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# Driving Dynamic Considerations: A Comparison of German and American Friction Coefficients for Highway Design

RUEDIGER LAMM

## ABSTRACT

One of the main safety goals in developing new German Guidelines for the Design of Rural Highways was to overcome previous driving dynamic deficiencies and to enhance traffic safety by increasing friction supply wherever possible. The objectives of this paper are to discuss the German approach in determining new tangential and side friction factors with respect to design speed and to compare these values with those currently in use in the United States. The comparison showed that for design speeds greater than 80 km/h (50 mph), the maximum allowable tangential and side friction factors used in the United States are definitely higher than the German values. Accordingly, the computations for minimum stopping-sight distances and minimum radii of curve showed for all investigated cases and driving dynamic models smaller values in the United States than in Germany. Therefore, there is no doubt that, on the one hand, the American rural highway design is more economic but, on the other hand, the German values provide higher friction supply in critical driving situations. Finally, a preliminary study between road sections conducted according to the new German design guidelines and those with old horizontal and vertical alignment showed, on average, a 1.67 times lower accident rate for the redesigned road sections. This result is confirmed by a new research

report for the Minister of Transportation of the Federal Republic of Germany, which will soon be published.

In the 1960s and the early 1970s the number of fatal traffic accidents and the number of heavy injuries increased in an unconscionable way in the Federal Republic of Germany. Many of these fatal accidents occurred on two-lane rural roads when the original design speed was exceeded by a substantial amount. Therefore, the demand for developing and introducing new guidelines, especially for two-lane rural highways, became more urgent. The main objective for the responsible Committee for Highway Design of the German Research Association for Road Engineering was to enhance traffic safety wherever possible.

The following driving dynamic considerations represent one main safety goal of the German Guidelines for the Design of Rural Highways (1,2). Other goals, which are directed to achieve operational consistency and to improve driving safety and comfort through a more uniform and balanced design of highway alignment, will be addressed in another publication.

One of the cardinal rules in horizontal alignment design is that friction supply should be greater than friction demand. With the revision of the German Guidelines for the Design of Rural Highways in the early 1970s, one of the main objectives was to check the conditions of friction between wheels and road. For example, a comparison between the guidelines used in the United States, the Federal Republic of Germany, and other countries had shown that there were enormous differences between the selection of allowable side friction factors and, result-

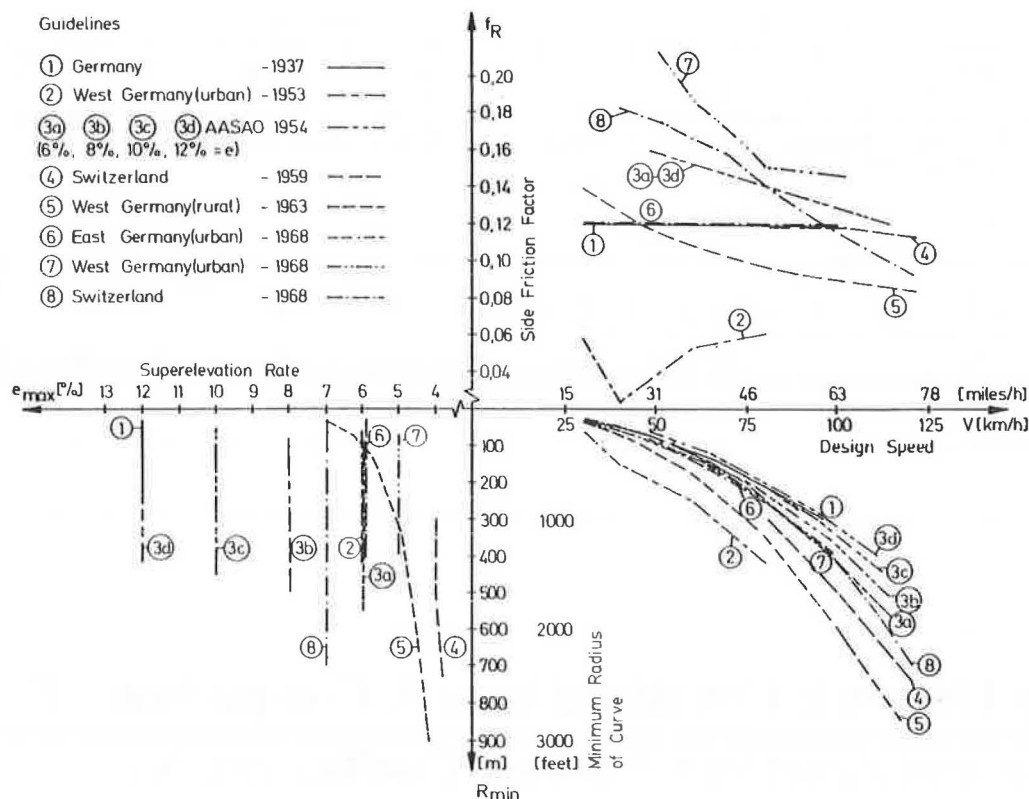


FIGURE 1 Side friction factors, minimum radii, and maximum superelevation rates for different countries and decades.

ing from that, between allowable minimum radii and maximum superelevation rates. Figure 1 shows some examples of such relations in different countries, as applied in the 1950s and 1960s.

Furthermore, previous studies about the forces that are necessary to keep the driving direction in curves as well as to accelerate and decelerate are mostly based on the premise that the vehicle can be considered as a rigid body and that the supporting forces can be imagined acting in the center of gravity. In doing so, the vehicle is idealized as a point of mass. However, it is easy to realize that such an explanation will not be able to determine the actual forces acting on each wheel of the vehicle and the strains of the resulting friction. Therefore, to overcome previous driving dynamic deficiencies and to enhance traffic safety, new principles for tangential and side (radial) friction factors were developed. These factors were taken as a basis for the highway design guidelines of the Federal Republic of Germany (1,2). The goal was to reduce the driving dynamic safety risk that may be involved by the selection of improper design elements and sequences in horizontal and vertical alignment.

#### TANGENTIAL FRICTION FACTOR

Based on skid-resistance measurements that have been conducted by the Institute of Road and Traffic Engineering at Berlin Technical University (3) (Figure 2), the following quadratic equation was developed by the author and Herring (4):

$$f_{Tmax} = 0.214 (V/100)^2 - 0.64 (V/100) + 0.615 \quad (1)$$

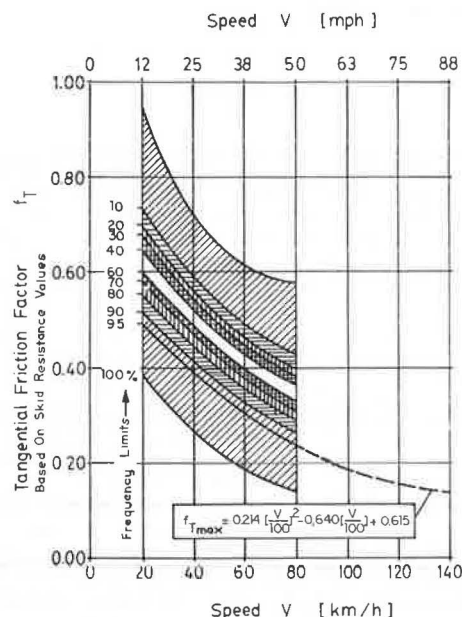


FIGURE 2 Results of measurements of skid-resistance values on wet road surface (3), Federal Republic of Germany.

where  $f_{Tmax}$  is the maximum allowable tangential friction factor and  $v$  is the vehicle speed (km/h).

By this equation the maximum allowable tangential friction factor corresponds to the skid-resistance values of 95 percent of new pavements in the Federal Republic of Germany (Figure 2). That means that by using these tangential friction values, only in 5

percent of any new road surfaces may the application of these values be invalid. Thus Equation 1 promotes high driving dynamic safety.

A similar percentile distribution of the relation between friction capability and vehicle speed for 500 pavements in one state of the United States is shown in Figure 3 (5).

The data in Table 1 give the maximum allowable tangential friction factors for wet pavements with respect to the design speed applied in the German highway design guidelines and the comparable American values of the AASHO Blue Book (6). Note that the maximum allowable tangential friction factors applied for highway design in the United States for

design speeds  $V_d > 80$  km/h (50 mph) are definitely higher than the German values. This means that for critical driving maneuvers, the tangential friction supply in the United States is accordingly smaller, but safe performance of desired maneuvers is dependent on the existence of sufficient friction. For example, a comparison of the 95 percent curve of Figure 2 and the 5 percent curve of Figure 3 shows that there is a certain conformity between American skid numbers and German skid-resistance values, especially for design speeds  $> 80$  km/h, although these values naturally are not directly comparable.

Most excessive speed accidents happen on two-lane rural roads. Since 1973 the Federal Republic of Germany has set a general speed limit of 100 km/h (~60 mph) for two-lane rural highways. Compared to the overall speed limit of about 90 km/h (55 mph) in the United States, the driving behavior on two-lane rural roads may be expected to be similar in both countries.

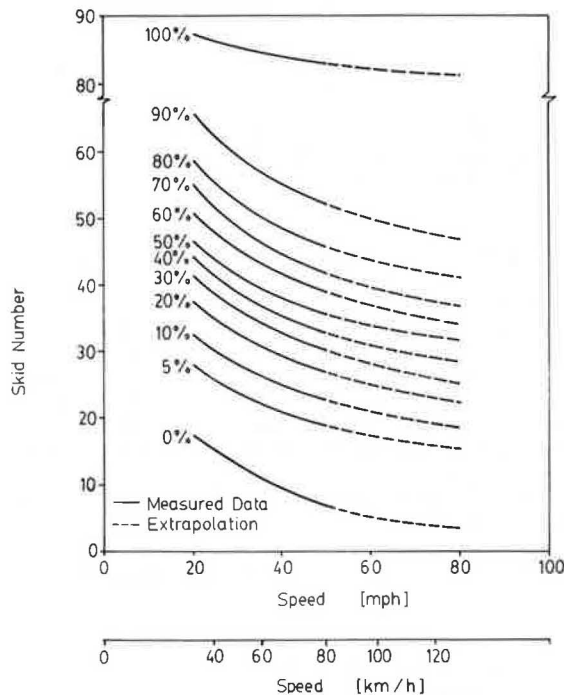


FIGURE 3 Percentile distribution of relation between friction capability and vehicle speed for 500 pavements in one state (5), United States.

#### SIDE (RADIAL) FRICTION FACTOR

In the past in the Federal Republic of Germany obvious discrepancies between design speeds and actual driving speeds measured in horizontal curves have been noticed. Typical speed distributions from 10 to 15 years ago are shown in Figure 4. Note that more than 80 percent of the vehicle drivers exceeded the design speed of  $V_d = 60$  km/h (~40 mph), even on wet pavements.

TABLE 1 Maximum Allowable Tangential Friction Factor and Design Speed Relationship

Design Speed, $V_d$ (km/h)	$f_{Tmax}$	
	Germany	United States
40	0.40	~0.37
60	0.31	0.33
80	0.24	0.31
100	0.19	3.30
120	0.16	0.28
140	0.14	~0.26

Note: 1 km/h = 0.621 mph.

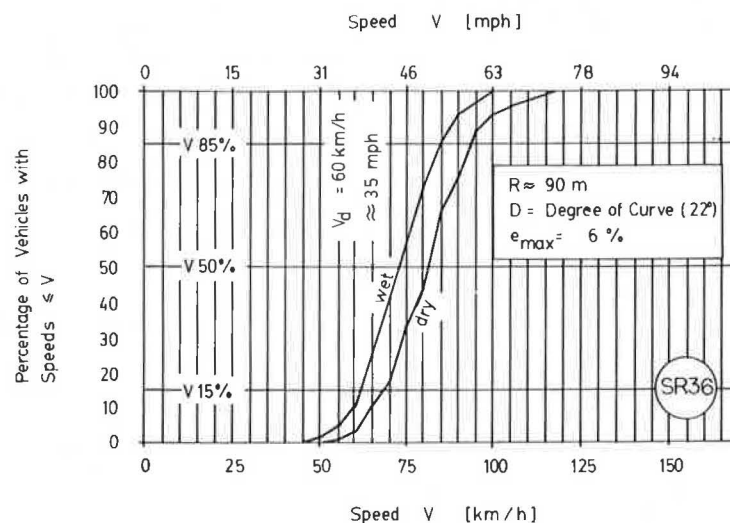


FIGURE 4 Characteristic speed distributions for collectives of passenger cars under free-flow conditions on dry and wet road surfaces, State Route 36, near Karlsruhe, southwest Germany.

Therefore, it was also important to provide a sufficient friction supply for side friction factors. After extensive investigations (4), the German Committee for Highway Design decided that the side friction factors shall be limited to 40 percent of the maximum allowable tangential values for rural highways and to 70 percent for urban roads (1,2). Thus the equation for the maximum allowable side friction factor for rural highways is

$$f_{Rmax} = 0.925 \cdot 0.4 f_{Tmax} \quad (2)$$

The factor 0.925 represents only tire-specific influences.

The general relationship between utilized side friction ratios and still available tangential friction ratios can be computed by the formula

$$f_R/f_{Rmax} = \sqrt{1 - (f_T/f_{Tmax})^2} \quad (3)$$

This formula was developed by Krempel (7) for vehicle tires; the results are given in Table 2. Note

**TABLE 2 Relationship Between Utilized Side Friction Ratios and Still Available Tangential Friction Ratios**

$f_R \times 100\%/f_{Rmax}$	$f_T \times 100\%/f_{Tmax}$
0	100
10	99.5
20	98.0
30	95.4
40	91.6
50	86.6
60	80
70	71.4
80	60
90	43
100	0

that by using 40 percent of side friction there is still more than 90 percent available for friction in the tangential direction. By this procedure, considerable dynamic safety reserves are still available in the tangential direction in spite of using the maximum allowable side friction factors.

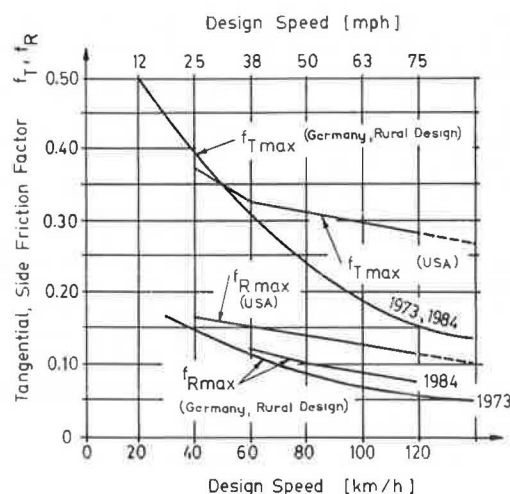
The German and American values for maximum allowable side friction factors for wet pavement conditions are given with respect to design speed in Table 3.

**TABLE 3 Maximum Allowable Side Friction Factor and Design Speed Relationship**

Design Speed, $V_d$ (km/h)	$f_{Rmax}$	
	Germany	United States
40	0.15	~0.16
60	0.11	0.15
80	0.09	0.14
100	0.07	~0.13
120	0.06	0.11
140	0.05	~0.10

Note: 1 km/h = 0.621 mph.

Figure 5 gives an overview of the maximum allowable side and tangential friction factors of the German guidelines and for highway design in the United States with respect to the design speed. Note that for design speeds greater than 60 km/h, the American values are higher than the German values. As the design speed increases, the gap widens.



**FIGURE 5 Maximum allowable side and tangential friction factors in the Federal Republic of Germany and in the United States.**

#### MINIMUM STOPPING-SIGHT DISTANCES

The minimum stopping-sight distance (SSD) is the sum of two distances: (a) the distance traversed by a vehicle from the instant the driver sights an object for which a stop is necessary to the instant the brakes are applied (brake reaction and perception distance), and (b) the distance required to stop the vehicle after the brake application begins (braking distance) (8).

SSD on a level roadway, therefore, may be computed by the formula

$$SSD = (V/3.6) \cdot t + [V^2/(3.6^2 \cdot 2g \cdot f_{Tmax})] \quad (4)$$

where

- SSD = stopping-sight distance (m),
- V = speed (km/h),
- t = brake reaction and perception time (sec) (usually 2.5 sec),
- $f_{Tmax}$  = maximum allowable coefficient of tangential friction on wet pavements, and
- g = acceleration of gravity (m/sec<sup>2</sup>).

The data in Table 4 give the computed SSDs by Equation 4 for both countries by using the tangential friction factors of Table 1 and a brake reaction and perception time of 2.5 sec. As expected, the American values are lower for design speeds  $V_d \geq 80$  km/h (50 mph).

But neither country built their highways according to Equation 4, perhaps because of the high cost involved. As a compromise, Germany selected a brake

**TABLE 4 Minimum SSD and Design Speed Relationship, Grade (G) = 0 Percent, Computed by Equation 4**

Design Speed, $V_d$ (km/h)	SSD (m)	
	Germany	United States
40	43	45
60	87	85
80	160	137
100	276	200
120	437	285

Note: 1 km/h = 0.621 mph, 1 m = 3.28 ft.

reaction and perception time of only 2.0 sec and introduced a new SSD formula that included air resistance (4):

$$SSD = \{V/1.8\} + (1/g) \int \{v/[f_{Tmax} + (W_L/G)]\} dv \quad (5)$$

with

$$f_{Tmax} = 2.773 \cdot v^2 \cdot 10^{-4} - 2.304 \cdot v \cdot 10^{-2} + 0.615 \quad (6)$$

and

$$W_L/G = (0.5 \cdot C_W \cdot F \cdot 0.13 v^2)/G \quad (7)$$

where

$v$  = speed (m/sec),  
 $W_L$  = air resistance (10N),  
 $C_W$  = shape factor of the vehicle,  
 $F = 0.9 \cdot B \cdot H$  (m<sup>2</sup>),  
 $B$  = width of the vehicle (m),  
 $H$  = height of the vehicle (m), and  
 $G$  = weight of the vehicle (kg).

For a representative vehicle (German Opel 1700 and German Ford 17 M, respectively),  $W_L/G$  becomes

$$W_L/G = (6.5 \cdot 0.39 \cdot 2.4/1065)v^2 \cdot 10^{-2} = 0.571 \cdot v^2 \cdot 10^{-4} \quad (8)$$

The computed results of Equation 5 for SSDs used in German highway design today are given in Table 5 (1,2,6).

TABLE 5 Minimum SSD and Design Speed Relationship, Grade (G) = 0 Percent (1,2,6)

Design Speed, $V_d$ (km/h)	SSD (m)	
	Germany	United States
40	36	42
60	70	73
80	117	105
100	186	520
120	274	675

Note: 1 km/h = 0.621 mph, 1 m = 3.28 ft.

On the American side, the SSDs are not computed for the original design speed, but for assumed speeds for wet pavement conditions that are lower than the design speeds. For example, in the Blue Book (6) an assumed speed of 44 mph is used for a design speed of 50 mph, or an assumed speed of 58 mph is used for a design speed of 70 mph. The results are given in Table 5.

Comparing the values, it can be seen that the minimum SSDs applied in highway design in the United States are shorter than the German ones for design speeds  $V_d \geq 80$  km/h (50 mph). That means, on the one hand, a more economic design based on U.S. values, but on the other hand, the German values provide greater minimum SSDs for critical driving situations.

The data in Tables 4 and 5 indicate that significantly different minimum SSDs could be computed by applying different models and tangential friction factors. To decide where the critical margin lies is a crucial consideration for engineers concerned with both cost and safety.

## MINIMUM RADII OF CURVES

Fundamentally, the radius of a curve should be as large as possible and the radii of sequent curves should be in a balanced relation. For balance in highway design, all geometric elements should provide, as far as economically feasible, safe and continuous operation at a certain design speed used as overall control. According to Fites and Jacobs (8):

A vehicle moving in a circular path is forced radially outward by centrifugal force. This force is resisted by the vehicle weight component due to the superelevation of the roadway and by the side friction between the tires and the roadway surface.

If the vehicle is not in a skid, these forces are in equilibrium and are represented by the formula...

$$f_R + e = V_d^2/127R \quad (9)$$

and

$$R = V_d^2/127(f_R + e) \quad (10)$$

where

$e$  = superelevation rate (m/m),  
 $f_R$  = side friction factor,  
 $V_d$  = design speed (km/h), and  
 $R$  = radius of curve (m).

The selection of the minimum radii of curves depends on the design speed, the maximum superelevation, and the maximum allowable side friction factor. The maximum side friction factors are given in Table 3 for German and American highway design. For a comparison of the minimum radii, a maximum superelevation of  $e_{max} = 0.06$  is selected. This superelevation rate has been applied in Germany as the maximum value in rural highway design since 1973 (1), although in the United States the same value is usually applied only in urban areas. The data in Table 6 give the minimum radii of curve with respect

TABLE 6 Minimum Radii of Curve and Design Speed Relationship, Superelevation Rate  $e_{max} = 0.06$

Design Speed, $V_d$ (km/h)	$R_{min}$ (m)	
	Germany	United States
60	160	140
80	350	250
100	600	420
120	1000	660

Note: 1 km/h = 0.621 mph, 1 m = 3.28 ft.

to the design speed for both countries. Because of the smaller side friction values applied for rural highway design in the Federal Republic of Germany (compare Table 3 and Figure 5), the minimum radii of curve are greater than the American values. The differences are about 30 to 35 percent for design speeds  $V_d \geq 80$  km/h (50 mph).

Perhaps because the current German solution is too generous, a new proposal for minimum radii in rural highway design of the 1980s is being developed, including a maximum superelevation  $e_{max} = 0.07$ , and exceptionally  $e_{max} = 0.08$ . Probably the new German design guideline will be introduced in 1984 or 1985. Together with the superelevation, the side



friction factors are increased slightly too (see Figure 5). In this case the utilization ratios of side friction corresponding to Equation 3 will be increased to a maximum of 50 percent. The data in Table 2 indicate that, by using 50 percent of side friction, there is still more than 85 percent available for friction in the tangential direction for unexpected driving maneuvers. The intended new German minimum radii of curve for a maximum superelevation rate  $e_{\max} = 0.07$  and the comparable American values are given in Table 7 with respect to the design speed.

TABLE 7 Minimum Radii of Curve and Design Speed Relationship, Superelevation Rates  $e_{\max} = 0.07$  and  $0.08$

Design Speed, $V_d$ (km/h)	$R_{\min}, e_{\max} = 0.07$ (m)		$R_{\min}, e_{\max} = 0.08$ , United States (m)
	Germany <sup>a</sup>	United States	
60	150	130	125
80	300	240	230
100	500	400	380
120	800	625	590

Note: 1 km/h = 0.621 mph, 1 m = 3.28 ft.

Here too, the American minimum radii of curve are smaller than the revised German values. The differences, compared in columns 2 and 3 of Table 7 for a superelevation rate of  $e_{\max} = 0.07$ , are about 20 percent or more for design speeds  $V_d \geq 80$  km/h.

A comparison with the American minimum radii of curve for a superelevation rate of  $e_{\max} = 0.08$  (column 4, Table 7), applied in the United States for open highways in regions with snow and ice, still shows greater differences (about 25 percent) compared with the German values (column 2, Table 7). Similar snow and ice conditions exist on roads in Germany.

In this connection it should be noted that some agencies in the United States even adopt a maximum superelevation rate of  $e_{\max} = 0.10$ , regardless of snow and ice conditions on open highways, with accordingly still smaller radii than those given in Table 7 (6). Whether or not such a design can be considered responsible should be a major discussion item of future highway design in the United States.

## CONCLUSIONS

An analysis of the data in this paper indicates that Germany uses allowable tangential friction factors that correspond to the skid-resistance values present in 95 percent of their newly built road network. Therefore, only 5 percent of all road surfaces will remain below the selected friction factors for the design and redesign of two-lane rural highways.

For side friction factors, a maximum utilization ratio between 40 and 50 percent is allowed so that always more than 85 percent of friction shall be available in the tangential direction for unexpected driving maneuvers on wet pavements. Such maneuvers would cover, for example, sudden acceleration, deceleration, or evasive movements. Furthermore, forces that result from cross wind or those that result from exceeding the original design speed may be corrected by applying the German tangential and side friction factors too. From the viewpoint of driving dynamics, these assumptions represent high driving dynamic safety demands and ensure high friction supply in critical driving situations. Compared with the German friction values, the American as-

sumptions for tangential and side friction factors are relatively high (compare Table 1, Table 3, and Figure 5) and thus represent less driving dynamic safety.

The computations for minimum SSDs and minimum radii of curve generally indicate, for design speeds  $V_d \geq 80$  km/h (50 mph), smaller values for rural highway design in the United States than in Germany. Therefore, there is no doubt that the American highway design is more economic than the German one. But, as mentioned previously, one cardinal rule in horizontal alignment design is that friction supply should be greater than friction demand. This is simply stated, but the question follows: To accomplish this rule, do we lower the demand or increase the supply? (8). The efforts on the German side in the past decade have been to increase the supply rather than to modify the demand.

Of course it is difficult to decide where the critical margins for friction factors and, derived by them, for minimum SSDs and minimum radii of curve shall be assigned. This is a crucial consideration for engineers concerned with both cost and safety. But a higher driving dynamic safety supply, as applied in the German Guidelines for the Design of Rural Highways (1) since 1973, has reduced, among other things, the number and severity of accidents. These are the newest results of a research report for the Minister of Transportation of the Federal Republic of Germany (9). It is not the intention of the author to make recommendations, but perhaps a discussion of a higher driving dynamic safety supply may be useful to reduce accidents on two-lane rural highways in the United States too. Because up to now there were often, in both the Federal Republic of Germany and in the United States, inadequate safety factors in the friction between wheel and road, friction demand often exceeded friction supply and caused more accidents than necessary.

Related to the driving behavior in both countries, it is worth noting that for two-lane rural highways, where the most excessive speed accidents occur by friction demand, the Federal Republic of Germany has set since 1973 a general speed limit of 100 km/h (~60 mph), which is only slightly higher than the overall speed limit of about 90 km/h (55 mph) in the United States. In addition, single-unit trucks have a speed limit of 80 km/h (50 mph) and semitrailer combinations and semitrailer-full-trailer combinations have a speed limit of 60 km/h (~40 mph) on two-lane rural roads.

## EVALUATION

A preliminary study was conducted on State Route 3 in the southwest of Germany (10) to answer the question: Is there any evidence that the new German guidelines for rural design have had any positive influence on traffic safety?

The investigated sections of State Route 3 in rural areas had an overall length of 30.865 km (19 miles). The investigation period encompassed 4 years (January 1, 1977 through December 31, 1980), during which 761 accidents resulted in 21 fatalities, 100 heavy injuries, and 251 light injuries. Fifty-three percent of the accidents can be attributed to "excessive speed" or "not sufficient stopping or passing sight distances." The average daily traffic was about 9,500 vehicles per day. The pavements of all investigated road sections were in excellent condition and were rebuilt in the last 2 years before the investigation period, not only for the sections with a new alignment but also for the widened sections with an old alignment.

**TABLE 8 Comparison of Accident Rates on Highway Sections with New and Old Alignments, State Route 3, Southwest Germany**

Highway Section	Length of Section (m)	Description of Alignment	Accident Rate (accidents per 10 <sup>6</sup> vehicle-km)
1	4000	New horizontal and vertical alignment; lane width = 3.75 m	1.21
2	500		1.68
3	500		1.48
4	—	Urban area	—
5	—		—
6	5125	New horizontal and vertical alignment; lane width = 3.75 m	1.27
7	2780		1.75
8	3200		1.49
9	2500	Old alignment; speed limit 70 km/h	1.92
10	1500	New alignment; lane width = 3.75 m	1.23
11	1800	Old horizontal and vertical alignment; wider pavements rebuilt; lane width = 3.5 - 3.75 m	2.23
12	800		2.06
13	2250		2.02
14	2210		3.07
15	1690		2.90
16	350	Intersection	3.40
17	960	New alignment; lane width = 3.75 m	1.07
18	800	Old alignment and intersection until 1980	3.44

Note: 1 m = 3.28 ft, 1 km/h = 0.621 mph.

State Route 3, which was subjected to investigation, consists of 18 highway sections, 16 sections in rural and 2 in urban areas. The lengths of the highway sections, the description of the alignment, and the accident rates are given in Table 8. Road sections 1, 2, 3, 6, 7, 8, 10, and 17 were rebuilt with a new horizontal and vertical alignment. On road sections 11 to 15 the pavements were renewed and widened, but the old horizontal and vertical alignment was not changed. Section 18 was rebuilt after 1980; whereas section 9, with a typical old alignment superimposing horizontal and vertical curves, was controlled with speed limits of 70 km/h (44 mph) since the beginning of the 1970s.

A comparison of sections of State Route 3 with a new alignment shows that their accident rates range from 1.07 to 1.75 accidents per 10<sup>6</sup> vehicle-km, whereas the accident rates on the sections with an old alignment range from 2.02 to 3.07 accidents per 10<sup>6</sup> vehicle-km and are basically higher for otherwise comparable conditions (i.e., pavements). On average, it can be shown that the accident rate on the sections with new horizontal and vertical alignment comes to a value of 1.49 accidents per 10<sup>6</sup> vehicle-km, whereas the average accident rate on the sections where the alignment was not redesigned comes to a value of 2.50 accidents per 10<sup>6</sup> vehicle-km. In short, a 1.67 times higher accident rate exists for the sections with old horizontal and vertical alignments compared with the newly designed sections of State Route 3 in southwest Germany. The previously mentioned research report for the Minister of Transportation of the Federal Republic of Germany (9) will document these statements.

In conclusion, a comment by the AASHTO Select Committee on Highway Safety on the subject of optimum versus minimum design in preparing the second edition of the Yellow Book, Highway Design and Operational Practice Related to Highway Safety, is appropriate:

The acceptance of minimum standards as the criteria for design too often occurred for reasons of economy. Frequently a more lib-

eral design would have cost little more over the life of the project and would increase its safety and usefulness substantially.

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## Survey of States' R-R-R Practices and Safety Considerations

JOHN M. MASON, JR., and HARRY C. PETERSEN

### ABSTRACT

A survey was conducted of resurfacing, restoration, and rehabilitation (R-R-R) type programs throughout the United States. R-R-R practices of state highway departments were solicited, with emphasis on seeking cost-effective designs that maintained acceptable levels of safety and serviceability. The reported R-R-R actions by various states are summarized, and the primary rulings on R-R-R design standards are briefly discussed. A philosophy tailored toward maximum mileage standards, accompanied by the application of value engineering, forms the basis of many R-R-R state policies. In every case, safety was found to be of primary concern. Three general philosophies appear applicable based on this R-R-R review: (a) rehabilitation to standards below full AASHTO new construction standards, and correcting major defects but maximizing the number of miles of highway treated; (b) reconstruction to full AASHTO standards only, for greater safety on fewer miles of roads; and (c) full funding for all projects as an ideal. Preliminary safety studies are reviewed, and guidelines are presented for maximum mileage rehabilitation projects drawn from the state surveys.

Under a recent contract with the Auditor General's Office, State of Arizona, the Texas Transportation Institute (TTI) had the opportunity to survey resurfacing, restoration, and rehabilitation (R-R-R) type programs throughout the United States. The objective of the study was to provide a summary of R-R-R practices reported by state highway departments. Empha-

sis was placed on seeking cost-effective designs that maintained acceptable levels of safety and serviceability. The reported R-R-R actions by various states are summarized, and the primary rulings on R-R-R design standards are briefly discussed. A philosophy tailored toward maximum mileage standards, accompanied by the application of value engineering, appears to form the basis of future R-R-R state policies.

### SUMMARY OF R-R-R ACTIONS

State highway departments were contacted by telephone regarding the implementation and results of R-R-R design features. Forty-one of the states responded that they regularly employ some type of R-R-R design. Although many of these states use some or all of the guidelines published in the Geometric Design for Resurfacing, Restoration, and Rehabilitation (R-R-R) of Highways and Streets (1), several states use R-R-R type actions that are not specifically enumerated in the guide.

The purpose in synthesizing information on R-R-R practices was to provide a reference source for future consideration by the Arizona Department of Transportation. Specific actions reported here were selected because the information was either not detailed or addressed in the R-R-R guide. The presentation that follows reflects the interpretations of the conversations and correspondence that the researchers had with representatives of various state agencies.

Although all states responded to the survey, the states listed in Table 1 provided the researchers with particular information on special R-R-R programs in the state. Their responses were grouped to isolate commonalities and type of project work. Each state indicated that safety considerations were