Minimum Stopping Distance of Automobiles

R. E. Martin, Hanover College

The ever-mounting toll of deaths on the highways due to excessive speeds of automobiles produces a problem of unusual significance. Many factors contribute to these high speeds—better roads, faster cars, use of alcohol, a growing desire for the thrill which results from fast driving, competition in all phases of living, and loose talking about high speeds attained. Certainly anything that can be done to reduce this toll should be done. It was thought that if drivers realized the least distance in which they could stop their cars in the event of necessity, then some of them might drive more carefully.

Of course, work on this phase of the problem is not new, nor is any claim made for originality in the solution of it. However, this problem is important enough that it should be kept before the driving public until something is done to reduce the death toll. Some worthy papers have been published on this problem. The most complete of these that has come to my knowledge is that of the Iowa State College of Agriculture and Mechanical Arts, Bulletin 120. This work at Iowa was conducted for a different purpose than that outlined above, and, of course, the results obtained were used differently. In that work the data were gathered to enable the highway engineer to provide sufficient view of approaching cars at a road intersection, and this information was made available to those engineers and not to the motoring public.

Due to the lack of funds, time, and personnel, the present work does not compare with that mentioned above. But it is thought that this work will bring the problem up to date and present it to a different audience for a different purpose. The fact that the Iowa College repeated its work in 1928 and 1932 after having first performed it in 1924 indicates that this is a problem that should be considered frequently.

The forces that bring a car to rest when in motion may be considered in two groups, (1) the force due to the brakes, (2) the forces due to the compression in the engine, the surrounding atmosphere, and rolling friction. In this work the combined effect of the forces in the second group has been determined. In most of the other papers these forces have been determined separately and their effects either neglected or combined. While various opinions and ideas may be had about the effect of the brakes and also their use, it seems that when an emergency arises the operator of the car will, in most cases, exert all the force he can on the braking system. This being the case, then we can determine the maximum effect, in case the brakes on the car are in good order, by measuring the coefficient of sliding friction and applying it to the problem.

In attacking this problem, then, I measured the coefficient of sliding friction for both new and used tires on the different types of roadway. This was done in the usual manner by dragging over the roadway a two-wheeled trailer equipped with the tires to be tested and measuring the horizontal pull required, with the suitable dynamometers. This pull being known, the coefficient of sliding friction, k, was calculated as follows (Fig. 1): If P represents the horizontal pull, W the total weight

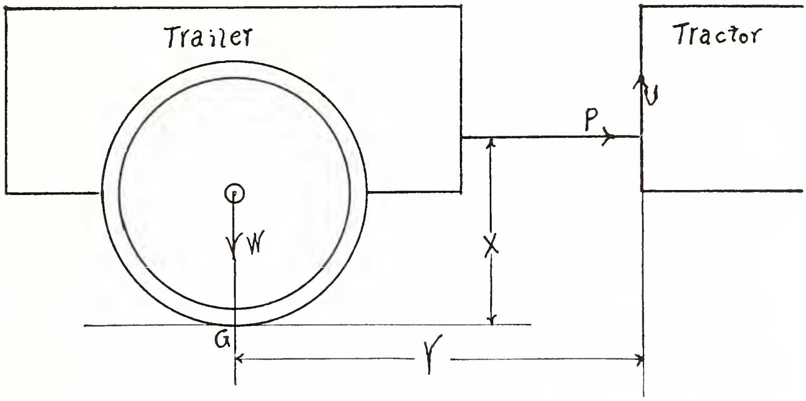

Fig. 1.

of the trailer, U the weight transferred to the tractor by the torque action due to fricion, Y the lever arm of the force U, and X the lever arm of the force P, then, $UP = PX$ (taking moments about G, the point of contact between tire surface and roadway). From the definition of the coefficient of friction, k is equal to W divided by, W minus U. After measuring P, W, X, and Y, k could be determined from the relation, $k = \frac{PY}{WY - XP}$. The values obtained are shown in Tables I-III.

TABLE I—Coefficients of Friction—Concrete Road

Road Wet Speed mi./hr.	Coef.	Road Dry Speed mi./hr.	Coef.
New Tires			
6.0	.55	5.4	.82
10.5	.51	11.0	.75
16.0	.45	15.25	.69
20.0	.41	21.0	.62
26.25	.38	25.5	.58
Old Tires			
4.8	.65	5.0	.74
9.7	.61	10.3	.65
15.1	.50	14.8	.59
20.0	.43	21.0	.52
24.6	.37	25.6	.48

TABLE II—Coefficients of Friction—Asphalt Road

Road Wet Speed mi./hr.	Coef.	Road Dry Speed mi./hr.	Coef.
New Tires			
4.7	.75	5.2	.88
9.8	.66	10.9	.81
15.1	.56	15.6	.77
20.4	.48	21.0	.74
25.0	.43	25.6	.71

Old Tires

4.9	.62	5.0	.81
10.2	.54	10.4	.76
14.8	.46	14.9	.72
21.0	.34	21.0	.68
24.6	.30	25.6	.65

TABLE III—Coefficients of Friction—Limestone Road

New Tires

Road Wet		Road Dry	
Speed mi./hr.	Coef.	Speed mi./hr.	Coef.
4.8	.60	5.1	.61
10.2	.61	9.8	.63
14.9	.63	15.1	.65
20.6	.69	20.2	.70
24.8	.71	25.0	.73
Old Tires			
5.0	.57	4.8	.58
10.2	.59	10.2	.60
15.1	.60	15.0	.64
19.8	.63	20.8	.67
24.6	.65	25.3	.69

It will be noted that these values are for speeds up to approximately 25 miles per hour. This shortcoming, common to all work on this problem, was due in this case to the limitations of the vehicle used to furnish the motive power, namely a tractor ordinarily used to pull a gang lawn mower. The extent of this shortcoming is significant, for at these speeds the stopping distance is not a problem but only becomes so at considerably higher values, say from 50 miles per hour and upward. In an attempt to reach values for the coefficient of friction which would be of service at these higher speeds, the data obtained in the tests were plotted, showing the variation of coefficient of friction with speed, and the curves thus obtained extended up to 50 miles per hour. In extending these curves it is realized that at best this is only an approximation, but in all cases an effort was made to make the error, if any, in the direction of a larger coefficient.

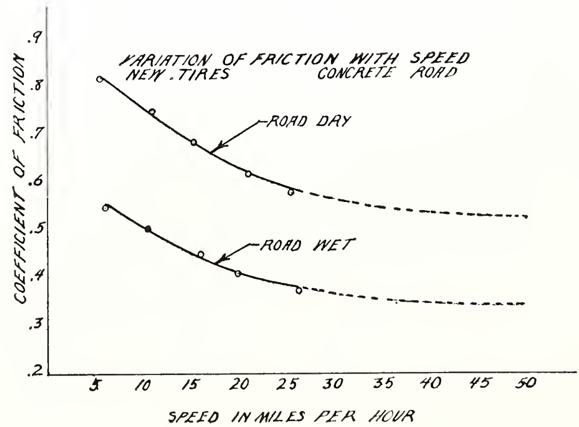

Fig. 2.

In the set of curves shown in Figure 2, which is for new tires on a new concrete road, it is quite evident that when the road is dry the coefficient cannot be more than .48 at 50 miles per hour, and when the road is wet not more than .34 at the same speed. Without any stretch of the imagination, much lower values might be assumed at this higher speed. The next three sets of curves (Figs. 3-5) are similar to the

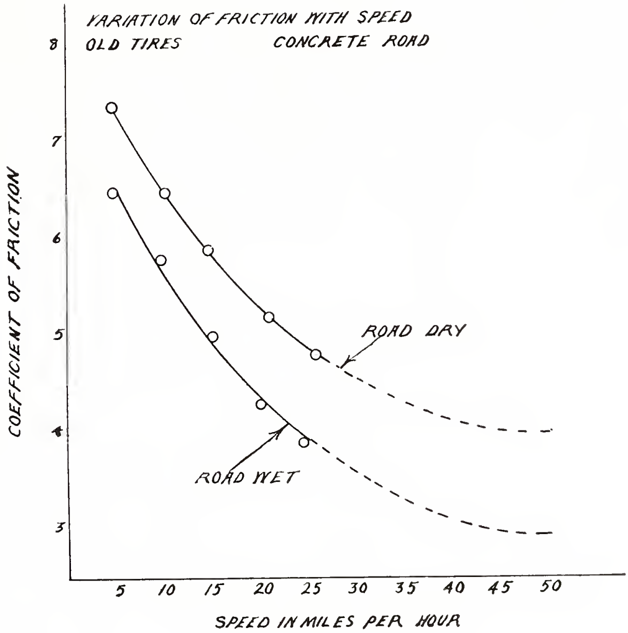

Fig. 3.

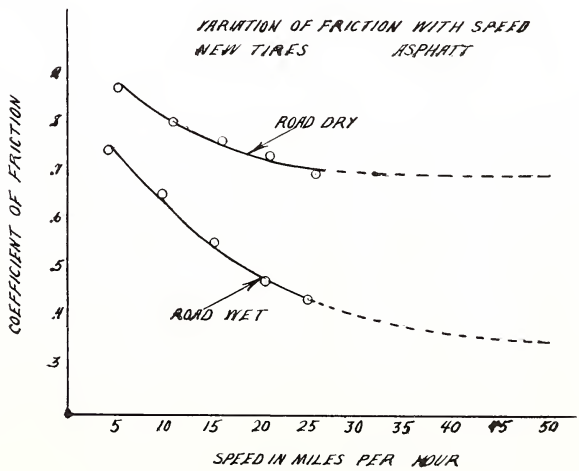

Fig. 4.

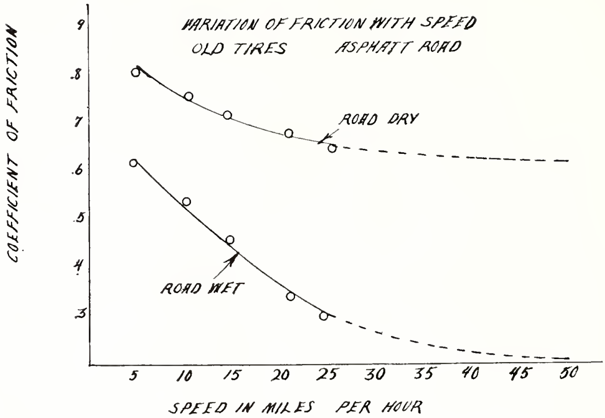

Fig. 5.

first and show conclusively that, for the types of road surfaces which they represent, the coefficient of sliding friction decreased with speed, reaching a value at high speeds much less than that for low speeds.

Now it is these high-speed values that determine the minimum stopping distances with which we are interested. Very few accidents are caused by being unable to stop quickly when traveling at 25 miles per hour. Hence, in my computations, the results of which will be given later, I used the coefficients determined for the speeds involved.

The two sets of curves, Figures 6 and 7, which are for both new and old tires on a well worn limestone road, are interesting in that they show that the coefficient of friction increases with speed. Some interesting results might be obtained by applying the same method of analysis to these curves, but, since high speed roads are not of this character, the results would not be very significant. This increase in coefficient for certain types of roadway has been noted by other experimenters, some of whom attribute it to the roughness of the surface, the effect of which increases with speed. In this work I am interested most in the

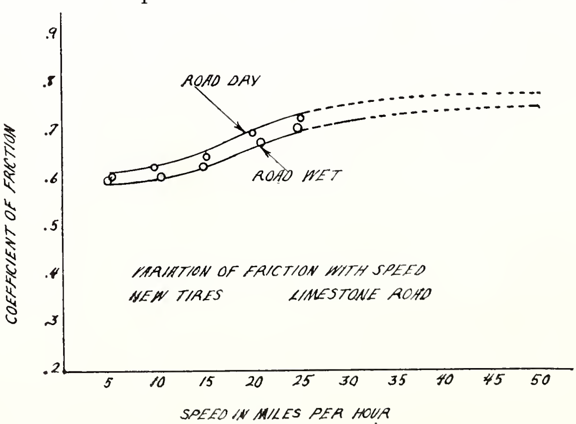

Fig. 6.

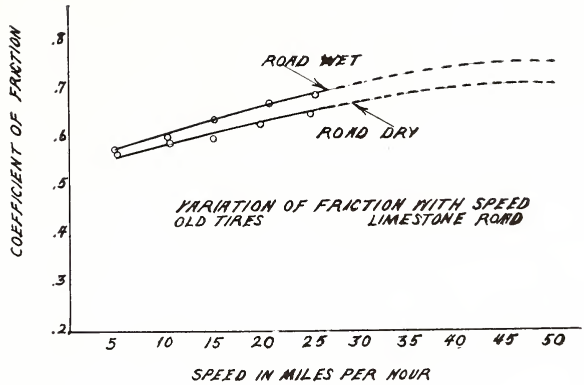

Fig. 7.

values taken from the first four sets of curves since they apply to the most common high-speed roads which we have in Indiana.

Also, the second group of forces mentioned above varies considerably with speed, a fact that I have not found considered by other workers on this problem. I determined this relationship for several cars. While the general trend for each was the same, the numerical values varied considerably, depending upon the model, age, mileage, and other particulars. The method was very simple. Selecting an approximately level strip of

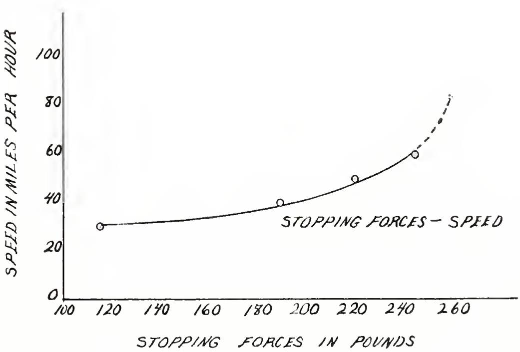

Fig. 8.

roadway, a day without a wind, and a car with an experienced driver, when the desired speed had been obtained, I turned off the ignition, and we let the car run with the clutch in until it stopped. We then measured the distance traveled while coming to rest. We took a similar set of observations while the car was traveling in the opposite direction over the same course so as to eliminate as far as possible the effects of grade and wind. Figure 8 shows a typical set of data. The car used was a

1937-model Chevrolet sedan, which had been driven about 2,000 miles. The mass of this car being known, the combined stopping forces were computed from the following relation: Force $= \frac{MV^2}{2D}$. *M* is the mass in slugs, *V* the velocity in feet per second at the beginning of the test, and *D* is the distance traveled while stopping. The force will then be expressed in pounds. It is evident from the figure that no constant value can be assigned to the resultant of this set of forces, but as speed changes, the value will change.

To combine our stopping forces, let us consider the car mentioned above, whose mass, when loaded with fuel, oil, water, and a 160-pound driver, is 3360 pounds, or, 105 slugs. Since the coefficient of friction varies with speed, and the distance traveled while being brought to rest varies with the square of the initial speed, it is necessary to find a so-called "effective speed" in order to determine the proper coefficient to use. This effective speed is defined as that single speed at which the car would have to travel to cover the same distance in the time which elapses while the car is being brought to rest. It can be shown to be equal to $\frac{V}{\sqrt{3}}$, where *V* is the speed at the instant the brakes are applied. The distance traveled while being brought to rest by the combined action of all the stopping forces is then given by the relation, $D^1 = \frac{MV^2}{2F^1}$, where F^1 is the force due to braking plus all other retarding forces, and the other terms represent the quantities heretofore assigned.

The stopping distance is also dependent on the "reaction" time of the driver. This reaction time has been determined by a number of experimenters recently. One such determination was made in the Indiana University Building at the State Fair of 1936. Due to the kindness of Dr. Frank Elliott, Director of Publicity, the general results of this determination have been made available to me. This "reaction" time has also been determined recently by the Keystone Automobile Association. It is generally believed that this time is slightly more than .5 seconds. But in all of these determinations the person being tested was expecting a signal. If this factor of expectancy is removed, psychologists are of the opinion that the reaction time is increased by at least 50%. While this is not the most important factor in this problem, yet it is of some weight and should be considered. It will account for a few extra feet, and in some automobile wrecks this may mean quite a lot.

The total stopping distance is then given by the relation, $D^{11} = \frac{MV^2}{2F^1} + Vt$, where all symbols have the significance defined above and *t* is the "reaction" time, which I have taken to be .75 seconds. Using this relation the values shown in Table IV were obtained.

TABLE IV—Minimum Stopping Distance

	Concrete Road				Asphalt Road			
	Wet		Dry		Wet		Dry	
Initial Velocity	New tires	Old tires	New tires	Old tires	New tires	Old tires	New tires	Old tires
10 mi./hr.	15 ft.	16 ft.	15 ft.	16 ft.	16 ft.	17 ft.	15 ft.	15 ft.
20	41	45	39	41	43	47	38	39
30	93	97	76	84	87	103	72	75
40	165	160	125	139	149	187	113	119
50	253	257	189	212	232	291	165	171
60	351	372	266	301	338	451	224	237
70	472	489	353	408	463	631	281	289
80	601	670	429	536	578	834	364	395
90	767	859	553	680	735	1007	452	494

From a graph published by Dr. Arthur L. Foley in his College Physics, we find that the minimum stopping distance for a car going 60 miles per hour under ideal conditions of roadway and tire surface is 222 feet. This value is somewhat less than most of mine, which are, 351, 373, 266, 301, 338, 451, 224, and 237, depending upon the type of road surface and the tires used. The Iowa Bulletin mentioned above gives a value of 250 feet for an initial speed of 61 miles per hour on an average surface.

This difference between the values which I have obtained and those of other experimenters is due primarily to the fact that I have used a coefficient of friction which varies with speed, and they have used a coefficient determined at a lower speed than that which would be experienced on the road while the car was being stopped. So far as I have been able to find out, all other experimenters have obtained this variation with speed but have not used it in their computations.

In conclusion, then, may I add that the experimental work which I have done only brings this problem up to date, but the use of the values obtained is new and leads to results quite different from those previously determined. Since life and property are at stake in the application of these results, perhaps this work will justify itself if it calls attention to these larger distances to be expected.

I am deeply indebted to the Research Committee of the Indiana Academy of Science for providing the funds necessary to carry out this experimental work. To Dr. Arthur L. Foley, chairman of that Committee, I am especially indebted for his interest and appreciation of the importance of the work. Mention should also be made of Mr. David Edwin Hine and Louise Martin, two of my students, who assisted me in the work.