Locked Wheel Skid Performance of Various Tires on Clean, Dry Road Surfaces

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Although engineering, legal and educational groups are concerned with the skid performance of tires on dry roadways, most skid investigations have been conducted on wet surfaces. Because of the paucity of data, it was considered desirable to investigate the skid performance of several makes of tires on clean, dry, level road surfaces. Factors investigated included skidding velocity, tire make, wheel loading, and type of road surface.

Data were obtained from trailer drag tests and panic stops of passenger vehicles. Tests were performed using tires of four different makes, three different road surfaces, and several different wheel loadings. For the drag tests, skidding speeds were from 10 mph to 50 mph. Panic stops with passenger vehicles were made from speeds of 30, 40, 50, and 70 mph.

It was found that among different makes of tires of comparable quality there existed differences in stopping ability. Differences in the length of skid and braking distance for a given initial speed and road surface type were found to be about ten percent for the four makes of tires tested. Similar differences were found on other road surfaces.

One of the most significant findings was that the coefficient of friction developed between a given tire and road was found to be greater at the higher speeds. This trend has not been reported by other investigators to the author's knowledge. The implication of this finding is that existing methods of estimating prior speed from length of skid marks laid down in an accident invariably gives a conservative estimate of speed. For a carefully executed experiment, speed estimates will be accurate to within five percent.

● It has been commonly assumed that no significant difference in stopping ability existed among different tires on a clean, dry, level road surface when the brakes of the vehicle have locked the wheels. Engineering, legal, and educational groups have generally accepted this assumption.

The interaction between tire and road surface during a locked wheel stop is a complex phenomenon. Many factors probably influence this interaction and the retarding force associated with it. In a recent publication, A. J. White (1) discussed some of these factors and implied that wide variations in stopping ability do exist among different tires. Since there is little recent experimental data for locked wheel stops on dry pavements, the test program reported here was undertaken.

The specific purpose of the research was to observe the performance of tires on a clean, dry, level road surface under locked wheel skid conditions with the objective of (a) determining the variation, if any, in

the coefficient of sliding friction and the variation, if any, in the length of skid required to bring a vehicle to a stop as affected by different speeds, different tires, different vehicles and wheel loadings, and different types of road surfaces; (b) determining the reliability of the square law formula for estimating the speed prior to skidding from the length of skid marks laid down; (c) obtaining motion pictures to be used to educate the public concerning the distances involved in slowing down and stopping from various initial speeds.

EXPERIMENTAL PROCEDURE

Tires

Four different tire manufactures each contributed 12 new tires for the test program. One hundred level, size 6.70 x 15, synthetic compound, blackwall, tubeless tires were used. These were selected at random from warehouse stocks by a representative of the Michigan State Highway Traffic Safety Center. Appendix A identifies the test tires by company and serial number. For this report, a group number and letter is used to distinguish between tires. All tires of the same make have the same group number; letters from A through L were used to differentiate tires in the same group. A photograph of the tires showing the tread designs represented is given in Appendix B. All test tires were run at least two hundred miles under normal operating conditions before being used in the experiments.

Road Surfaces

Three different road surfaces were used in the experiment. All were in the vicinity of Milford, Michigan. All testing done on these road surfaces was completed between August 28 and September 9, 1957.

Most of the tests were run on the General Motors Proving Grounds north-south straightaway, which is a straight, level, bituminous asphalt surface. This will be referred to as Road Surface A throughout the paper. Tests were also made on the east-west straightaway on the General Motors Proving Grounds. This surface is a level, portland cement concrete surface and will be referred to as Road Surface B. The third test surface was a 500 ft section of US 16 approximately 200 yd west of the Kensington Road intersection, subsequently referred to as Road Surface C. This was a heavily used bituminous asphalt highway. Checks using a surveyor's level indicated that the maximum grade was less than three-tenths percent and that the surface was level to within one ft over the entire test length. Photographs are given in Appendix C to further identify the type and texture of the test surfaces.

Passenger Vehicles

Panic stop tests were performed with two different vehicles. A 1956 Chevrolet station wagon belonging to Michigan State University was used for the majority of these tests; the second vehicle was a 1956 Chevrolet 4-door sedan. Use of a third vehicle was contemplated but it was not convenient to obtain a suitable model. Therefore, the Chevrolet sedan was sandbagged to produce a wheel loading equivalent to one of the Pontiac lines of cars. Photographs of the vehicles are given in Appendix D.

Drag Dynamometer

The General Motors Proving Grounds' trailer dynamometer was used

for obtaining the drag test data. A photograph of the drag trailer is given in Appendix E. It is a two-wheel trailer unit pulled by a light truck. The trailer is equipped with a pneumatic braking system which locks the trailer wheels during the test. An arrangement of bonded resistance wire strain gauges mounted on the torque tube assembly of the trailer is used as the drag force transducer. A servo instrument mounted in the tow truck cab continuously indicates the average drag friction between the road surface and the trailer tires. The truck speedometer is used for measuring the speed at which the drag is made. A more complete description of the dynamometer and its calibration is contained in a paper by Paul C. Skeels (2).

Trailer Drag Test Procedure

Test tires were mounted in pairs on the drag trailer. Wheel loading was measured on platform scales. For the majority of the drag tests the load per wheel was 1,000 lb. At the test site the road surface temperature was measured and the tire pressure adjusted to 28 psi. For each different test condition, four drags were made. The cycle time for each drag was approximately four to five seconds. About one second was required for the trailer wheels to become fully locked; one to two seconds was required for the indicator reading to stabilize and for the observer to make a reading; the remaining time was for release of the trailer brakes. Depending on the speed of the preceding drag, successive drags were made after one-half to two miles of free running. This permitted the tire temperatures and pressures to stabilize between drags.

One pair of tires was reserved as control tires during the entire program of experimentation. These were dragged periodically to check for unaccountable differences in the friction characteristics of the various road surfaces used.

Panic Stop Test Procedure

Data for most of the panic stop tests were obtained using the station wagon. The remainder was obtained using the sedan. Prior to the experimentation the brakes of both vehicles were carefully inspected and adjusted to give rapid and uniform response to brake pedal movement. No difficulty in locking the wheels was encountered during any of the tests. Observations indicated that there was no tendency for the wheel to lock at the same angular orientation each time.

Tires were mounted on vehicles in groups of four. Where a tire was tested on different vehicles and different road surfaces, it was always used at the same wheel location on the vehicle.

The basic measurements made were speed and distance. On the station wagon, a Wagner fifth wheel was used to actuate a Standard Time, Inc. chronopousometer. A photograph of this indicating device is shown in Appendix F. A motion picture camera was used to make a permanent record of the chronopousometer dials during each test run. The chronopousometer continuously indicated vehicle speed and was triggered by a plunger-type switch to give braking distance and time. The switch was mounted on the steering column in such a position that one-half in. of brake pedal travel closed the switch. In addition to actuating the braking distance indicator and timer, closure of the switch actuated a mechanical detonator which deposited a chalkmark on the pavement at the point of brake application.

Braking distances determined by the chronopousometer and the detonator deposited chalkmark agreed to a fraction of a foot consistently.

The speed indication of the chronopousometer was checked over the entire range of test speeds. Two verification procedures were used. The first method was to time a constant speed run over a measured course. The second consisted of comparing the indication with that of a carefully calibrated fifth wheel. For both check procedures the speed indication of the chronopousometer was found correct to within a fraction of one percent consistently. The maximum observed deviation during all of these checks was six-tenths of a mile per hour, which corresponded to a difference of approximately one and one-half percent. Since an independent fifth wheel actuated speed indicator was used by the test driver for controlling the speed from which each stop was made, further evidence was obtained indicating that the chronopousometer was accurate and stable throughout the entire test program.

Several different devices were used for making distance measurements. Each was verified by comparison with a tape measure. Where there was some question whether the texture of the road surface would affect the reading, the device was checked on the test surface in question. In every instance the indication from the distance measuring device was within one-quarter of one percent of that given by the tape.

During the panic stops two persons were in the vehicle, a test driver and an observer. After preparing the vehicle and instruments for a test run, the vehicle was driven toward the test area. A sufficiently long approach was used so that the test driver had ample opportunity to make speed corrections and enter the test area at a constant speed. Several seconds prior to applying the brakes and on signal from the test driver, the observer would start the camera trained on the chronopousometer dials. When the car was in the test area the driver removed his foot from the accelerator and struck the brake pedal as quickly and as forcibly as possible. A full skid was developed within 10 ft for 70 mph skids and in proportionately shorter distances at the lower speeds. After the vehicle came to rest, the timer and camera were turned off, the skid tracks were marked for measurement, and the detonator was reloaded. The test vehicle was driven to the side of the road and readied for the next test run while measurements were being made on the road surface. Stops were made in alternate directions along the test surface with a minimum of approximately five minutes between successive skids.

Calculations

In calculating coefficients of friction from the drag test observations, the average indication of four drags was used. This was converted to an average friction or drag force by multiplying by the calibration factor as follows:

$$F = kr \tag{1}$$

where

F = friction or drag force in pounds
k = calibration factor in pounds per dial unit
r = instrument reading in dial units

the coefficient of friction was then found from equation 2.

$$f = \frac{F}{W - \frac{b}{L} F} \qquad (2)$$

where

f = coefficient of friction
F = friction drag force in lb
W = wheel loading in lb
b = height of trailer hitch from road surface in in.
L = horizontal distance from hitch to trailer wheels in in.

the factor $\frac{b}{L}$ F in equation 2 accounts for the weight transfer off the trailer wheels when the drag force F is acting.

For calculating the average coefficient of friction during the panic stops, the well known work-energy relation was used to obtain equation 3.

$$f = \frac{v^2}{2\ gs} \qquad (3)$$

where

v = the initial speed in ft per sec.
g = the gravitational acceleration 32.2 ft per sec. squared
s = the length of skid in ft or the braking distance in ft

TEST RESULTS

Trailer Drag Tests

The effect of drag or skidding speed is indicated in Figures 1, 2, 3, and 4 for each of the four pairs of tires tested. The trend was for the friction coefficient to increase with higher speeds. The degree of dependency between average friction coefficient and drag speed varied from slight in the case of the tires in group 1 to very marked for the tires in group 3. In the latter case, the friction coefficient at 50 mph was about 13

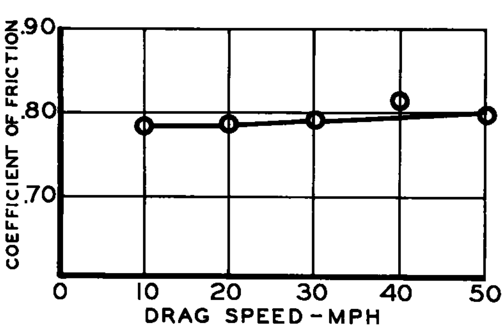

Figure 1. The effect of speed on the skid resistance of a pair of tires from Group 1. Each point represents the average obtained from four drags on Road Surface A.

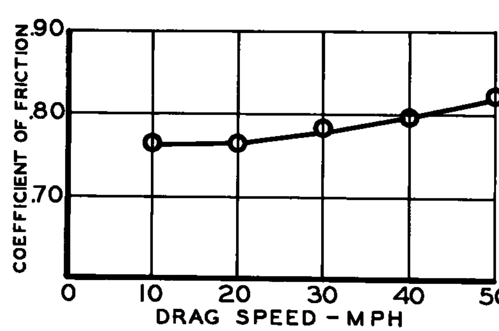

Figure 2. The effect of speed on the skid resistance of a pair of tires from Group 2. Each point represents the average obtained from four drags on Road Surface A.

percent higher than at 10 mph. This same tendency was observed for other tires and on other road surfaces.

To check whether different tires of the same make exhibit differences in stopping ability, a second pair of tires of each make was tested. Table 1 indicates the comparison obtained. For a given speed and road surface, the average coefficient of friction computed for two different pairs of tires of the same make varied as much as 9 percent.

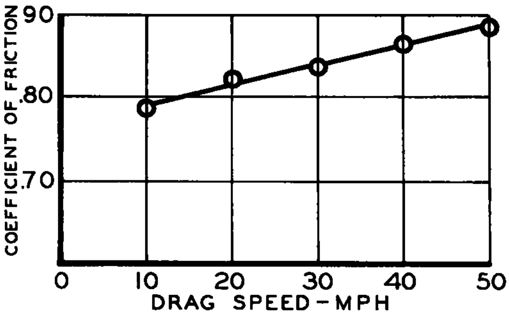

Figure 3. The effect of speed on the skid resistance of a pair of tires from Group 3. Each point represents the average obtained from four drags on Road Surface A.

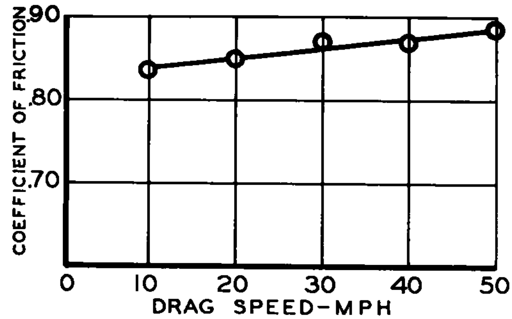

Figure 4. The effect of speed on the skid resistance of a pair of tires from Group 4. Each point represents the average obtained from four drags on Road Surface A.

TABLE 1

RESULTS OF DRAG TESTS COMPARING DIFFERENT PAIRS OF TIRES OF THE SAME MAKE*

Tire Pair Identification	Coefficient of Friction for Drag Speeds of	
	20 MPH	40 MPH
1A-1B	.79	.82
1C-1D	.83	.87
2A-2B	.77	.80
2C-2D	.83	.87
3A-3B	.82	.87
3C-3D	.87	.92
4A-4B	.85	.86
4C-4D	.82	.88

*All tests performed on Road Surface A.

TABLE 2

RESULTS OF DRAG TESTS AT DIFFERENT WHEEL LOADINGS FOR THE SAME PAIR OF TIRES*

Wheel Load Pounds per Wheel	Coefficient of Friction for Drag Speeds of	
	20 MPH	40 MPH
770	.84	.87
1000	.77	.80
1500	.77	.78

*Tire pair 1A - 1B used in this test.

Wheel loadings on the drag trailer were varied within the limits of practicability to obtain an indication of the effect of load on the friction developed between tire and road surface. Only one pair of tires was used. The results are given in Table 2. These limited observations were in agreement with those previously reported by Moyer (3). A decrease in the friction coefficient was observed with increased wheel loading. Over the range of loads checked the greatest variation was at the higher drag speed of 40 mph for which the friction coefficient decreased about 9 percent as the wheel loading was increased from 770 to 1,500 lb per wheel.

To compare the friction properties of different road surfaces, four pairs of tires were dragged over three different road surfaces at speeds of 20 and 40 mph. The results of these tests are summarized in Table 3. This table indicates that road surfaces B and C are about comparable in gripping power and that road surface A is somewhat superior to the other two.

Drag tests made with the control tires produced non-uniform results. At first it was thought that road surface temperature might have been the

TABLE 3

RESULTS OF DRAG TESTS USING SAME PAIRS OF TIRES ON DIFFERENT ROAD SURFACE

Tire Pair Identification	Coefficient of Friction on		
	Surface A	Surface B	Surface C
		(20 MPH Drag Speed)	
1C-1D	.83	.76	.80
2C-2D	.83	.78	.78
3C-3D	.87	.89	.86
4C-4D	.82	.78	.72
		(40 MPH Drag Speed)	
1C-1D	.87	.79	.78
2C-2D	.87	.78	.77
3C-3D	.92	.84	.86
4C-4D	.88	.79	.81

cause. A plot of friction coefficient versus temperature is shown for the control tires in Figure 5. No consistent trend is in evidence. In Figure 6 a plot of control test results is shown against date. This figure suggests several possibilities: that there were great differences in the friction characteristics of the road surface from one location to another, that the drag trailer instrumentation was unstable, or that the drag force indication was appreciably affected by tire wear.

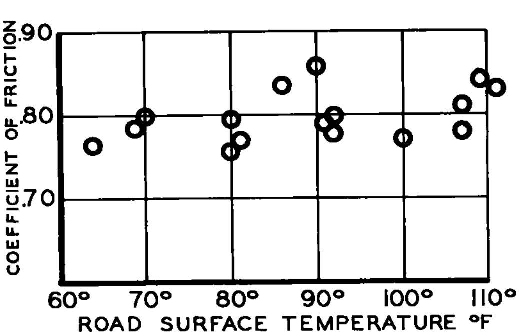

Figure 5. The results of control tests plotted against road surface temperature. Each point represents the average obtained from four drags on Road Surface A.

Subsequent checks of the drag trailer instrumentation were made. The results indicated that the instrument was stable over long periods of time. Therefore, the stability of the instrumentation during the drag experiments cannot be questioned.

Each point plotted in Figures 5 and 6 is the average value computed on four consecutive drags under identical conditions. These drags were made at different locations along the road surface and should, therefore, reflect any inherent differences in road surface characteristics from location to location. Throughout the entire test program the variation

in the four consecutive drag readings was of the order of one to two percent whenever the test tires had not been previously dragged. This would indicate that the road surface characteristics do not vary materially from one location to another.

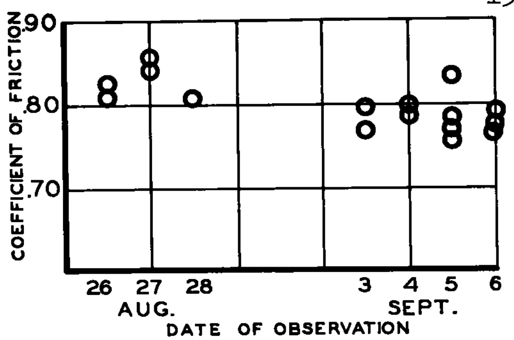

Figure 6. The results of control tests plotted against date of observation. Each point represents the average obtained from four drags on Road Surface A.

During a drag test, the instrument reading tended to stabilize for a fraction of a second immediately following the development of a full locked-wheel skid condition. As the drag continued, the indication would decrease. This is thought to be caused by a softening of the rubber due to heat generation. The reading recorded was the value at which the indicator stabilized immediately after the wheels locked. It was not easy to assign a definite value for the reading.

It was noted that as the tires accumulated wear, the consistency of four consecutive drag force observations decreased. For example, the first four drags of the control tires produced readings that agreed to within one percent; the eighth set of four drags with the same tires produced readings that agreed to within seven percent; subsequent sets of four readings exhibited spreads that varied from two percent to as high as 15 percent. It is felt, therefore, that the flat spots and roughened areas that were produced on the tires as the tests progressed and the possibility of human error in reading the instrument are the major causes of variability in the drag test results.

Conclusions based on the drag tests are somewhat speculative in view of the variability in the test results. However, since the test tires were each subjected to only a fraction of the number of skids that the control tires experienced and since the data for the test tires were more consistent than for the control tires, it is very probable that valid

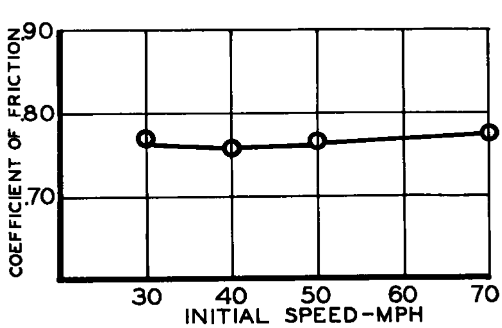

Figure 7. The effect of speed on the skid resistance of a set of tires from Group 1. Each point represents the average obtained from four panic stops on Road Surface A excepting at the 70 mph speed, which is the average of two stops.

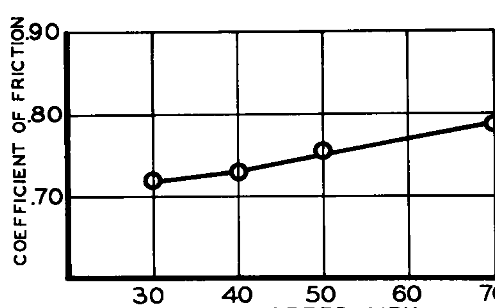

Figure 8. The effect of speed on the skid resistance of a set of tires from Group 2. Each point represents the average obtained from four panic stops on Road Surface A excepting at the 70 mph speed, which is the average of two stops.

indications of the effects of some of the test variables were obtained. For example, the tires of group 3 stood out by yielding the highest coefficient of friction under practically every test condition where comparison of tire makes was possible. For these reasons, it is held that the drag tests provided reliable qualitative indications of the effect of speed, wheel loading, and tire make on stopping ability.

Panic Stop Tests

Results of the panic stop tests were much more consistent than those of the drag tests. The spread of individual coefficients of friction which were averaged to obtain the numerical values reported was less than 0.04 in every case. In more than two-thirds of the tests a spread of 0.03 or less was observed.

In order to assess the effects of speed, one set of tires of each of the four different makes was subjected to panic stops on road surface A from speeds of 30, 40, 50, and 70 mph. The results of these tests are shown in Figures 7, 8, 9, and 10. The friction coefficients plotted are based on the average of four skids from speeds of 30, 40, and 50 mph and the average of two skids from 70 mph. Results indicate that for the tires tested the coefficient of friction developed is either reasonably constant or increases as the skid speed increases. This finding is in agreement with the results obtained from the trailer drag tests. In addition it is interesting to note that the tires of group 1 exhibit the least change in friction coefficient with speed in both the panic stop and drag tests and that the tires of group 3 show the greatest increase in friction coefficient with speed in both tests. Since the findings on the effects of speed differ from results previously reported, the fact that the skid test results corroborate the drag test results is considered to be very significant.

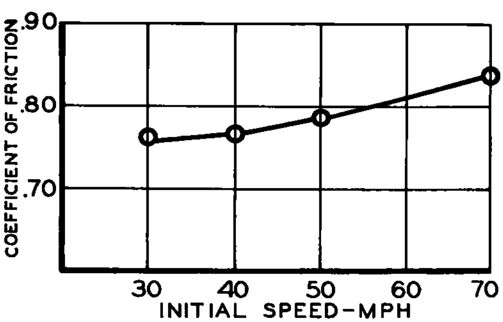

Figure 9. The effect of speed on the skid resistance of a set of tires from Group 3. Each point represents the average obtained from four panic stops on Road Surface A excepting at the 50 mph speed, which is the average of three stops, and at the 70 mph speed, which is the average of two stops.

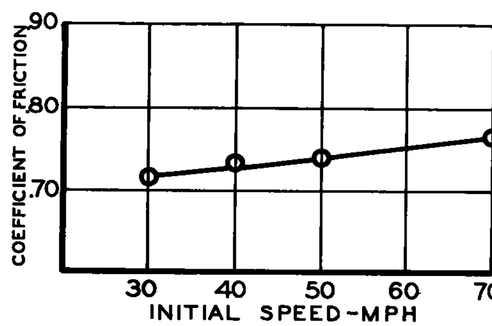

Figure 10. The effect of speed on the skid resistance of a set of tires from Group 4. Each point represents the average obtained from four panic stops on Road Surface A excepting at the 70 mph speed, which is the average of two stops.

These same graphs indicate that there are differences in stopping ability among different makes of tires. The greatest difference in the

TABLE 4

RESULTS OF PANIC STOP TESTS COMPARING DIFFERENT SETS OF TIRES OF THE SAME MAKE*

Tire Set Identification	Coefficient of Friction
1E-1F-1G-1H	.76
1I-1J-1K-1L	.76
3E-3F-3G-3H	.77
3I-3J-3K-3L	.77
4E-4F-4G-4H	.73
4I-4J-4K-4L	.74

*Based on length of skidmarks using average of 40 mph with station wagon on road surface A.

TABLE 5

RESULTS OF PANIC STOP TESTS COMPARING DIFFERENT VEHICLES WITH A GIVEN SET OF TIRES*

Vehicle	Gross Wt. pounds	Coefficient of Friction
1956 Chevrolet Station Wagon	4126	.76
1956 Chevrolet 4 Door Sedan	3576	.79
1956 Chevrolet Loaded to Simulate Pontiac	3926	.76

*Based on length of skidmarks using average of four panic stops from 40 mph on road surface A with tire set 1I-1J-1K-1L.

TABLE 6

RESULTS OF PANIC STOP TESTS COMPARING DIFFERENT ROAD SURFACES*

Road Surface	Coef. of Fric. for Tire Set 3I-3J-3K-3L	4I-4J-4K-4L
A	.77	.74
B	.79	.76
C	.80	.77

*Based on length of skidmarks using average of four panic stops from 40 mph with station wagon.

TABLE 7

RESULTS OF PANIC STOP TEST SHOWING EFFECT OF SPEED*

Tire Set Identification	Coefficient of Friction of Speed of 30 mph	70 mph
1E-1F-1G-1H	.72	.75
2E-2F-2G-2H	.68	.76
3E-3F-3G-3H	.71	.81
4E-4F-4G-4H	.66	.75

*Based on braking distance using average of four panic stops at 30 mph and two panic stops at 70 mph. Tests made using station wagon on road surface A.

average friction coefficient and skidding distance was about 10 percent at the 70 mph speed. Smaller variations were observed at lower speeds.

Runs at 40 mph were made to determine whether variations in stopping ability existed among tires of the same make. Table 4 gives the results of this comparison. For the sets of tires tested, the results were remarkably uniform indicating that there was little significant difference among tires of the same make. This does not agree with the drag test results. Lack of agreement may be attributed to two possible factors, the variability in the drag test data and the greater averaging effect in the panic stop tests due to the use of four tires at a time as compared to the drag tests for which the tires were taken two at a time.

To examine the effect of load on stopping ability, tests were performed using one set of tires and the same road surface but with different

TABLE 8

RESULTS OF PANIC STOP TESTS COMPARING DIFFERENT SETS OF TIRES OF THE SAME MAKE*

Tire Set Identification	Coefficient of Friction
1E-1F-1G-1H	.72
1I-1J-1K-1L	.71
3E-3F-3G-3H	.73
3I-3J-3K-3L	.73
4E-4F-4G-4H	.70
4I-4J-4K-4L	.70

*Based on braking distance using average of four panic stops from 40 mph with station wagon on road surface A.

vehicles and wheel loadings. The results are shown in Table 5. The panic stop test findings were in qualitative agreement with the drag test findings indicating that stopping ability decreases as load increases. The fact that the results using the station wagon compared with those using the sandbagged sedan suggest that vehicle characteristics also play some part. The panic stop tests produced a difference of 4 percent in the friction coefficient as compared to a difference of 9 percent for the drag tests. This is attributed to a wider range of wheel loadings used in the drag tests.

Small differences in the performance of a given set of tires at a given speed were also observed from one road surface to another. Table 6 shows these differences for skids from a 40 mph speed. These results do not agree well with the drag test results. However, it is felt that the panic stop test data are more reliable and more correctly represent the differences in the friction or gripping characteristics of the three test surfaces.

All of the previously discussed results were based on a measured length of skid. Since the different road surfaces exhibited different marking characteristics, calculations on the basis of braking distance were made. The results of calculations based on braking distance are independent of the inherent ease with which a given test surface is marked up during a skid. Results are shown in Tables 7, 8, and 9. In connection with the effects of different skid speeds, different tire makes, different tires of the same make, and different test surfaces, the results based on braking distances are in very close agreement with the results based on skidding distance.

RELIABILITY OF THE SPEED SQUARED FORMULA

In accident investigation, speed estimates are frequently made from skidmark lengths (4, 5). One procedure is to determine the drag factor (average coefficient of friction) of the pavement by making experimental skids from a low speed. Equation 3 is used for the calculation of a friction coefficient or drag factor. Substitution of the experimentally determined value of drag factor and the distance that the car involved in the accident skidded into Equation 3 yields a

TABLE 9

RESULTS OF PANIC STOP TESTS COMPARING DIFFERENT ROAD SURFACES*

Road Surface	Coefficient of Friction for Tire Set	
	3I-3J-3K-3L	4I-4J-4K-4L
A	.73	.70
B	.73	.69
C	.75	.72

*Based on braking distance using average of four panic stops from 40 mph with station wagon.

solution for the estimated speed of the accident vehicle prior to skidding.

To check the reliability of this method, the data for a set of tires of each of the four different makes was used. All data were observed during test runs on road surface A. For each set of tires the four 30 mph panic stops were used to calculate a coefficient of friction. This value and the measured length of skid for each panic stop at the other speeds were used to make an estimate of the speed from which each stop was made. The estimated speed and the observed speed were compared. Table 10 gives the results of this comparison. Estimates of speed were in error a maximum of +0.7 and -3.5 mph and were predominantly lower than the observed car speed.

In the above comparisons the same tires were used for the experimental determination of friction coefficient as were used in the skids from which prior speed was estimated. In an investigation, it might happen that the drag factor is determined using a different set of tires. In

TABLE 10

COMPARISON OF OBSERVED SPEED AND SPEED

ESTIMATED USING VELOCITY SQUARED FORMULA WHERE AVERAGE FRICTION COEFFICIENT WAS DETERMINED FOR SAME TIRE SET AT LOWER SPEED

Avg. Lgth. Skidmark ft	Estimated Speed mph	Observed Speed mph	Avg. Lgth. Skidmark ft	Estimated Speed mph	Observed Speed mph
Tire Set 1A-B-C-D f = .77*			Tire Set 2A-B-C-D f = .72*		
72.8	40.9	40.2	74.7	40.1	40.2
69.4	40.0	39.8	73.0	40.0	40.0
67.4	39.5	39.0	76.5	40.7	41.0
65.7	38.9	39.0	73.3	39.8	40.4
109.9	50.3	50.0	112.6	49.3	50.2
110.8	50.6	50.4	112.5	49.3	50.0
111.8	50.8	50.2	112.9	49.4	50.4
111.7	50.7	50.8	108.0	48.3	49.8
215.6	70.5	70.4	205.0	66.4	69.2
212.8	70.0	70.4	208.2	67.0	70.0
Tire Set 3A-B-C-D f = .76*			Tire Set 4A-B-C-D f = .715*		
73.4	41.1	41.0	74.0	39.8	40.2
71.2	40.4	40.2	72.3	39.4	40.2
72.2	40.7	40.6	75.8	40.3	40.8
72.6	40.8	41.0	73.3	39.6	40.0
104.7	49.1	49.4	113.7	49.4	50.4
104.5	48.9	50.0	114.9	49.7	50.4
108.4	49.9	50.4	114.7	49.7	50.0
101.7	48.2	50.0	115.5	49.8	50.6
193.4	66.5	70.0	209.8	67.2	69.4
192.5	66.4	69.4	212.6	67.5	69.8

*Based on skidmarks using average of four panic stops from 30 mph with station wagon on road surface A.

TABLE 11

COMPARISON OF OBSERVED SPEED AND SPEED

ESTIMATED USING VELOCITY SQUARED FORMULA WHERE AVERAGE FRICTION COEFFICIENTS WERE EXTREME VALUES FOUND AT LOWER SPEED

Tire Set	Avg. Lgth. Skidmark ft	Estimated Speed Using f = .715* mph	Estimated Speed Using f = .77* mph	Observed Speed mph
1A-B-C-D	215.6	68.0	70.5	70.4
1A-B-C-D	212.8	67.6	70.0	70.4
2A-B-C-D	205.0	66.2	68.6	69.2
2A-B-C-D	208.2	66.9	69.3	70.0
3A-B-C-D	193.4	64.4	66.7	70.0
3A-B-C-D	192.5	64.3	66.6	69.4
4A-B-C-D	209.8	67.2	69.5	69.4
4A-B-C-D	212.6	67.5	70.0	69.8

*Based on skidmarks using average of four panic stops from 30 mph with station wagon on road surface A.

Table 11 the speeds were estimated based on the lowest and highest average coefficient of friction obtained from the 30 mph panic stops. The comparisons are indicative of the errors that might be made in speed estimates where the drag factor is not determined using the same tires as were involved in the accident skid. The 70 mph panic stops were used for this comparison. The range of error in the estimated speeds was found to be +0.2 to -5.6 mph. In the majority of cases the estimated speed was lower than the measured speed.

CONCLUSIONS

The ability to stop by skidding on a clean, dry, level road surface is dependent on speed, vehicle characteristics, road surface type, and tire characteristics. In the research reported here, skidding speed and tire characteristics were the most influential factors.

The most important result of this research was the consistent trend for friction coefficient to increase as the speed of skidding is increased. This has not been reported previously to the author's knowledge . In most publications the friction coefficient is shown to decrease with speed. This indicates that further research should be done on dry skidding. In addition to resolving this point of difference concerning the effect of speed, it would be desirable to have additional data for comparing tires of the same make, for evaluating the effects of wheel load, and for assessing the effects of vehicle characteristics.

Of the two basically different testing methods, the drag test is less expensive, quicker, and less dangerous than a panic stop test. However, the observed data are less uniform in the case of the drag test. This indicates that further development of drag test equipment is both necessary and desirable. Specific recommendations are to use a recorder in place of an indicator to reduce the factor of human error, to devise a rapid calibration procedure that would permit more frequent calibration checks to be

made, and to find some means of reducing localized tire wear. The latter might be accomplished by reducing the time duration of the locked wheel skid or by using a differential slipping device similar to the one reported by Kullberg (6) to distribute the wear more uniformly over the test tire.

Because of the variations found in tires, care must be exercised when making tests for road surface characteristics. The development of standardized equipment for this purpose will necessarily include the development of standard specifications for test tires. Comparable and reproducible results will not otherwise be obtained.

In spite of the many factors that will influence the distance in which a vehicle can be skidded to a stop on a clean, dry pavement, the recommended method of estimating speeds in accident investigations involving the use of the speed squared law is reliable. Under carefully controlled conditions, using the same tires, vehicle, and road surface, estimates are within 5 percent of the true speed. Even where different makes of tires of comparable condition and quality are involved, estimated speeds within 10 percent of actual speed are highly probable. Even more significant is the fact that speed estimates are predominantly conservative. This occurs because tires tend to develop more tractive effort skidding at higher speeds than at lower speeds.

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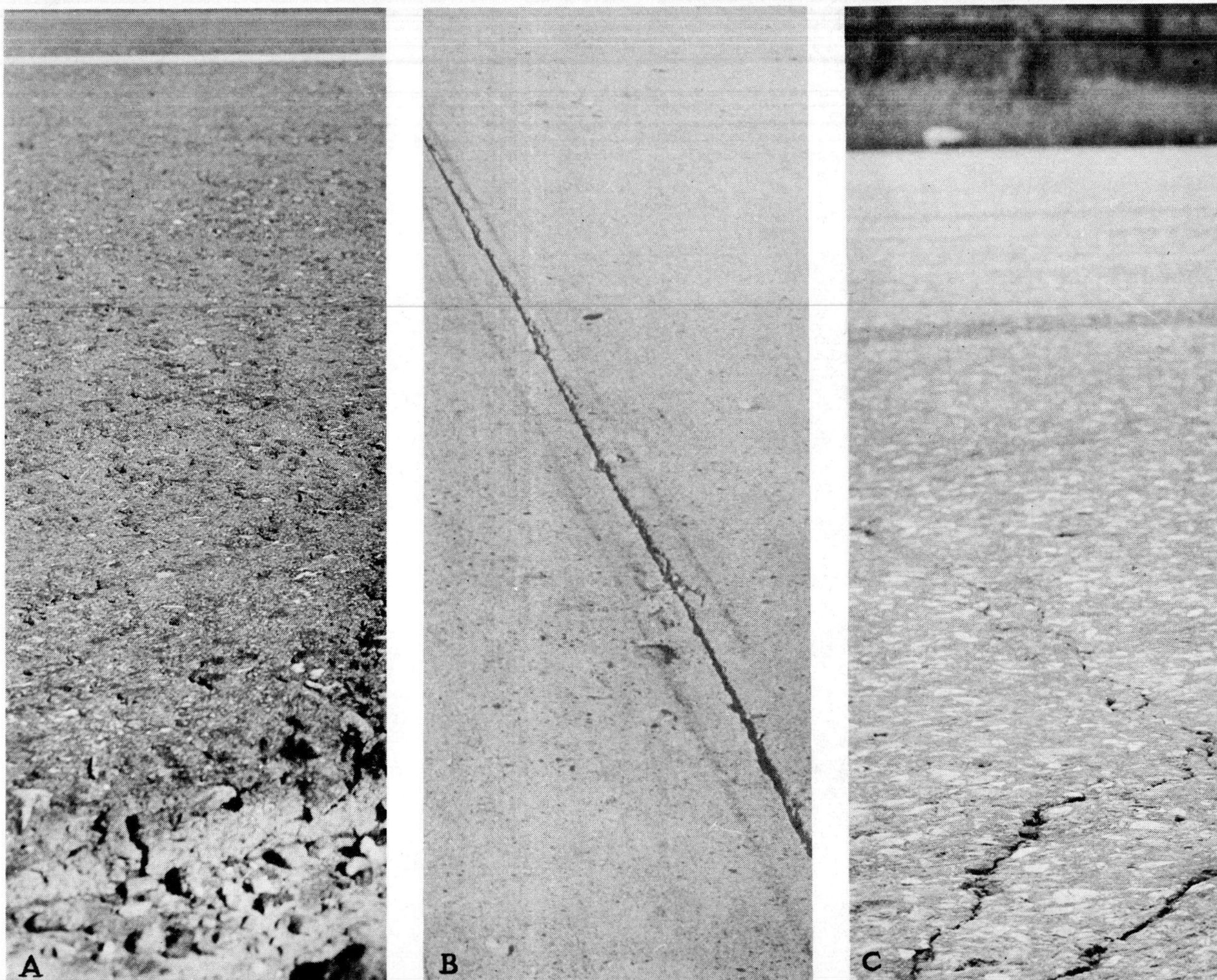
Appendix A

Tires used in research listed by company and serial number.

B.F. Goodrich	U.S. Royal	Firestone	Goodyear
74116 YNL	CT 471197	000177J2EM	E2ES0858
11932 YNL 1	CT 462639	WJ004416C2	E23SH360
11841 YNL 1	CT 437192	WJ003497J2	E23SH262
11878 YNL 1	CT 478138	000178J2EM	E23SH293
11872 YNL 1	CT 414639	000182J2EM	E23SH261
11232 YNL 1	CT 471368	WJ003498J2	E21563G9
11231 YNL 1	CT 437139	WJ000981J2	E23SH221
70186 YNL	CT 461621	WJ003476J2	E2ES0852
70773 YNL	CT 471484	WJ004422C2	E21541G6
11268 YNL 1	CT 471509	WJ001043J2	E2ES085
70613 YNL	CT 461545	000180J2EM	E2ES0845
11372 YNL 1	CT 404668	WJ000975J2	E23SH218

Appendix B - Tire Tread Designs

Appendix C - Test Surfaces



Appendix D - Vehicles Used in Tests

Appendix E - Drag Trailer Dynamometer

Appendix F - Chronopousometer