CHAPTER 5 Friction Variations

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Transverse Friction

Transverse variations of friction across a lane, sometimes called differential friction, can cause significant problems for a braking vehicle. This condition arises when the individual wheel paths on which a vehicle's tires ride have significantly different coefficients of friction. This problem may be minor or extremely serious, depending on the magnitude of the frictional difference, its relationship to the average coefficient of friction, and the speed at which a vehicle travels across the surface.

This phenomenon was first described theoretically by Zuk (1) in 1959. Zuk developed equations to predict the total yaw angle of a vehicle based on its mass, speed, and the coefficient of friction for each of the wheel paths. Zuk concluded that a difference in the friction coefficients of the wheel paths could be potentially hazardous even though the average surface friction was relatively high.

Fifteen years later Burns (2) provided further information on this subject by performing braking tests using various vehicles under highway conditions. These tests provided detailed observations of the movement of vehicles braking on split-friction surfaces, as well as indications of the relative controllability of vehicles under those conditions. An example found on the highway during Burns' study was where the left wheel path was bleeding and the right wheel path was chip-sealed. The right wheel path had a wet stopping distance number (SDN_{40}) of 67 and the left had a wet SDN_{40} of 41. This difference of 26 represents a 63 percent braking force differential. A car braking at 40 mph on this surface rotated 90 degrees clockwise. The same car braking at 50 mph rotated 270 degrees clockwise. The results of these tests are shown in Figure 1 (2).

Burns developed equations to predict the amount of rotation that would occur for a vehicle braking on a surface, given specific levels of differential friction, average coefficient of friction, and speed. He suggested that a surface that produced total rotations greater than those listed in the following table could create a major loss of vehicle control while braking:

Speeds at Which Wheels Are Locked (mph)	Total Rotation After Car Has Stopped (°)
30	30
40	50
50	70

This research also identified the most commonly found differential wheel path conditions. They are (a) differential flushing or bleeding, (b) unequal wear, (c) partial seal coating of a lane, (d) dissimilar shoulder surfaces, (e) maintenance crack

FIGURE 1 Vehicle rotation during stopping maneuver *(2)*—top: 90-degree clockwise rotation at 40 mph; bottom: 270-degree rotation at 50 mph.

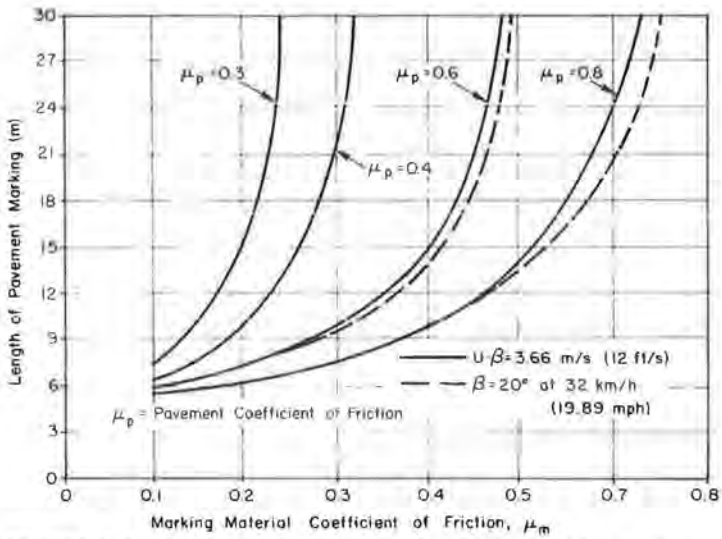

FIGURE 2 Recommended maximum lengths of differential friction for safe operation of cars during hard braking conditions (vehicle initial speed is 55 mph) *(3)*.

patching of only one wheel path, and (f) unequal drainage properties.

In 1981 Hayhoe and Henry (3) conducted research to better determine the levels of acceptable differential friction. A simulation of the skidding behavior of cars in plane rotation on differential friction surfaces was used to develop the curves shown in Figure 2 (3). These curves are used as follows. μ_1 is the higher of the two coefficients. Plot the position of the lower coefficient (μ_2) and the length of the split-coefficient surface. If the resulting point is to the left of the μ_1 curve, the situation is potentially unsafe; if it is to the right, a relatively safe situation is indicated.

These and other studies have confirmed that differential friction can have a significant effect on a braking vehicle. The vehicle-rotation phenomenon can occur at high as well as low friction levels and should be considered in any pavement friction evaluation. The greatest problem arises when the driver releases his brakes after the car has begun to spin. When this is done the vehicle is propelled in the direction it is facing. This could be off the road or into oncoming traffic. Thus the greater the degree of rotation, the more uncontrollable the vehicle.

Longitudinal Friction Variations

In the longitudinal direction variations in the friction properties of pavement surfaces occur more frequently than is commonly assumed. There are several types of such discontinuities. One type exists where one construction project adjoins another or where a surface has been repaired. In these cases the transition from one pavement to the other is often quite sharp, and usually it is recognizable by drivers. Whether drivers can and do judge correctly the related changes in friction properties, or even realize the possible existence of such changes, is debatable, as is whether they adjust their driving pattern to perceived changes. Because not all existing changes are perceived and, even if they are, likely to be judged incorrectly or ignored, they can constitute a potential hazard.

Gradual transitions occur at locations where the friction demand is higher than elsewhere along a roadway, as on curves and where acceleration and deceleration occur frequently and consistently. At these locations available friction tends to be lower than on the adjacent tangents with freely flowing constant speed traffic. The friction properties of the surface are degraded by the greater rate of pavement wear and polishing that accompanies speed changes and cornering. The friction needed for these vehicle maneuvers might be available elsewhere on the same pavement, but at the maneuver sites it may eventually decrease below that demanded by a significant number of drivers. The problem of measuring skid resistance on curves has been addressed only recently (4); thus no data are available for assessing the magnitude of the hazard at this and other maneuver sites. It is, however, well established that certain types of surface courses suffer considerable loss of friction potential under the influence of traffic, and that this loss is accelerated when the tires do more than normal amounts of scrubbing (5).

Short sections that have quite different friction properties than the adjoining pavement result from pavement markings, particularly at pedestrian crossings or where spot repairs have been made that extend across a traffic lane. In the first example the available friction is likely to be lower than that of the basic pavement, and in the second example it is likely to be higher than that of the basic pavement. Normally this is of little consequence, but it can present a hazard if an emergency maneuver must be executed at this location. The consequences will be much the same as if the front and rear brakes on a vehicle are out of balance, except that the friction imbalance is of a short duration only. The driver would have to react to two changes superimposed on an emergency maneuver, and this is at best within the capability of only the most skilled driver.

Remedies for some of the described cases of longitudinal friction variations are available. For instance, instead of repairing a few feet of pavement on a curve, overlaying the entire curve will

prevent drivers from unexpectedly encountering a different friction level at a critical point. Overlaying a curve in its entirety raises the available friction on the curve, if only temporarily, above that of the adjacent tangents. This is desirable and will be cost effective if the curve was a high accident location even before the pavement needed repair. On the other hand, it is difficult to prevent variations between adjoining projects. If highly skid- and polish-resistant surface courses could be used everywhere, this will not only reduce the total number of skidding accidents, but the difference in accident experience between old and new projects will be reduced. This is so because, as is generally thought, the relationship of skidding accident rate versus skid resistance is flatter at higher skid numbers than it is at low ones (6). Alternately, if surfacing projects were designed to involve long sections of roadway, the number of changes in available friction would be reduced. Because drivers appear to go through a learning period whenever they encounter a change in driving environment, uniform sections of greater length may result in disproportionately greater improvements in accident rates than might be expected from the reduction in the number of abrupt changes in surface properties.

Many aspects of the problem of longitudinal variations of friction have not been investigated. There are no applicable statistics, but the following example illustrates the potential hazard that traveling from a high friction surface to one with much poorer friction properties can present. When the latter is of such design that the combination of summer heat and heavy truck traffic pumps the asphalt to the surface of the pavement, the wheel paths get quite slippery. Bleeding pavements can have an SN_{40} as low as 10 (see Figure 3). If such a section is encountered on an upgrade by a vehicle coming from a surface with an SN_{40} of 40, running under full power, the drive wheels may suddenly begin to spin unless the driver anticipates the change and reduces power. The transition zone may be no more than 10 ft long, and in some cases less. At 55 mph it takes 0.12 sec for the vehicle to travel the 10 ft, which does not give the driver enough time to sense the impending wheel spin and prevent it. The consequence can be a serious deviation from the intended path. Vehicle spin-out may occur. Similar hazards exist during braking and cornering or whenever the wheels of a vehicle suddenly encounter a drop in available friction. In the reverse case, other instabilities occur that can catch an inattentive or inexperienced driver off guard.

Thus, from the viewpoint of safety, there is little doubt that longitudinal variations in pavement properties should be avoided where possible and, if this cannot be done, these variations should be held to a minimum. Where major variations exist, warning signs may be an appropriate measure until surface conditions can be corrected.

FIGURE 3 Extreme variation in friction (skid number of the advance pavement is 70, and skid number where the wheel paths have flushed is less than 10).

Pavement Markings

Pavement markings are primarily used to provide visual guidance for drivers and to guide traffic flow. Turn arrows, hazard warning messages, and so forth are frequently marked directly on the pavement surface. In their intended roles pavement markings are universally held to provide positive benefits, particularly under conditions of poor visibility (7,8), but the degree of skid resistance that they provide is of increasing concern with the growing use of plastic materials and heavy marking in sections such as ramps and gores. Marking materials generally lower the skid resistance of a pavement and, when applied over large sections, increase wet skid stopping distances. Differential friction caused by the application of marking materials also gives rise to such hazardous conditions as excessive vehicle yaw during locked-wheel skids, loss of control during motorcycle or bicycle turning and braking maneuvers, and slipping and falling by pedestrians on crossings.

Skid-resistance requirements for marking materials have traditionally been specified in terms of low-speed wet friction measurements (7). However, high-speed skid resistance measurements recently made by the Massachusetts and Michigan departments of transportation (9,10) have demonstrated that low-speed measurements do not accurately reflect the absolute skid resistance of marking materials for vehicles traveling at highway speeds. Results for three materials field-tested in the Michigan study were as follows:

Material	SN_{40}	BPN
Fast-drying white paint (with beads)	37	31
Extruded hot plastic (with beads)	23	35
Smooth cold plastic (no beads)	4	14
Bare pavement substrate surface	67	-

In this table SN_{40} is the skid number at 40 mph as measured by ASTM E274 method of test, and BPN is the British pendulum number as measured by ASTM E303 method of test. Two of the three materials had lower SN_{40} than BPN, with the unbeaded plastic having a friction level consistent with hydroplaning.

In a later, more comprehensive study (11), the performance of 11 different materials applied to four different pavement surfaces was evaluated. A total of 113 combinations of material type, material formulation, and pavement surface were included in the study. Macrotexture, SN_{40}, and BPN measurements were made on each sample surface. Predictor equations relating SN_{40} to BPN and root mean square (RMS) macrotexture height were then developed by linear-regression techniques. A single regression equation, which would encompass all of the materials, could not be formulated at an acceptable level of correlation, so the materials were grouped into eight categories, and a separate equation was developed for each category. Thus the results of the study may be used to estimate the high-speed skid resistance of typical marking materials from low-

speed laboratory measurements. In most cases a BPN measurement is sufficient to provide the SN_{40} estimate, although the addition of a macrotexture measurement may be beneficial in improving the correlation. The average skid resistance numbers measured on the various materials included in the study are given in Table 1 (11).

TABLE 1 Average High-Speed Skid Resistance of Five Marking Materials *(11)*

Marking Material	No. of Applications	Avg Skid Resistance (SN_{40})	Standard Deviation
Traffic paint (unbeaded)	22	20.7	8.0
Traffic paint (beaded)	41	26.7	6.8
Thermoplastic (unbeaded)	12	18.7	10.1
Thermoplastic (beaded)	26	24.7	7.5
Preformed plastic	11	25.2	8.7

Specific findings of the study were as follows.

1. For all combinations of material, formulation, and pavement surface, the high-speed skid resistance of the marking material was lower than that of the bare substrate pavement surface, whereas the low-speed skid resistance in some cases was higher than that of the substrate.
2. The skid resistance of markings applied in the field did not increase significantly with time and suffered seasonal and short-term variations similar to those of the substrate pavement surface.
3. Beaded paint and plastic marking materials had significantly higher skid resistance than unbeaded materials. The use of unbeaded materials should be avoided.
4. Chlorinated rubber-based paints had significantly lower skid resistance than alkyd resin paints.
5. Spray thermoplastics had higher skid resistance than hot-extruded thermoplastics.

The effects of differential friction caused by marking materials on highway safety is difficult to determine because of a lack of accident studies specifically directed toward the problem. However, single- and double-delineation stripes do not appear to be hazardous to the operation of cars and trucks (11). When a large section of marking material is present on wet pavement, a differential friction problem could exist. In a computer simulation study of cars skidding on pavements with differential friction caused by marking materials (11), a design procedure was developed for determining the maximum allowable differential friction between pavement and material, given the length of the marking on the pavement. Boundaries of safe operation are shown in Figure 2, the same figure that gave boundaries for transverse friction variations. Safe operation is indicated if a given combination of the lower coefficient of friction (μ_2) and if the length of differential friction surface falls to the right of the appropriate μ_1 curve; otherwise braking is potentially unsafe.

The criteria for safe operation were somewhat difficult to quantify, but they were based on the following observations of vehicle behavior when drift angle was large (drift angle is the angle between the forward and resultant velocity vectors at the center of gravity of a vehicle). If a vehicle is executing a yawed skidding maneuver with locked wheels and the wheels suddenly unlocked, then (a) the driver has no steering control over the vehicle if the drift angle is approximately equal to or greater than 20 degrees or (b) the vehicle will tend to travel along the line of its longitudinal axis if the drift angle is less than approximately 20 degrees (assuming no control action by the driver). Under the latter circumstance the rate at which the vehicle will travel laterally across the pavement can be approximated by the product of vehicle speed and drift angle ($U\beta$). If ($U\beta$) = 12 ft/sec, the vehicle will move laterally one complete lane width in 1 sec.

Justification for the criteria is along the same general lines used by Burns (2) to identify boundaries of safe operation on surfaces with differential friction, although a direct comparison between the criteria shown in Figure 2 and Burns' criteria is difficult to make.

Pavement markings present a wet skidding hazard to operators of motorcycles and bicycles. However, the extent of the hazard and its overall impact on highway safety cannot be determined at present, particularly in view of the acknowledged, but obviously positive, benefits of pavement marking materials.

Pedestrian safety is another concern at crossings in urban areas. Requirements for satisfactory walking traction are a static coefficient of friction of 0.5 or higher and a sliding coefficient of friction higher than the static value (12). The walking traction performance of marking materials in current use appears to be satisfactory, or at least (for materials with the most unsatisfactory performance) no worse than borderline.

Steel Grid Flooring

Steel grates for bridge riding surfaces are rarely constructed today, even though the current AASHTO bridge specifications (13) contain sections governing their use. An earlier edition (14), published in 1961, refers to the friction available on these surfaces with the following statement: "The upper edges of all members forming the wearing surface of an open type grid surface should be fabricated or treated to give the maximum skid resistance." What the maximum skid resistance should be, quantitatively, is not specified. This statement remains unchanged in the current AASHTO bridge specifications.

In 1951, the TRB Committee on Surface Properties Related to Vehicle Performance, under the chairmanship of R.A. Moyer, published a graph showing the coefficients of friction available on an open grid steel bridge deck as a function of speed (15). This graph [Figure 4 (15)] shows the coefficient of friction for a new tire made of synthetic rubber varying from 0.4 at 11 mph down to 0.25 at 40 mph.

In response to several loss-of-control events on a Louisiana bridge in the late 1970s, an investigation was undertaken to determine if the steel grid deck was a contributing factor. ASTM E274 skid numbers were determined on the bridge at several different positions. Although the bridge deck was more than 30 years old and polishing of the steel was apparent in the wheel paths, the values of the skid numbers were not exceptionally low, varying from 25 to 38. These values compare favorably with those reported by Moyer more than 30 years ago. It was concluded that the problem was more likely caused by the susceptibility of the deck to icing, rather than by low values of wet friction.

In all probability steel grid decks are subject to the same concerns discussed under longitudinal

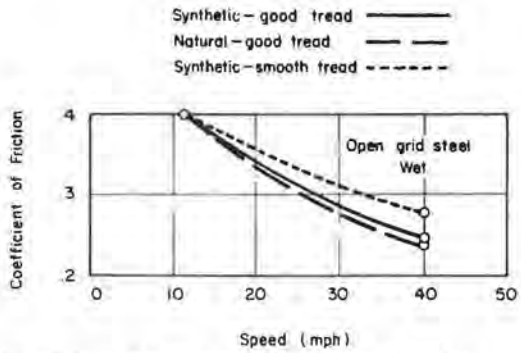

FIGURE 4 Effect of different type tires on skid resistance for wet open-grid steel bridge floors *(15)*.

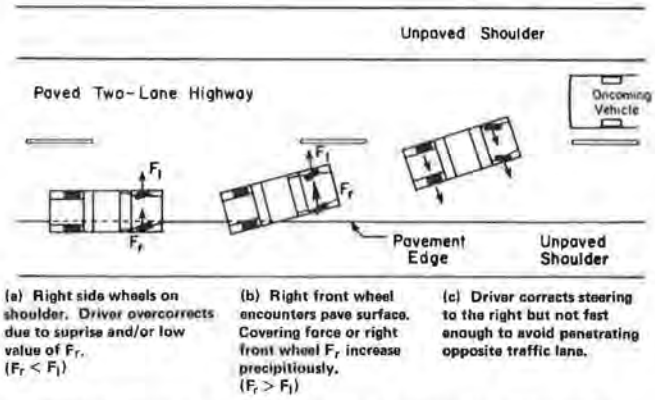

FIGURE 5 Illustration of loss of control caused by oversteering on low-friction shoulder.

and transverse friction variations, because they normally occur on old bridges where wheel path polishing is pronounced. They also are more susceptible to icing because the steel should lose heat much faster than a portland cement concrete deck. This problem relates to the excessively low friction available on icy surfaces, which will be discussed further in a subsequent chapter.

Traveled Surface to Shoulder

The problem of friction variation between the paved surface and the shoulder is related to the lateral variation influence. Although it is such a special influence and such a relatively common (and critical) influence, it will be given special treatment.

The primary focus here concerns the existence of a lower friction surface on the shoulder immediately adjacent to a traveled lane. There are accidents each year that are triggered by a single vehicle loss of control resulting from the inability of some drivers to deal with a lower friction shoulder surface. A driver, either through inattention or from some external influence, allows his vehicle to run off the paved surface, perhaps only a foot or two, so that the wheels, at least on one side of the vehicle, are on an unpaved, lower-friction surface. It may be sand, loose gravel, soil, or perhaps a muddy wet surface. The next reaction of the driver, as he becomes conscious of the situation, is critical. If the driver reacts with restraint, allowing the vehicle to slow while using modest steering inputs, the paved surface can be easily and safely regained. All too often, however, this is not the case. The driver reacts quickly with a steering input that is too large. The result is a precipitous steer force generated when the offside front wheel regains the paved surface. These actions may result in a collision with another vehicle or a roll. Figure 5 illustrates this phenomenon.

In Figure 5a the vehicle is shown with the right wheels on the shoulder (lower friction) surface just after the driver has made a left steer input that is too intense. The steering may even feel appropriate to the driver in terms of the rate at which he is regaining the appropriate lane of the roadway. The driver is not prepared, however, for the radical increase in the cornering force and thus the rate of cornering when the right front tire comes in contact with the higher friction lane surface, as shown in Figure 5b. The result is a vehicle fundamentally out of control, as shown in Figure 5c. Here the vehicle goes into adjacent lanes, may even go completely across the highway, or may spin out, possibly resulting in a vehicle roll. The high lateral acceleration produced in the case shown further complicates the recovery problem for an unbelted driver on a bench front seat. This driver may be thrown completely out of the wheel position, precluding any further efforts of value in regaining control. Figure 6 shows the results of an accident due to the oversteering phenomenon.

FIGURE 6 Honda CVCC after spinning into the path of a larger vehicle.

One aspect of this phenomenon is that the existence of even extremely modest pavement edge height differentials, even 1 in. or less, may be blamed for the loss of control. The chapter on Pavement Edges (Chapter 4) illustrates the insignificance of these low values of edge differentials on loss of control. The degree to which a lower friction surface on the shoulder may influence safety is a function of the exposure to people allowing vehicles off the paved surface, perhaps related to geometrics (16), and to the degree to which the shoulder surface friction is lower than that of the paved surface. The available friction of paved surfaces both dry and wet is widely known. A major treatise on this subject is given by Kummer and Meyer (17). Data concerning available friction levels on surfaces covered by sand, gravel, soil, and mud are much more limited.

It appears there was much more interest in this type of surface when paved roads were rarer. Data

TABLE 2 Sites Measured for Differential Skid Numbers

Site	Pavement	Shoulder or Adjacent Surface	Surface	Condition[a]	Run 1	Run 2	Run 3	Mean Skid No.
1	Bituminous concrete	Crushed limestone gravel, 5-25 mm; some asphalt overspray	Pavement	D	87.4	87.3	86.1	85.9
			Pavement	W	34.6	39.8	34.3	36.2
			Shoulder	D	75.6	81.4	77.1	78.0
			Shoulder	W	72.5	72.7	74.5	73.2
2	Seal coat, asphalt bleed; heavy truck distress (tread impressions)	Poorly graded gravel from 20 mm to silt	Pavement	D	38.4	37.1	41.2	38.9
			Pavement	W	22.6	12.3	13.9	16.3
			Shoulder	D	61.3	61.7	62.8	61.9
			Shoulder	W	56.3	57.5	59.7	57.8
			Shoulder	W*	40.3	56.5	49.8	48.8
3	Prepared fill (roadway under construction)	Gravel, sand, and clay mixture	Pavement	D	69.7	71.7	74.1	71.8
			Pavement	W	56.3	50.9	53.1	53.4
			Shoulder	D	69.8	68.1	67.4	68.4
			Shoulder	W	59.9	63.4	61.6	61.5
4	Bituminous concrete, some asphalt bleed	Gravelly sand	Pavement	D	44.2	42.3	39.5	42.0
			Pavement	W	23.8	33.7	26.6	28.0
			Shoulder	D	61.6	59.8	60.2	60.5
			Shoulder	W	59.7	60.5	61.3	60.5
5	Bituminous concrete; weathered, somewhat raveled	Silty sand, course gravel, some spillover bituminous concrete and vegetation	Pavement	D	45.5	46.1	46.5	46.0
			Pavement	W	39.3	41.4	39.6	40.1
			Shoulder	D	59.6	60.1	63.9	61.2
			Shoulder	W	58.7	59.6	62.5	60.3
6	Seal coat, asphalt bleed	Peat with some gravel, vegetation	Pavement	D	45.7	44.2	41.3	43.7
			Pavement	W	22.8	24.2	24.3	23.8
			Shoulder	D	57.9	59.6	62.3	59.9
			Shoulder	W	44.8	32.8	31.7	36.4
			Shoulder	W*	25.5	22.1	19.3	22.3
7	Concrete	Silty gravel	Pavement	D	68.5	—	—	68.5
			Pavement	W	42.4	—	—	42.4
			Shoulder	D	63.0	61.7	62.4	62.4
			Shoulder	W	56.6	55.7	51.8	54.7
			Shoulder	W*	31.0	29.0	—	30.0

[a]Note that D = dry, W = wet, and W* = wet after significant natural rainfall.

on the values of available friction on mud, soil, gravel, sand, and sod are given in Chapter 7. These values can range from as low as 0.2 to more than 1.0. The lowest values are found on wet clay and on wet grass. Some gravels exhibit surprisingly high values in either wet or dry conditions.

The most recent work has been provided by R.J. Koppa (Pavement Edge, Roadway Discontinuities, and Vehicle Stability, unpublished Task Report on Project 328, Texas Transportation Institute, October 1982). By using an ASTM E274 locked-wheel skid trailer, Koppa measured both the locked-wheel friction on unpaved shoulder surfaces and the friction on the pavement immediately adjacent to the shoulder. The difference in friction, as indicated by locked-wheel braking, was thus directly observed. The data in Table 2 describe the surface types and the results of Koppa's tests. In the fourth column, labeled Condition, the pavement condition is given [note that D = dry, W = wet (ASTM internal watering system), and W* - wet (by significant natural rainfall)]. Only on sites 2, 6, and 7 were skid numbers determined after significant natural rainfall, a condition more critical than the quick coating provided by the internal watering system. The results on site 2 were somewhat surprising in that the dry skid number on the pavement was lower than the wet skid number on the shoulder (38.9 for pavement dry compared with 48.8 for shoulder wet).

A real contrast in relative values would be when both surfaces are wet: pavement wet (SN = 16.3) and shoulder slightly wet (SN = 57.8). This would not produce the control sequence described in Figure 2, but it could produce a problem if a rapid return was produced that resulted in a spin-out due to the low available friction on the pavement.

On sites 6 and 7 the results were more as expected. Assuming the pavement surface dries more rapidly than the adjacent shoulder, the critical situation would be when the pavement surface has just dried and the shoulder is still wet: 43.7 compared with 22.3 on site 6, and 68.5 compared with 30.0 on site 7.

In general, the friction values obtained on the gravel shoulders were rather high, which indicates good traction. The real problems would be expected on wet soil with a high clay content and where wet vegetation contributed to lowering available friction. On surfaces of this type little is known about the relationship between available cornering friction and braking friction. In this case it is the cornering friction that is critical, and few observations of this type are available. Braking skid numbers may not provide satisfactory estimates.

REFERENCES

1. W. Zuk. The Dynamics of Vehicle Skid Deviation as Caused by Road Conditions. Proc., International Skid Prevention Conference, Charlottesville, Va., Sept. 1958.
2. J.C. Burns. Differential Friction: A Potential Skid Hazard. In Transportation Research Record 602, TRB, National Research Council, Washington, D.C., 1976, pp. 46-53.
3. G.F. Hayhoe and J.J. Henry. Effects of Differential Pavement Friction on the Response of Cars in Skidding Maneuvers. In Transportation Research Record 836, TRB, National Research Council, Washington, D.C., 1981, pp. 61-66.
4. R.L. Rizenbergs, J.L. Burchett, and L.A. Warren. Relation of Accidents and Pavement Friction on Rural, Two-Lane Roads. In Transportation Research Record 633, TRB, National Research Council, Washington, D.C., 1977, pp. 21-27.
5. S.H. Dahir, W.E. Meyer, and R.R. Hegmon. Laboratory and Field Investigation of Bituminous Pavement and Aggregate Polishing. In

Transportation Research Record 584, TRB, National Research Council, Washington, D.C., 1976, pp. 1-13.
6. L.H.M. Schlösser. Traffic Accidents and Road Surface Skidding Resistance. In Transportation Research Record 623, TRB, National Research Council, Washington, D.C., 1977, pp. 11-20.
7. Road Marking and Delineation. Road Research Group, Organization for Economic Cooperation and Development, Paris, Feb. 1975, 156 pp.
8. S.G. Bali, H.W. McGee, and J.K. Taylor. State of the Art on Roadway Delineation Systems. Report FHWA-RD-76-73. FHWA, U.S. Department of Transportation, May 1976, 95 pp.
9. M.D. Turo. Skid Testing Reflective Markings. Interoffice correspondence. Massachusetts Department of Public Works, Boston, Dec. 23, 1974.
10. C.L. Richard. Skid Testing of Pavement Marking Materials: Final Report, Project TSD-284-76. Michigan Department of State Highways and Transportation, Lansing, April 1976, 9 pp.
11. J.J. Henry, D.A. Anderson, and G.F. Hayhoe. Skid Resistance of Pavement Marking Materials. Report FHWA-RD-80-199. FHWA, U.S. Department of Transportation, March 1981, 115 pp.
12. J. Brungraber. An Overview of Floor Slip-Resistance Research with Annotated Bibliography. NBS Technical Note 895. National Bureau of Standards, U.S. Department of Commerce, Jan. 1976, 113 pp.
13. Standard Specifications for Highway Bridges, 12th ed. AASHTO, Washington, D.C., 1977.
14. Standard Specifications for Highway Bridges, 5th ed. AASHO, Washington, D.C., 1961.
15. R.A. Moyer and J.W. Shupe. Roughness and Skid Resistance Measurements of Pavements in California. Bull. 37. HRB, National Research Council, Washington, D.C., 1951, pp. 1-37.
16. J.M. Roberts, J.W. Hutchinson, and F.R. Hanscom. Driving Behavior and Self-Testing Attitudes. Presented at 55th Annual Meeting of the Transportation Research Board, Jan. 19-23, 1976.
17. H.W. Kummer and W.E. Meyer. Tentative Skid-Resistance Requirements for Main Rural Highways. NCHRP Report 37. HRB, National Research Council, Washington, D.C., 1967, 80 pp.