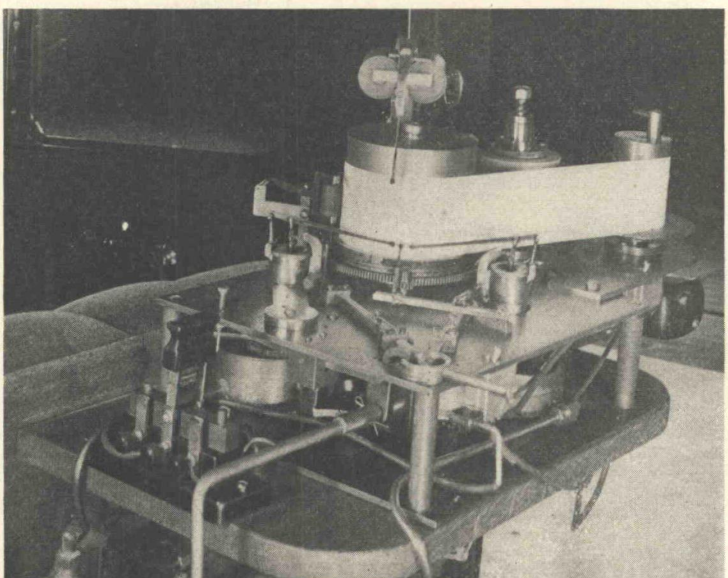

Figure 4. Recording Mechanism

cylinder supplied from a tank at the rear of the trailer. The brake was applied and released by electrical control from the towing car.

Because of the small brake area and the elaborate mechanism required to operate the hydraulic brake, the trailer was recently equipped with a Warner electric brake having direct electric control from the towing car

A six-point cam was mounted on the shaft of the test wheel This cam operated an electric contact every one-sixth revolution of the wheel and produced a record of the initial point of slide.

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 cylinder and piston, and the roller-

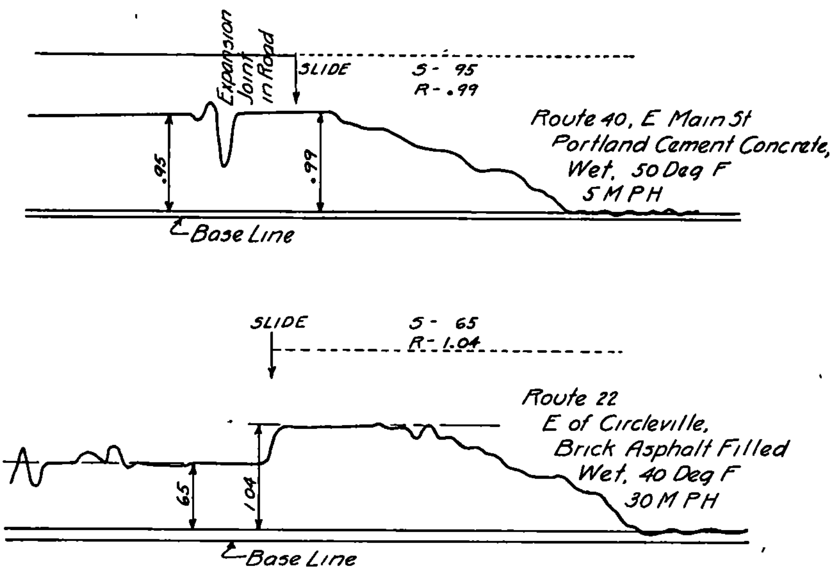

Figure 5. Sample Charts

bearing support The cylinder is bored to a two inch diameter and lapped to fit the piston, no packing or piston rings being used 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 recording and controlling mechanism is mounted in the rear of the towing car The brake is controlled through electric switches The recording mechanism consists of a spring-driven phonograph motor which carries the recording drum Sensitized paper is passed over the drum at approximately two inches per second and is re-rolled after leaving the drum Two records are made on this drum—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 electric breaker points on the test wheel shaft A base line is drawn by a third stylus for use in analyzing the record

METHOD OF TEST

All tests were made during appreciable rainfall, after the dust had been washed from the road surface No tests were made during the initial sprinkling due to the great variation possible, although this condition is known to be the most slippery obtainable The brake mechanism was adjusted to require about two seconds for complete application and the resulting sliding of the tire The air pressure in the test tire was maintained at 32 pounds per square inch unless otherwise specified

The towing car is driven at the desired test speed When speed and road conditions are satisfactory, a signal is given and the operator throws the switch which controls the application of the brake, while the driver regulates the engine throttle to maintain a constant speed As soon as the test tire slides the operator releases the brake With a little practice it is quite easy to maintain a uniform speed during the test At least ten tests are made for each speed in a series, the average of these being taken as the result

The test of any road surface was made with the fundamental idea of obtaining results representing the average condition of the surface The readings were taken while driving continuously over several miles of road when available, no attempt being made to test any small section of surface The road surfaces tested were in most cases practically new and no variation in results could be noted when testing in or out of the traffic lanes

CALCULATION OF RESULTS

The initial tractive effort is indicated on the sample charts shown, (Figure 5) as the distance above the base line at the right end of the record This line is extended parallel to the base line The distance above this line to the maximum height of the curve before sliding is a relative measure of the rolling coefficient of friction while the average height of a two inch section of the curve beyond the point of sliding is taken as the measure of the sliding coefficient This average height is determined from the planimetered area The accompanying calibration curve shows the oil pressure and tractive effort for the movement of the recording stylus When the net height of the curve is obtained from the test chart, the net tractive effort can then be found from the calibration curve The coefficient of friction $= \frac{T E}{W - 0 2 T E.}$ where W is the dead load on the test wheel In this case it was 801 pounds A net height on the chart of one inch represented a tractive effort of 504 pounds and $\frac{504}{801 - 0 2 \times 504} = 72$

DESCRIPTIONS OF ROADS TESTED

T-50-D-16 East Broad Street in Bexley This is a petroleum asphalt road surface on a concrete base It was completed in October, 1933. The surface of 1¼ inches sheet asphalt (Type D, Ohio State Highway Specifications 1933) was built of materials conforming to the following specifications

Sand

Passing a No 4 sieve	100%
Passing a No 4 sieve, retained on a No 8 sieve	0–5%
Passing a No 8 sieve, retained on a No 40 sieve	12–40%
Passing a No 40 sieve, retained on a No 80 sieve	25–60%
Passing a No 80 sieve, retained on a No 200 sieve	25–45%
Passing a No 200 sieve	0–5%

Bituminous Material

Specific gravity 25°C / 25°C , not less than	1 01
Flash point, not less than	200°C
Penetration at 25°C , 100g —5 sec	50 to 60
Ductility at 25°C , not less than	50 cm
Loss at 163°C 50 g —5 hours, not over	1%
Penetration of residue at 25°C , not less than % of original	60%
Total bitumen (sol in CS_2) not less than	99 5%

No cement was scattered on the machine-finished surface

T-5-40 Hebron to Jacksontown on U S 40 This portland cement concrete road was resurfaced with medium texture hot-mixed, hot-laid bituminous concrete (Ohio State Highway Specification T-5, Type B 1932) The composition of the mixture by weight was as follows

Passing screen or sieve	Retained on screen or sieve	Per cent		
		Minimum	Ideal	Maximum
¾ Inch	½ Inch	0	0	5
½ Inch	¼ Inch	41	48	55
¼ Inch	No 10	0	5	10
No 10	No 20	8	12	15
No 20	No 50	12	16	20
No 50	No 100	2	9	13
No 100		0	3	5
Total stone content retained on No 10 sieve				45 to 55%
Bitumen		6 5		8 5

The road was completed in November, 1932

T-6-22 U S Route 22, east of Circleville This is a cold-mixed, cold-laid bituminous concrete road which was completed in the autumn of 1932 (Ohio State Highway Specification T-6 Type B, 1932) The composition of the surface course was as follows:

Stone Size	No 6
Coarse Aggregate	67 0 to 89 5 per cent
Fine Aggregate	5 0 to 25 0 per cent
Liquefier	0 0 to 1 5 per cent
Bitumen	5 0 to 8 0 per cent

BA-40. East Main Street in Columbus and east of Bexley This surface consists of a three-inch, wire-cut vertical-fiber lug brick filled and covered with type F-1 asphalt (Ohio State Highway Specification Type F-1) The road was completed in November, 1931 Sand was placed on the asphalt during the summer of 1932

BA-23 North High Street, Columbus, between Arcadia and Oakland Park Avenues on U. S Route 23 This street was constructed of three-inch repressed brick filled and approximately 25 per cent covered with asphalt. The paving was completed about 1926

BA-22 East city limits of Circleville on U S Route 22 Three-inch vertical-fiber wire-cut lug bricks with asphalt filler (Ohio State Highway Specification Type F-1) were used for the surface The surface of the bricks was white-washed before pouring the filler so as to permit removal of the excess

BO-23 Between Worthington and Columbus on U S Route 23 This road was constructed about 1920 and consisted of a repressed brick with a grout filler The filler has broken out so that it is about one-half inch below the surface of the bricks. The edges of brick are badly chipped

BO-OP. Oakland Park Avenue, Columbus, between High Street and Indianola Avenue. On this street repressed brick with tar filler gives a surface similar to BO-23 due to the fact that the filler has gone down However, the edges of the brick are not broken so as to give a rounded surface on each brick

C-40. U. S Route 40, east from the Columbus city limits This 50-foot portland cement concrete road between Columbus and Reynoldsburg was completed in December, 1930 Crushed gravel aggregate was used in a 1:5.5 mix The surface was machine finished.

DISCUSSION OF RESULTS

A typical range in results is shown in Figure 6, for tests of rolling and sliding friction of a nonskid tread design tire on a bituminous concrete surface The shaded areas show the limits of variation The occasional tests that depart widely from such range limits can generally be traced to a radical change in road surface or other test conditions

Several sets of tests have been made on some of the test roads to see if the results could be duplicated and also to observe the variation of the coefficient of friction with age The only changes noted in the tests so far are shown in Figures 11 and 12 between curves BA-22-32

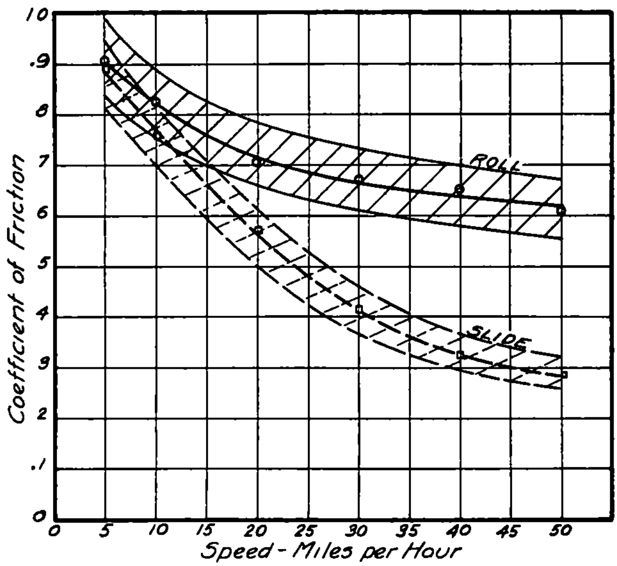

Figure 6. Friction Range of Tire HT (Non-skid) on Portland Cement Concrete Resurfaced with Bituminous Concrete, Type T5, February 7, 1933.

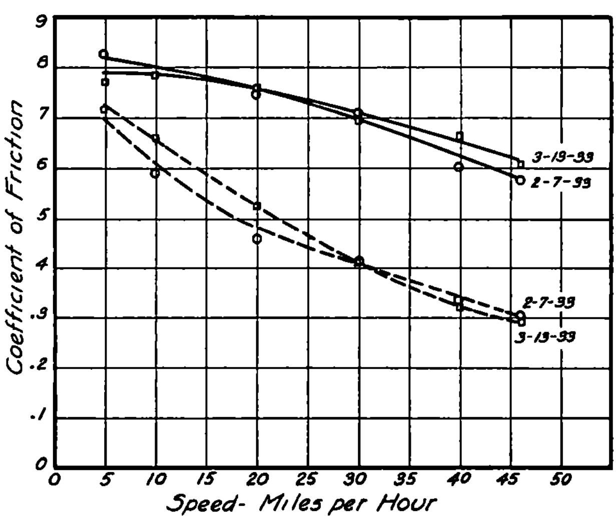

Figure 7. Comparison of Tests on Portland Cement Concrete (C 40), Non-skid Tire HT, February 7 and March 13, 1933.

and BA-22-33 which show the effects of summer bleeding of asphalt. Figure 7 shows the agreement obtained on two series of tests made on C-40 about one month apart.

The difference in coefficient of friction between smooth and nonskid tires was investigated A few tests have been made using two

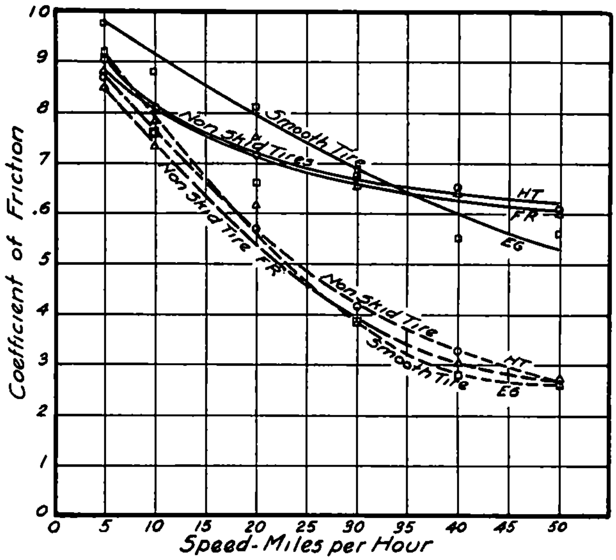

Figure 8 Rolling and Sliding Friction Variation on Bituminous Concrete Surface T-5-40. March 3, 1933. Solid Lines, Rolling, Dash Lines, Sliding

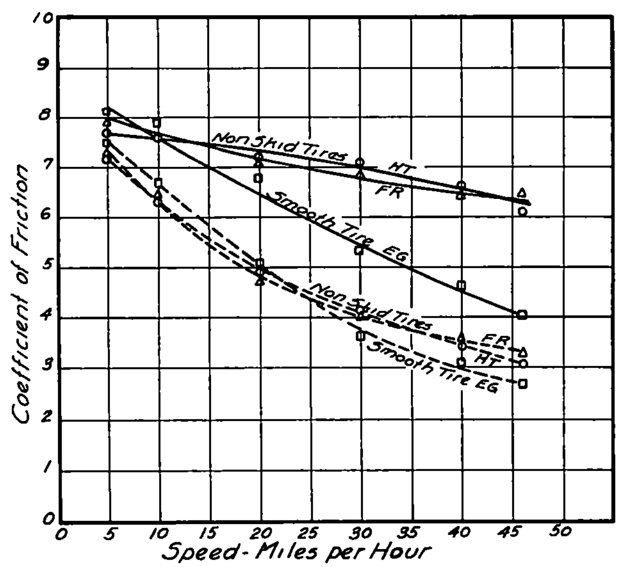

Figure 9. Rolling and Sliding Friction Variation on Portland Cement Concrete Surface, C-40. March 13, 1933. Solid Lines, Rolling, Dash Lines, Sliding.

designs of nonskid tread and a smooth tire The nonskid tread design tires (HT and FR in the figures) have a design consisting of three ribs.

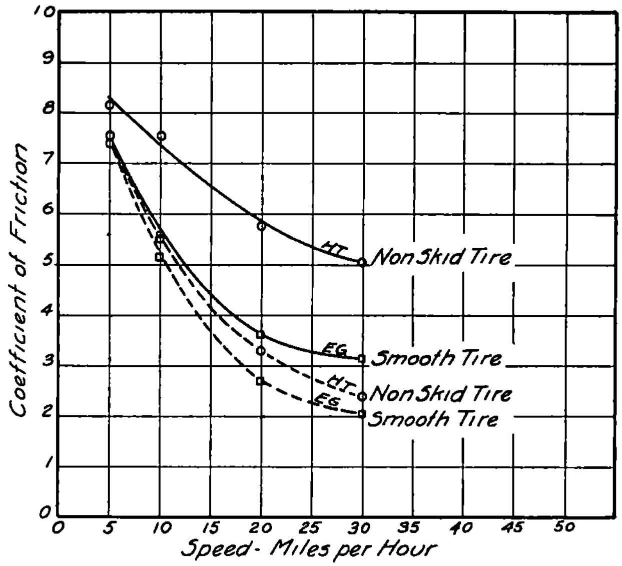

Figure 10 Rolling and Sliding Friction Variation on a Repressed Brick Surface, Filled and Approximately 25 Per Cent Covered with Asphalt. March 13, 1933. Solid Lines, Rolling, Dash Lines, Sliding

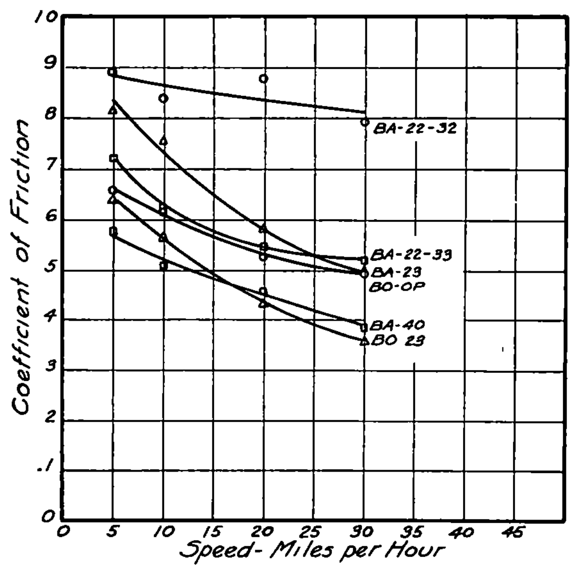

Figure 11. Rolling Friction on Brick Pavements With Non-Skid Tread Tire HT, November 25, 1933.

BA-22. Vertical Fiber, Wire Cut Lug Brick. Excess Asphalt Filler Removed.

BA-23. Repressed Brick, Approximately 25 Per Cent Covered with Asphalt Filler.

BA-40. Vertical Fiber, Wire Cut Lug Brick, Covered with Asphalt Filler, Sanded.

BO-OP. Repressed Brick, Tar Filler.

BO-23. Repressed Brick, Grout Filled, Grout Below Surface.

The center rib has nonskid patterns on each side while the outer ribs have nonskid patterns on the outer edges only. On tire HT the non-skid edges are normal and parallel to the direction of travel, while on the FR tire the edges are at a 45 degree angle Tire EG is worn to an abnormally smooth tread The results are shown in Figures 8, 9, and 10.

The rolling coefficient of friction does not vary radically on the T-5-40 bituminous concrete road, but on the C-40 portland cement concrete and the BA-23 asphalt-filled brick roads there is a decided decrease

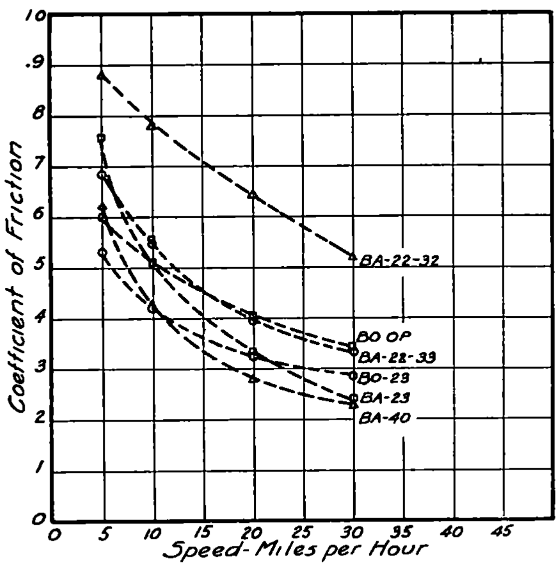

Figure 12. Sliding Friction on Brick Pavements, with Non-Skid Tread Tire HT, November 25, 1933.

BA-22. Vertical Fiber, Wire Cut Lug Brick. Excess Asphalt Filler Removed

BA-23. Repressed Brick, Approximately 25 Per Cent Covered with Asphalt Filler.

BA-40. Vertical Fiber, Wire Cut Lug Brick, Covered with Asphalt Filler, Sanded.

BO-OP Repressed Brick, Tar Filler.

BO-23. Repressed Brick, Grout Filled, Grout Below Surface.

when using the smooth-tread tire "EG" This might be due to the more open structure of the road surface The sliding coefficient of friction is more nearly the same for all tires, the variation at high speeds being in favor of the nonskid tires on all three roads

Figures 11 and 12 show the rolling and sliding coefficients of friction found on several brick road surfaces The variation between a vertical-fiber brick road, BA-22-32, free of asphalt filler, and a repressed brick road, BO-OP, here termed "open," as no filler was visible, is shown by comparing the curves for these two roads The repressed brick has rolling and sliding coefficients of friction at thirty miles per hour which are about 61 and 65 per cent respectively of those obtained for the vertical-fiber brick

During the summer of 1933 the asphalt filler bled from the joints on road BA-22 and covered in some places as much as 50 per cent of the road surface. The results of the tests on the original road are shown in curves BA-22-32 while the results of a series of tests on the same road made in October, 1933, are shown in curves BA-22-33 During the summer the rolling and sliding coefficients of friction at thirty miles

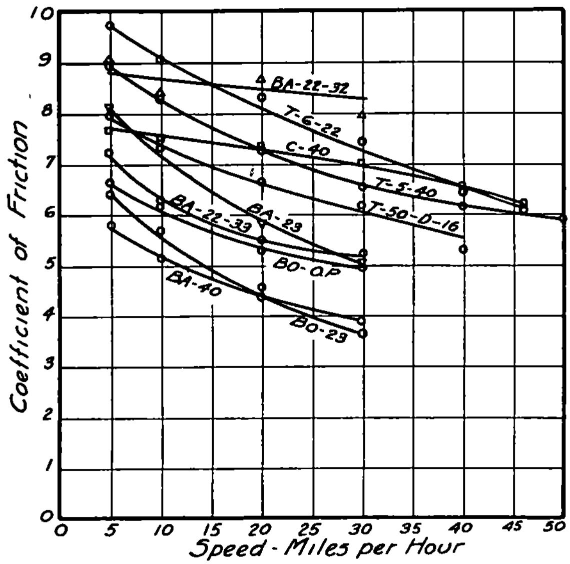

Figure 13. Rolling Friction Variation, with Non-Skid Tread Tire HT, November 25, 1933

BA-22 Vertical Fiber, Wire Cut Lug Brick. Excess Asphalt Filler Removed

BA-23. Repressed Brick Approximately 25 Per Cent Covered with Asphalt Filler.

BA-40. Vertical Fiber, Wire Cut Lug Brick, Covered with Asphalt Filler, Sanded.

BO-OP. Repressed Brick, Tar Filler.

BO-23. Repressed Brick, Grout Filler, Grout Below Surface.

C-40. Portland Cement Concrete.

T-5-40 Bituminous Concrete.

T-6-22. Cold Mix, Cold Laid Bituminous Concrete.

T-50-D-16. Sheet Asphalt

per hour decreased to about 64 and 62 per cent respectively, of the original values

Another vertical-fiber brick road, BA-40, was flooded with asphalt filler and the filler not removed, but heated and sprinkled with sand which was then rolled into the asphalt

The nonskid quality of the vertical-fiber brick was completely lost and the road can be seen to have a much smaller coefficient of friction, both rolling and sliding, than either BA-22-32 or BA-22-33.

The curves for roads BO-OP and BO-23 show comparative results on a good open repressed brick road and one that was 13 years old and very badly chipped The good road, BO-OP, has much larger coefficients at all speeds

A comparison of the curves for roads BA-23 and BO-OP will show the variations of the coefficients of friction between repressed brick road surfaces (a) when using asphalt filler with the surface fairly free of asphalt—not over 25 per cent covered (BA-23) and (b) when the

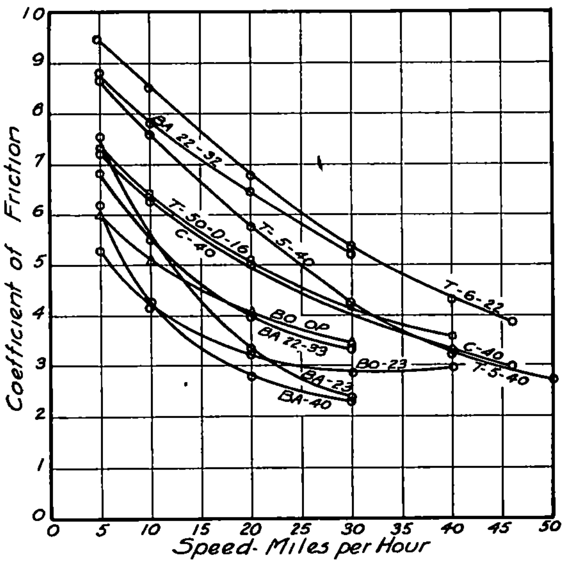

Figure 14 Sliding Friction Variation with Non-Skid Tread Tire H T, March 13, 1933

BA-22. Vertical Fiber, Wire Cut Lug Brick Excess Asphalt Filler Removed.

BA-23 Repressed Brick Approximately 25 Per Cent Covered with Asphalt Filler.

BA-40. Vertical Fiber, Wire Cut Lug Brick, Covered with Asphalt Filler, Sanded.

BO-OP Repressed Brick, Tar Filler.

BO-23. Repressed Brick, Grout Filler, Grout Below Surface.

C-40. Portland Cement Concrete.

T-5-40. Bituminous Concrete.

T-6-22. Cold Mix, Cold Laid Bituminous Concrete

T-50-D-16. Sheet Asphalt.

joints are open (BO-OP) The values for the rolling coefficient are better at low speeds for BA-23 but at 30 miles per hour both roads have the same value, while the sliding coefficient is much better for BO-OP above 15 miles per hour

The three bituminous-concrete road surfaces tested show a variation of rolling coefficient of friction in Figure 13 and this difference is in favor of the open types of surface in the order of T-6-22, T-5-40, and T-50-D-16 The surfaces of the T-5-40 and T-6-22 roads have about the same degree of roughness and open structure Portland-cement concrete, C-40, curve shows much less slope, at low speeds having the same value as T-50-D-16 while at 40 miles per hour and over it is at least equal to T-6-22

On Figure 14 the sliding coefficient of friction curves for T-5-40 and T-6-22 roads are seen to be parallel but favorable to T-6-22 T-50-D-16 has a lower sliding coefficient at low speeds than either of these but as the speed increases the slope of the curve is much less This is also true of the portland-cement concrete road, C-40, the curve being practically identical with the T-50-D-16 curve, both curves being at least equal to the T-5-40 beyond 40 miles per hour This might be due to the greater uniformity of the T-50-D-16 and C-40 surfaces

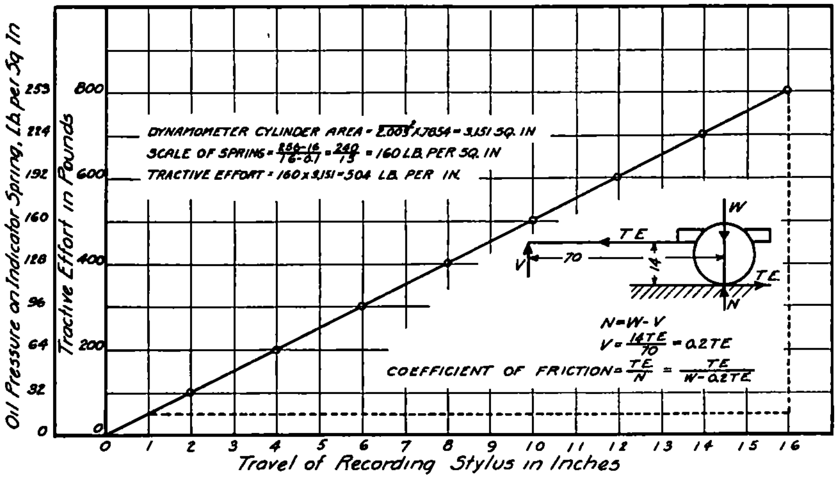

Figure 15. Calibration of Dynamometer Pressure Recording Mechanism October 26, 1932.

A comparison of portland-cement concrete, C-40, and sheet asphalt, T-50-D-16 can be seen on Figures 13 and 14 The rolling coefficients of friction are about the same at low speeds, but at higher speeds the C-40 maintains higher values The sliding coefficients are very interesting as they are practically identical up to 30 miles per hour when there is a slight advantage for the T-50-D-16

The rolling and sliding coefficient of friction curves for new vertical-fiber brick road surface BA-22-32 are well above those just mentioned for C-40 and T-50-D-16 However, after the bleeding of the asphalt, the curves BA-22-33 are seen to be some distance below the portland-cement concrete and sheet asphalt curves

From the standpoint of safety there are two trends shown by these tests that are worthy of consideration (1) The coefficients of friction on all road surfaces decrease with increase of speed (2) The difference between the rolling and sliding coefficients increases with increase of speed Considering these points, the driving hazards are much more serious on wet roads than on dry roads as the speed is increased, not only because of the decrease in the rolling as well as sliding coefficients of friction, but also on account of the increasing difference between the values of rolling and sliding coefficients of friction This latter variation is exceedingly serious when brakes are applied suddenly as any type of brake may operate unequally at times on the four wheels and when one wheel slides there is a radical decrease in braking force on this wheel, which may easily cause the driver to lose control of the car

DISCUSSION

ON

SKIDDING TESTS AND COEFFICIENTS OF FRICTION

MR E O RHODES, *Koppers Products Company.* I would like to call attention to certain points that need to be stressed in work of this kind, so that they may be considered in the continuation of these experiments

It is extremely important that the history be given in detail for each road surface tested—the type of the road, type of binder, specifications for the binder, method of construction or treatment, age, and surface condition at the time of test Also the records as to treatment subsequent to construction should be included, for we know there is a possibility that some of these road surfaces may have had several kinds of materials placed upon them

Also, I think it is important that this work be continued by making a great number of tests on each type of surface

The matter of testing in center of road as compared to testing in the traffic lanes should be considered Actually we are principally interested in the condition of the surface on which we are doing most of our riding If we go to the center of the road, are we testing the surface which is carrying most of the traffic?

Whether the pavements are wetted by rain or artifically, the prevailing conditions, such as time, the amount of rainfall, the weather conditions prior to time of tests, and temperature prior to time of tests, are important factors and need to be considered

That some of the coefficients which have been presented do not agree very satisfactorily with coefficients that have been determined by other experimenters in other countries is probably not so much due to the differences in apparatus as it is due to the differences in surfaces of the same type

MR E M FLEMING, *Portland Cement Association* Coefficients of surface friction are only valuable for practical application in so far as they measure the relative safety of the various surfaces The question naturally arises as to which of the three coefficients mentioned is the critical one

In the report the coefficient of straight skidding is given most weight This, together with the sideways skid coefficient, is a measure of the ease and rapidity of skidding *after* the action has already started Very little is said about the coefficient of *impending* skid, which measures the ability of the surface to set up resistance to any skidding motion

It seems to me that the coefficient of impending skid is more nearly a measure of surface safety than either of the two others

In one chart the impending skid coefficient on concrete is about 0 80 at 40 miles per hour Under the same conditions the coefficient for sideways skid is 0 60 and for straight skid about 0 40 While all three coefficients at low speeds (five miles per hour) are approximately equal, yet the impending coefficient remained practically constant with increasing speed while the others decreased rapidly

Some discussion of the relative importance of the three coefficients in so far as they measure driving safety would be desirable It would be interesting to know for other types of surfaces the relation of the impending coefficient to the side and straight coefficients and also to compare the values of this coefficient at various speeds on those surfaces with the ones on concrete

The Ohio skid tests show clearly that the maximum rolling skid coefficients, or perhaps, more properly, impending skid coefficients, are much higher on all types than the straight skid coefficients As previously mentioned, the impending skid coefficients are the true criterion of skidding accidents since the car must first start to skid before the sliding skid coefficients govern

The curve comparing rolling friction or impending skid coefficients on various types of pavements shows that concrete has the highest values for speeds of 40 miles an hour and greater-speeds at which skidding accidents may be dangerous The same trend of increase in sliding friction on concrete above other types is also indicated at the higher speeds, although the tests do not cover this point as fully as tests on rolling friction

In comparing the Ohio and Iowa skid tests, it will be noted by the Iowa tests that the close-textured bituminous types have higher values than the open-textured bituminous types, yet by the Ohio tests, the opposite condition was found Since only a specific project was tested in each case, it indicates that additional work is needed to establish the comparative skid coefficients on the open and close-textured bituminous types as well as with other types

MR BERNARD E GRAY, *The Asphalt Institute*· In making further studies of the skid resisting qualities of road surfaces, it is suggested that account be taken of the character of aggregate composing the pavement It is recognized that a considerable variation exists in this regard, particularly in the case of the cover coat aggregates used in low cost types The endeavor of the highway builder should be to have traffic carried on the aggregate rather than upon a film of bituminous material, and certain aggregates under traffic tend to become polished and slippery whereas certain other aggregates, because of a rough surface texture, have a high resistance to skidding

MR GEORGE E MARTIN, *The Barrett Company*: While these tests give results for the individual sections where the work was done, the data are not sufficient to justify conclusions as to the relative skid-resistance of various pavement types

Many of the variables which influence the results are not included in this report Some of these are the detailed method of construction of the surface, its age, previous maintenance history, and kind and amount of traffic

The report does not give the results of individual tests but only a summary for a particular pavement type It is impossible to tell, therefore, how much variation there may have been between individual results

Motor vehicles skid on the driving wheels and there is no certainty that the results for pulled wheels would be an accurate measure of those for driving wheels

The value of the coefficient of impending skidding, which is undoubtedly of most importance to the motorist, is reported for only a very few experiments

The method of producing a wet pavement gives results which are only partially comparable to natural wet weather conditions

This report is a good progress report on one method of approaching the problem but cannot be considered as giving final results relative to the comparative skid resistance of various roadway surfaces

MR G F SCHLESINGER, *National Paving Brick Association* The report of Professors Stinson and Roberts shows that on a pavement constructed with a vertical fiber lug type of brick and from which the filler had been removed at the time of construction the paving surface had a high coefficient of friction—one of the highest of the different types represented by the curves shown This skid-proof quality was reduced when the same pavement was tested a year later with the automobile traveling in the main line of traffic, although it still had a fairly high coefficient of friction This reduction was due to the asphalt filler having risen in the joints and spread over a portion of the brick surface It is my opinion, however, that, if this same pavement is tested from year to year, the coefficient will gradually be restored to its original value because of the disappearance of asphalt from the surface under the action of traffic

Professor Moyer tested some brick pavements in the city of Des Moines, Iowa, and, according to his results, the pavement with about 25 per cent of asphalt on the surface had more friction than the clean brick pavement This is inconsistent with the tests of Professors Stinson and Roberts, and, in my opinion, is not according to practical experience I have investigated several brick pavements concerning which there had been complaints regarding slipperiness In every instance, these pavements were covered with asphalt in which the mineral cover material had not been properly incorporated The National Paving Brick Association recommends the surface removal method of filler application and the vertical fiber lug type of brick believing that these requirements will produce the most non-skid qualities for the brick type of pavement

Professor Moyer, *Author's Closure, by Letter* In the light of the present knowledge of the subject, it appears that the facts and principles established in this paper are fundamentally sound and should form the basis for future investigations The suggestions made in the discussion should prove helpful in carrying out such a program The differences in the coefficient of friction due to variation in the types of asphalts, tars, aggregates, mineral fillers and other road surfacing materials now in use can for the most part only be determined accurately by actual test Since it would require too extensive a program to determine the effect of all these variables, it was thought desirable for the present to restrict the program to work from which it would be possible to rationalize the results obtained in the tests and to formulate a theory by which the effects of skidding might be predicted for any given set of conditions

In the cases where tests were made in the center of the road, it was possible at the same time to test in the center traffic lanes. The purpose for testing in the center of the road was largely to eliminate the effects of crown

The writer takes exception to the statement that the results of tests reported in this paper do not agree with results obtained in other countries Probably the most outstanding piece of work along this line was that conducted by the National Physical Laboratory of England during 1930 In a paper by Bradley and Allen[1] data are reported for about ten types of surfaces These data are in substantial agreement with the data reported in this paper in the cases where the types of test and surfaces conditions are similar

The side skid and straight skid coefficients are most likely to be critical coefficients for the reasons previously stated in the paper The

[1] "Factors Affecting the Behavior of Rubber-tired Wheels on Road Surfaces" by J Bradley and R F Allen, 1930–31, Proceedings of the Institution of Automobile Engineers

coefficients for impending skidding can hardly be considered critical, since the brakes on comparatively few cars, are adjusted uniformly enough to make available this high coefficient at each of the four wheels It is also quite likely that few drivers can apply brakes so skillfully that they can bring the four wheels to the point of impending skidding It should be observed, however, that the side skid and skidding impending coefficients are generally about the same for regular balloon tires

The coefficients for the brick and concrete surfaces were approximately the same with the coefficients for brick slightly lower than those for concrete Brick and concrete have certain characteristics in common which in part accounts for the similarity in their skidding actions An important common characteristic is that these surfaces are hard and dense The cementing or bonding materials are exceptionally hard and for this reason a slight polishing effect can be observed on these surfaces due to the abrasive action of the tires Althougn these surfaces may have an exceptionally high coefficient when new, the tests on surfaces which have been subjected to traffic indicate that this rough-textured condition will not exist for a great length of time after the road is open to traffic Nevertheless, the surface texture on these surfaces should never be so smooth as to cause the coefficients on the wet surfaces to be dangerously low It is quite likely, that the type of bituminous filler and the extent to which fine aggregate and mineral filler are present in the bituminous filler of brick surfaces, are responsible for the large variable effect in the skidding characteristics of brick surfaces