

# Skid Resistance of Adjacent Tangent and Nontangent Sections of Roads

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The objective of this study was to compare skid resistance on adjacent tangent and nontangent sections of roadways based on the results of a full-scale field testing program. Test sites were selected in New York State and in Texas to provide data from different climatic regions. It was found that blank-tire skid numbers in both regions are significantly lower on nontangent curved sections than on adjacent tangent straight sections. The ribbed-tire skid number measurements in Texas followed the same pattern; however, no significant difference was found between tangent and nontangent ribbed-tire skid numbers on sites in New York. The absence or presence of winter effects, which stimulate recovery of the pavement microtexture, seem to be responsible for the different observations regarding ribbed-tire data in Texas and New York.

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One of the main conditions for safety of a vehicle negotiating a curve is that the level of tire/pavement friction is sufficiently high to counteract the lateral force developed during cornering. If the lateral force at the tire/pavement interface exceeds available lateral friction force, the vehicle will skid off the road. At the same time, as the friction demand is higher, skid resistance on nontangent (curved) sections is expected to be lower than on adjacent tangent (straight) sections because of the more severe polishing action of traffic.

Heavy trucks, which constitute a significant percentage of highway traffic, are primarily responsible for polishing pavement texture. The lateral tire/pavement forces generated by a tractor-semitrailer in a 450-ft (137-m)-radius curve at 40 mph (64 km/h) are approximately ten times higher than the lateral tire/pavement forces generated by a passenger car under the same conditions. The truck lateral forces calculated using the Phase 4 computer program were 800 lb on tractor front axle and 1,500 lb and 1,600 lb on tractor rear axle and trailer axle, respectively. For a typical medium-size sedan the lateral tire/pavement forces calculated using HVOSM program were 195 lb and 120 lb on the front and rear axle tires, respectively. The consequently expected lower skid resistance, combined with increased demands for pavement friction, makes nontangent sections particularly critical for highway safety.

This paper compares skid resistance on tangent and nontangent sections of roadways to find out if, indeed, the skid resistance in curves is significantly lower than in adjacent straight sections.

## TESTING PROGRAM

The full-scale testing plan developed for this study involved measurements of skid resistance on pairs of adjacent tangent and nontangent sections of roadways. The measurements were conducted using a two-wheel skid tester in accordance with ASTM Method of Test E 274 (1).

When a standard two-wheel trailer is operated on a curve in accordance with the ASTM method, some conditions may cause deviations from the specified procedure:

- Lateral inertial forces acting on the trailer may displace it from its normal attitude relative to the towing vehicle.
- As a result of altered trailer attitude, the force component at the tire/road interface will not act in the plane of the skidding test tire.
- Weight transfer across the trailer caused by the lateral acceleration will change the vertical load on the test tire, which may deviate by more than the allowable amount from the nominal normal load.
- For a radius of curvature less than approximately 400 ft (122 m), it is not possible to maintain a speed of 40 mph (64 km/h) without exceeding acceptable lateral acceleration limits.
- The limited length of nontangent sections may make it impossible to obtain five skid tests along a given curve, thus the curve may have to be tested by repeated passes.
- The influence of the lateral acceleration may cause the distribution of the water film across the tire pavement interface to be unacceptable.

In a study conducted at the Texas Transportation Institute (TTI) (2), it was determined that, compared with other systems, ASTM Method E 274 provided the best all-round performance in the nontangent mode in spite of the limitations already listed. By conducting a series of controlled track tests supplemented by highway tests, researchers determined the accuracy and limitations of this system operating in the nontangent mode. It was found that the limit of maneuverability of the typical ASTM E 274 test trailer in a locked-wheel test occurs when the lateral inertial force caused by road curvature reaches approximately 0.3 to 0.4 g in the two-wheel trailer's horizontal plane. This limit is imposed by the finite capability of the second trailer wheel, which is rolling freely on dry pavement, to generate the side force necessary to keep the trailer on course. It was also determined that, to obtain accurate measurements in nontangent sections, the trailer must be capable of measuring both the longitudinal traction force and the dynamic vertical load on the test wheel. These forces are then used to compute the skid number. When force transducers capable of measuring these two forces are used, the

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TABLE 1 SKID NUMBER MEASUREMENTS FOR NEW YORK SITES, 1986

Site	May 15		June 18		July 16		August 4		Sept. 11		Oct. 16		Nov. 18	
	SNB	SNR	SNB	SNR	SNB	SNR	SNB	SNR	SNB	SNR	SNB	SNR	SNB	SNR
1S	42.3	56.7	44.8	57.7	38.1	58.1	40.0	53.9	42.9	57.0	36.6	52.3	42.2	52.1
1R	40.3	55.3	43.4	55.5	37.7	58.3	40.0	54.4	41.7	57.0	39.7	52.5	39.5	51.8
2S	51.9	54.7	54.5	55.8	61.3	51.2	50.5	52.8	50.9	51.0	49.4	52.4	47.8	50.4
2R	50.2	53.0	51.9	54.1	57.3	51.9	52.8	55.9	49.9	51.7	46.4	49.6	49.8	50.2
3S	36.6	36.8	41.9	40.8	38.5	40.9	38.1	37.6	35.2	34.2	36.5	36.8	37.1	36.0
3L	34.9	41.3	39.0	47.0	35.4	43.1	38.1	41.8	33.2	44.9	34.9	40.8	35.4	41.0
3R	29.2	32.5	35.1	38.8	32.9	37.7	31.0	34.6	28.9	34.1	28.9	33.0	29.7	33.2
4S	21.9	45.1	21.7	45.0	22.0	47.1	22.5	45.1	22.2	39.5	20.9	44.3	24.2	42.2
4R	23.3	48.3	22.7	47.8	23.0	51.4	22.2	47.8	22.6	44.0	22.4	45.0	24.9	45.8
5S	39.1	57.3	40.1	56.8	32.5	60.8	38.6	56.5	40.4	55.1	34.3	57.4	34.3	55.6
5R	29.7	54.3	31.8	57.5	24.2	58.8	28.9	56.6	29.7	54.2	26.2	58.5	28.9	56.7
6S	21.0	39.5	23.5	39.5	23.3	44.0	20.7	36.7	20.5	37.5	20.4	40.2	23.3	37.0
6L	16.8	34.7	19.6	35.6	19.0	42.3	17.4	32.8	16.0	32.6	16.9	35.7	19.1	32.4
7S	22.4	35.5	24.2	34.8	24.9	41.1	22.6	35.1	21.0	34.1	23.0	36.4	21.6	35.2
7R	22.9	36.0	22.8	37.6	24.1	38.9	22.0	35.7	20.5	34.6	25.8	37.7	23.2	36.2

S = tangent section; R = nontangent, right curve; L = nontangent, left curve

SNB = Skid Number with the blank test tire; SNR = Skid Number with the ribbed test tire

errors caused by the inertial forces and load transfer on the trailer are insignificant.

The TTI study concluded that the accuracy of the skid number measurements on nontangent sections is comparable with that of tangent sections, provided the tested curves do not generate lateral accelerations in excess of 0.3 g and the instrumentation system measures both the longitudinal and vertical force components. Moreover, the study recommended that testing on nontangent sections be avoided when the water tank level is low because the water may move away from the water outlet of the tank unless the tank is specially baffled.

The skid tester used in this study was equipped with force transducers measuring the tire/pavement force components

in longitudinal and vertical directions. Also, following the TTI recommendations, nontangent test sections with a radius of curvature no less than 450 ft (137 m) were selected. At 40 mph (64 km/h) the maximum lateral acceleration on a curve with a 450-ft (137-m) radius is 0.25 g. Both ribbed and blank standard ASTM test tires were used in the program (3, 4).

Because weather conditions affect the skid resistance of road surfaces (5), the testing was conducted on sites in New York State and Texas. Eight pairs of adjacent tangent and nontangent sections were selected in New York State and four pairs in Texas. All curves were "soft," generating lateral accelerations of less than 0.25 g at the test speed of 40 mph (64 km/h). Both bituminous and concrete pavements were tested.

To determine if significant seasonal changes are present in the data, the skid resistance measurements in New York State were repeated at approximately monthly intervals from May through November.

### TEST RESULTS

In both New York and Texas ribbed- and blank-tire measurements were made on all sites, following the same wheelpath with both tires. The results of the measurements are given in Tables 1 and 2.

To determine whether a statistically significant difference existed between skid numbers on tangent and nontangent sections of the same roads, the following regression model was used to relate the tangent and nontangent data:

$$SN_T - SN_{NT} = \alpha SN_T \quad (1)$$

where  $SN_T$  is a skid number on a tangent section of the road and  $SN_{NT}$  is a skid number on an adjacent nontangent section. The values of  $\alpha$  for each monthly set of data using linear regression are listed in Table 3. Also given in Table 3 are the  $t$ -ratios that indicate that the regression coefficient can be considered statistically significant. The results of the computation are shown in Table 3. The values of the parameter  $\alpha$  are also plotted in Figure 1 for May through November 1986.

In Texas, four pairs of adjacent tangent and nontangent sections of roads were tested. Only two sets of data were collected, one in July 1985 and the other in November/December 1985, since small seasonal effects were not expected to be a factor under Texas climatological conditions. The model used in the New York data analysis, Equation 1, was applied to relate tangent and nontangent skid numbers for the four Texas sites. The results of the linear regression analysis are shown in Table 4.

TABLE 2 SKID NUMBER MEASUREMENTS FOR TEXAS SITES, 1985

Site	July		Nov./Dec.	
	SNB	SNR	SNB	SNR
1S	40.6	44.9	39.2	38.3
1R	36.7	39.8	35.5	35.3
2S	48.6	51.5	50.9	48.8
2L	46.5	46.9	48.2	43.2
3S	50.9	54.1	53.4	51.0
3L	48.5	49.5	52.2	48.1
4S	11.0	18.4	13.5	21.7
4R	8.5	16.6	11.4	18.9

S = tangent section; R = right curve; L = left curve

SNB = Skid Number with blank tire

SNR = Skid Number with ribbed tire

### DISCUSSION OF THE RESULTS

The results obtained with the ribbed and blank tires at the New York sites, as presented in Table 3 and in Figure 1, differ considerably from each other. For the ribbed tire, the param-

TABLE 3 RESULTS OF REGRESSION ANALYSIS OF NEW YORK DATA

		May 15	June 18	July 16	Aug. 14	Sept. 11	Oct. 16	Nov. 18
Ribbed	Parameter $\alpha$	0.0214	-0.0033	0.0041	-0.0148	-0.0107	-0.0033	-0.0086
Tire	$t$ -ratio	0.83	-0.13	0.22	-0.67	-0.33	-0.13	-0.34
Blank	Parameter $\alpha$	0.0909	0.0895	0.0886	0.0618	0.0930	0.0693	0.0613
Tire	$t$ -ratio	2.56	3.40	3.13	1.47	2.50	1.56	1.74

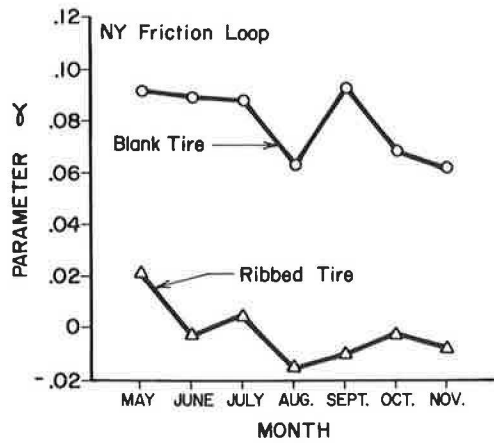


FIGURE 1 Difference between skid resistance on adjacent tangent and nontangent roads in New York in terms of Parameter 2, Equation 1.

eter  $\alpha$  was close to zero and the values of the  $t$ -ratio were also very small, which indicates that there is no significant difference between skid numbers on adjacent tangent and nontangent sections.

The parameter  $\alpha$  for the blank tire varied between 0.06 and 0.09, which corresponds to a 6 to 9 percent difference between skid numbers on adjacent tangent and nontangent sections of the same paving project. Furthermore, since the parameter  $\alpha$  is always positive, it can be said that the blank-tire skid numbers on tangents are 6 to 9 percent higher than on adjacent curves. The relatively high  $t$ -ratio values confirm the statistical meaningfulness of the results.

The different results obtained with the two tires indicate that the pavement macrotexture and microtexture are subject to different processes on tangent and nontangent road sections. The limited amount of experimental data collected in this project allows for only a hypothetical explanation. Macrotexture is reduced more by wear and compaction, while microtexture is reduced more by polishing. Both effects seem to be more pronounced on nontangent than on tangent sections of roads, even though the nontangent sections are limited to relative "soft" curves. (The lateral acceleration at 40 mph [64 km/h] does not exceed 0.25 g.) It appears, however, that the microtexture recovers during the winter months so that the ribbed-tire skid numbers show little difference between tan-

gents and curves. The pavement macrotexture, on the other hand, does not recover, or does not recover completely, during the winter; hence, a significant difference is observed between the blank-tire skid numbers on tangent sections and those on nontangent sections.

The magnitude of the difference between the blank-tire skid numbers on tangent and nontangent sections varies among the test sites. This may be explained by considering the long-term changes in skid number on both types of sections. Assuming, as before, that the pavement macrotexture does not recover during the winter, the blank-tire skid numbers on both tangent and nontangent sections will decrease in time; and the rate of the decrease will be higher for the nontangent sections because of the more severe wear and surface compaction by traffic. If the changes of the blank-tire skid numbers have an approximately exponential character, as shown in Figure 2, the difference will change with time, as shown in Figure 3. The curve of Figure 3 starts at zero because the skid numbers are expected to be the same when the pavement is new. With time, and with progressing wear of the surface macrotexture, the difference increases, reaches a maximum, and then decreases, approaching zero when the macrotexture of both tangent and nontangent sections becomes heavily worn. Three stages of pavement wear—none, light to moderate, and heavy—are indicated in Figure 3. Although it is impossible to define the three stages precisely, it can generally be concluded that the difference in the blank-tire skid numbers on tangent and nontangent sections of roads is largest at the stage

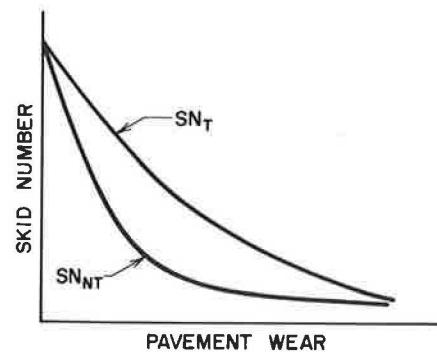


FIGURE 2 Blank-tire skid number of adjacent tangent ( $SN_T$ ) and nontangent ( $SN_{NT}$ ) sections versus pavement wear.

TABLE 4 RESULTS OF REGRESSION ANALYSIS OF TEXAS DATA

Tire		July 1985	Nov./Dec. 1985
Ribbed	Parameter $\alpha$	0.0927	0.0949
	$t$ -ratio	5.37	5.29
Blank	Parameter $\alpha$	0.0953	0.0958
	$t$ -ratio	6.80	4.62

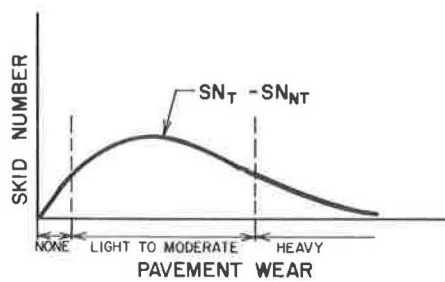


FIGURE 3 Difference between skid numbers on adjacent tangent and nontangent sections versus pavement wear.

of light-to-moderate wear of the pavement macrotexture and is very small on new and on heavily worn pavements.

Figure 4 shows the difference between the measured blank-tire skid numbers for sites in New York and Texas and the blank-tire skid numbers on nontangent test sections, which is here considered a measure of wear of the pavement macrotexture. There is a considerable scatter of data in this plot, but it should be kept in mind that these data points represent a variety of pavement materials, various levels of average daily traffic, and the drastically different climatic conditions of New York and Texas. It should not be expected, therefore, that these data points will form a smooth curve similar to that in Figure 3. Such a smooth curve could be obtained, provided the conceptual explanation offered here is sound, only if all data points represented the same pavement at different stages of wear. Nonetheless, the distribution of the data in Figure 4 suggests that the difference between skid numbers on tangent and nontangent sections is very small if the blank-tire skid number on the nontangent section is greater than 40. A blank-tire skid number of 40 might therefore separate new from lightly to moderately worn pavements. The cutoff between lightly to moderately worn and heavily worn pavements is less obvious, but a value of 20 for the blank-tire skid number can tentatively be considered the borderline. In summary, the difference between the blank-tire skid numbers on tangent and nontangent sections of roads should be expected to be very small if the blank-tire skid number on the nontangent section is either greater than 40 (new pavements) or less than 20 (pavements with heavy wear of the macrotexture).

The ribbed-tire results from the Texas sites are quite different from the New York results. The ribbed-tire skid numbers on nontangent sections are significantly and consistently lower than on tangent sections. Thus, the ribbed-tire data from Texas follow the same pattern as the blank-tire data, which is in accordance with the earlier explanation of the blank-tire results from the New York sites except that in Texas the pavement macrotexture does not recover, or does not recover completely, because of the absence of winter effects.

## CONCLUSIONS

The level of skid resistance on nontangent sections of roadways is usually lower than on adjacent tangent sections. The decrease in skid resistance combined with increased demand for friction by a vehicle negotiating a turn may create serious safety problems in the curved sections of roadways.

The difference between frictional characteristics of pave-

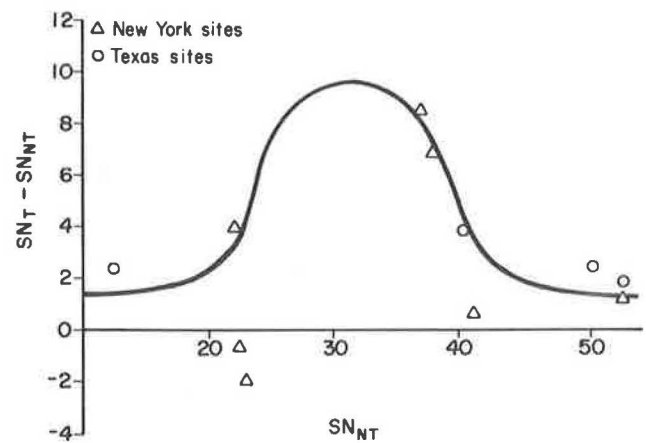


FIGURE 4 Difference between blank-tire skid numbers on adjacent tangent and nontangent sections versus skid numbers on nontangent sections.

ments on adjacent tangent and nontangent sections of roads depends on the climatic conditions in the region. At northern latitudes (New York State) no significant difference was found in the pavement microtexture measured by the ribbed-tire skid number. The blank-tire skid number of the same sites, which characterizes pavement macrotexture, was consistently lower, by 6 to 9 percent, on nontangent sections. At southern latitudes (Texas) both ribbed- and blank-tire skid numbers on nontangent sections were lower than on the adjacent tangent sections. The difference in the ribbed-tire skid numbers can be explained by the lack of winter effects that would stimulate recovery of pavement microtexture observed in the northern climate.

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## REFERENCES

1. Standard Test Method for Skid Resistance of Paved Surfaces Using a Full Scale Tire, E 274-85. *Annual Book of ASTM Standards*, Section 4, Vol. 04.03, 1987, pp. 755-762.
2. R. A. Zimmer and R. D. Tonda. Pavement Friction Measurements on Nontangent Sections of Roadways. Comprehensive Report FHWA/RD-82/150, Vol. 11. FHWA, U.S. Department of Transportation, 1983.
3. Standard Specification for Standard Tire for Pavement Skid-Resistance Tests, E 501-82. *Annual Book of ASTM Standards*, Section 4, Vol. 04.03, 1987, pp. 777-781.
4. Standard Specification for Smooth-Tread Standard Tire for Special-Purpose Pavement Skid-Resistance Tests, E 524-82. *Annual Book of ASTM Standards*, Section 4, Vol. 04.03, 1987, pp. 790-793.
5. S. H. Dahir and J. J. Henry. Seasonal and Short-Term Variations in Skid Resistance. In *Transportation Research Record 715*. TRB, National Research Council, Washington, D.C., 1979, pp. 69-76.

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