Effects of Pavement Grooving on Friction, Braking, and Vehicle Control

J. E. Martinez, Texas Transportation Institute, Texas A&M University

Pavement grooving is a technique by which longitudinal or transverse cuts are introduced on a surface to increase skid resistance and reduce the number of wet-weather accidents. The objective of the research was to determine the effect of pavement grooving on motorist safety by studying the effects of grooving on friction, braking, and vehicle control by computer simulation and full-scale testing. Vehicles considered were automobiles, motorcycles, and automobile and towed-vehicle combinations. The computer simulation was developed by obtaining test data for a variety of conditions and performing a regression analysis of the data. The result was a set of equations that were incorporated into vehicle-handling models that predicted vehicle response due to the grooves. The motorcycle rider detected a perceptible difference between worn and unworn grooving. The effect of grooving on motorcycle response could not be detected by electronic instruments that measured steering angle and torque. No significant difference was found for various grooving geometries. Electronic instrumentation could not detect the effects of grooving on a typical small automobile and towed-vehicle combination at different speeds for various trailer and tongue loads. Based on computer simulation, the effect of grooving is more beneficial for low-friction than for high-friction pavement; also, grooves provide a noticeable increase in the directional stability of a vehicle.

Pavement grooving is becoming a widely accepted means of improving the stability of vehicles on pavements. Grooving is primarily longitudinal on highways in the United States and transverse on aircraft runways and in other countries. For a given pattern, various dimensions of the groove width, depth, and spacing have been studied; however, an optimum pattern has not been accepted. Most studies of highway grooving have relied on measurements on in-service roadways. Factors such as skid numbers, texture or surface wear, and accident rates were investigated before and after grooving. To a limited extent, driver response and vehicle behavior were monitored, primarily by public response.

When grooves were first introduced, motorcyclists filed a large number of complaints with the state highway departments and motorcycle magazines (1). The riders claimed that the grooved pavements produced uncomfortable and hazardous riding. Experience has shown that the effect of grooving on motorcycles varies with the width of the grooves. Farnsworth states that 6.4-mm (0.25-in) wide grooves generated complaints from motorcyclists and drivers of small automobiles and that 3.2-mm (0.125-in) wide grooves still brought complaints, though fewer, from motorcyclists (1, 2). In addition, narrower grooves were just as effective in controlling skids as wider grooves.

This paper presents the findings of a study that involved laboratory and full-scale tests in which various groove geometries and pavements were used and the effects of slip, camber and approach angles, normal load, tire geometry, pavement, speed, groove geometry, and wet or dry conditions were considered. The data were collected by using the Texas Transportation Institute (TTI) low-speed tire tester and the Highway Safety Research Institute (HSRI) mobile tire tester.

The direct advantage of grooved pavement under rainfall conditions in producing large values of lateral friction and the indirect advantage in reducing accidents are thoroughly documented. Therefore, this study placed primary emphasis on the determination of vehicle handling or stability problems on dry pavements. The wet-pavement data were obtained only because the process for doing so was readily available. Consequently, a wet pavement merely refers to a pavement with a particular skid number as obtained by the HSRI tester; the truck-borne water systems produced low friction levels but not low enough to be consistent with rain-wetted surfaces (3, 4).

Free-rolling and braking data were taken with the two machines. The data were next used as input to a regression model that produced a functional relation for the grooved side or circumferential force in terms of the variables mentioned previously. These representations for the free-rolling and braking cases were next integrated with computer programs for the handling of automobiles, motorcycles, and towed vehicles.

A regression analysis resulted in a model that produced results consistent with data found in the literature. The trends were quite realistic.

Full-scale tests were performed with an instrumented motorcycle and a small automobile and towed-vehicle combination. The results of the motorcycle study are presented in this paper, and the results of the automobile and towed-vehicle study are presented in another report (5).

The conclusions presented are based on contact with leading researchers in the field, on evaluation of grooved pavements by automobile drivers and motorcyclists, and on laboratory, full-scale test data, and computer simulation.

EXPERIMENTAL APPROACH

The degree of slip, camber, and approach angles of tires that were considered in the tests are given below.

Vehicle	Slip	Camber	Approach
Automobile	4	0	-10
	8	5	0
	16	10	10
			45
			90
Trailer	4	0	–
	8	5	–
	16	10	–
Motorcycle	0	0	-10
	6	20	0
		40	10
			45
			90

The load values in newtons (1 N = 0.225 lbf) of the tires that were considered are given below.

Automobile	Trailer	Motorcycle
2891.3	1779.0	889.6
4003.3	2891.3	1779.0
6227.5	4003.3	
	6227.5	

Types of tires considered are given in Table 1. The effect of various tires was accounted for through the use of $(\mu_y)_{max}$ and $(\mu_x)_{max}$ [i.e., the ratio of the peak side (free-rolling) or circumferential (braking) force to the normal load] and through the use of a tire cornering or camber coefficient. The tire coefficient was computed as the slope of the side force versus slip angle (for automobile and trailer tires) or camber angle (for motorcycle tires) at zero slip angle divided by the normal load for free-rolling cases and as the slope of the braking force versus percentage of slip at zero slip angle divided by load for the braking cases.

The groove width, depth, and spacing in millimeters (1 mm = 0.039 in) that were used in the tests are given below.

Test	Width	Depth	Spacing
Laboratory	2.8	3.2	19.0
	3.2	6.4	25.4
	5.6	9.5	38.0
Full scale	2.8	3.2	19.0
			25.4

The tester operated at a speed of 3.62 km/h (2.25 mph) in the laboratory tests and at speeds of 32.2 and 64.4 km/h (20 and 40 mph) in the full-scale tests.

The effect of the various pavements was accounted for through the use of the locked-wheel skid number obtained with the Goodyear custom power cushion tire in the full-scale tests and with the ASTM E-249 tire in the laboratory tests.

In the full-scale tests, longitudinal grooves were cut in two straight sections of portland cement concrete (PCC) and two curved sections of asphaltic concrete (AC) as follows (1 m = 3.3 ft and 1 mm = 0.039 in):

Type	Dimension (m)	Curvature Radius (m)	Groove (mm)
Straight, PCC	48.8 x 11	–	2.8 x 3.2 x 25.4
Straight, AC	48.8 x 7.3	–	2.8 x 3.2 x 25.4
Straight, PCC and AC	91.4 x 6.7	106.7	2.8 x 3.2 x 19

In the laboratory tests, grooves were cut in PCC and AC slabs approximately 1.8 m × 61 cm × 5 cm (6 ft × 2 ft × 2 in). The grooves were cut longitudinally, transversely, and at skewed angles of -10, 10, and 45° as follows:

2.8 × 3.2 × 25.4 mm,
2.8 × 3.2 × 19 mm,
3.2 × 3.2 × 19 mm,
3.2 × 3.2 × 25.4 mm, and
5.6 × 6.4 × 38 mm.

FULL-SCALE TESTING

A preliminary motorcycle test at the TTI Research Annex on the grooved pavements determined the rider's evaluation of the grooving. An uninstrumented 1974 Yamaha RD 350 motorcycle was used that had a standard ribbed Dunlop front tire and a Dunlop K-87 rear tire.

Table 1. Types of tires used in tests.

Vehicle	Manufacturer	Size	Rated Load (N)	Pressure (kPa)
Automobile	Goodyear custom power cushion	8.25×14	7206.1	220.6
	ASTM E-249	7.50×14	4826.3	165.5
	Goodyear custom G8	5.60×15	4314.8	220.6
Motorcycle	Trials knobby	3.50×18	–	–
	Dunlop Gold Seal F7	3.00×18	–	–
	Dunlop K-95	3.50×18	–	–
Small trailer	Goodyear super rib	4.80×4.00×18	–	–

Note: 1 N = 0.225 lbf; 1 kPa = 0.145 lbf/in².

Three riders were selected. One was a highly skilled professional who had considerable experience; one was an average rider who had approximately 2 years of experience on dirt and street riding; and one was an inexperienced rider, the principal investigator of the research project, who had less than 1 year of experience on street riding only.

The inexperienced and average riders rode over the grooved surfaces at speeds up to 112.6 km/h (70 mph); however, the highly skilled rider was allowed to ride at speeds exceeding 112.6 km/h (70 mph). Most of the riding was done on an 18-deg curve paved with PCC. The maneuvers consisted of in-lane and lane-change travel. The three riders agreed that at speeds below 80.5 km/h (50 mph) there was no noticeable effect on the handling. At speeds above 80.5 km/h (50 mph), but below 96.5 km/h (60 mph), a slight wobble was detected when no attempt was made to follow the grooves. This wobble disappeared, however, when an effort was made to follow the grooves. The consensus of the riders was that a perceptible wobble was present at speeds between 96.5 and 112.6 km/h (60 and 70 mph) when the grooves were not followed, but only a slight wobble was evident when the grooves were followed. At speeds exceeding 112.6 km/h (70 mph), the skilled rider reported a feeling of hazardousness when he did not try to follow the grooves and a feeling of uneasiness when he did try.

This first series of tests was performed on a curved pavement section that had newly cut grooves. Another series of tests was done on a straight pavement section that had worn grooves. That section was 6.4 km (4 miles) of the eastbound and westbound lanes of Loop 410 in San Antonio between the Blanco Road exit on the east and the Fredericksburg exit on the west. The inexperienced rider and the motorcycle were the same as those involved in the first tests. A TTI vehicle equipped with a motion picture camera followed the motorcycle to photograph any wobble that might be caused by the grooved pavement.

Runs with speeds well exceeding 88.5 km/h (55 mph) were made when safe traffic conditions were present, and the motion picture showed no wobble. The rider felt only a slight vibration through the seat at the high speed, but not at the low speed whether he followed the grooves or changed lanes.

The test motorcycle was then equipped with new Trials Universal (semiknobby) tires, commonly used on dual-purpose motorcycles for riding on streets and dirt roads. When no attempt was made to follow the grooves, the rider felt a slight wobble at speeds of 88.5 km/h (55 mph) and an uneasy feeling at 105 km/h (65 mph). The rider had not previously ridden on semiknobby tires, which do not handle the same way as street tires do.

In later tests with worn semiknobby tires, the rider could reach speeds above 105 km/h (65 mph) before he felt uneasy. The reason may partially be that he had become accustomed to semiknobby tires.

The motorcycle, equipped with both street and semiknobby tires, was also ridden on pavement with a metal tine texture, which is sometimes mistaken for a grooved texture. The rider felt more uncomfortable on the tine surface than on the grooved surface. The motorcycle tended to drift, even at speeds below 88.5 km/h (55 mph), and tended to drift even more and slightly wobble at higher speeds. In some instances, the motorcycle tended to follow the wavy pattern of the metal tine texture, and perhaps some tire-groove interlock took place. In other instances, the motorcycle tended to drift across the lane of travel. In a strong crosswind and heavy traffic, riding a motorcycle on metal tine texture could be hazardous.

Motorcycle testing was also conducted on an 0.8-km (0.5-mile) grooved portion of I-45 in Navarro County near

Angus, Texas. Several runs made with and without a steering damper produced no disturbing effects at speeds below 88.5 km/h (55 mph). Wobble seemed to increase with speed when no steering damper was used. The wobble continued until the speed was reduced to approximately 80.5 km/h (50 mph). The wobble did not occur immediately at any speed but seemed to take approximately 30.5 to 61 m (100 to 200 ft) to develop depending on the speed.

The runs made in Navarro County indicated that pavement grooving affects motorcycle handling, and the effect depends on the physical properties of the motorcycle. In the opinion of the test rider, the wobble is not hazardous, except perhaps to someone who is inexperienced. (Many other motorcyclists, however, do not agree with this opinion.) The rider felt that the longer distance gave the disturbance more time to become evident and that significant differences were experienced between ungrooved pavements.

A roadway disturbance analysis was conducted in Navarro County. The full-scale test data included motorcycle steering torque and steering angle time histories over the segment of grooved pavement. The test speeds varied from 64.4 to 120.7 km/h (40 to 75 mph). Data from the angle and torque transducers were telemetered to a mobile base station where the data were recorded on FM analog magnetic tape and simultaneously displayed on visicorder paper. Unfortunately, inspection of raw signals for grooved pavement showed no startling differences from those of ungrooved pavement, although the driver experienced a perceptible difference. These signals were used as input to a motorcycle-handling computer program (6).

Figure 1. Lateral velocity in HVOSM computer simulation.

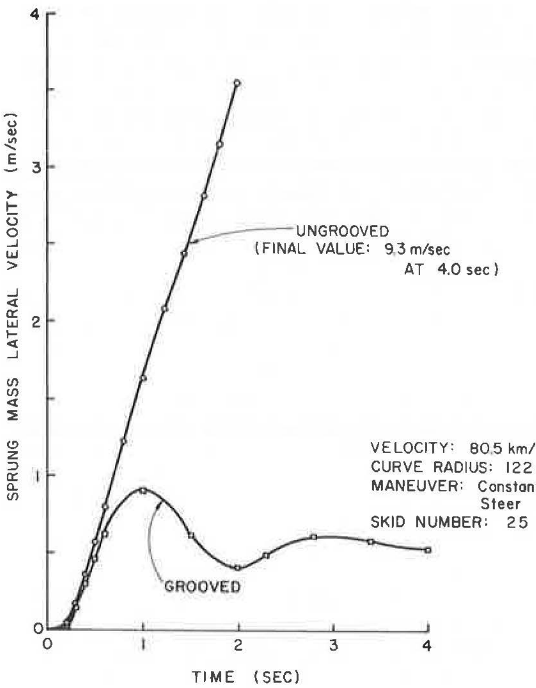


Figure 2. Lateral acceleration in HVOSM computer simulation.

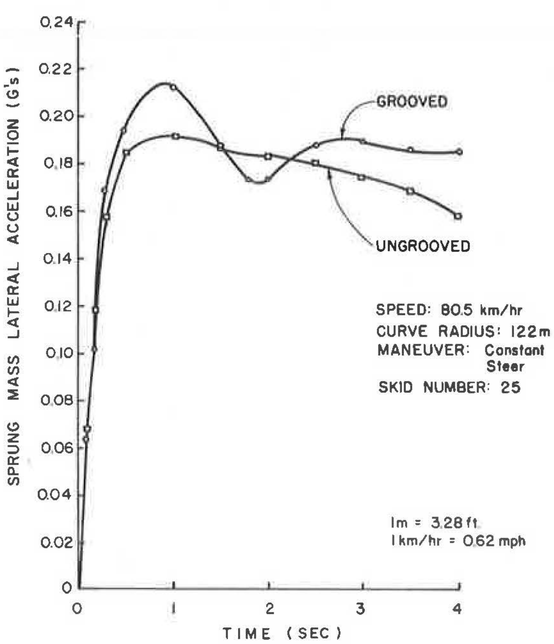


Figure 3. Yaw rate in HVOSM computer simulation.

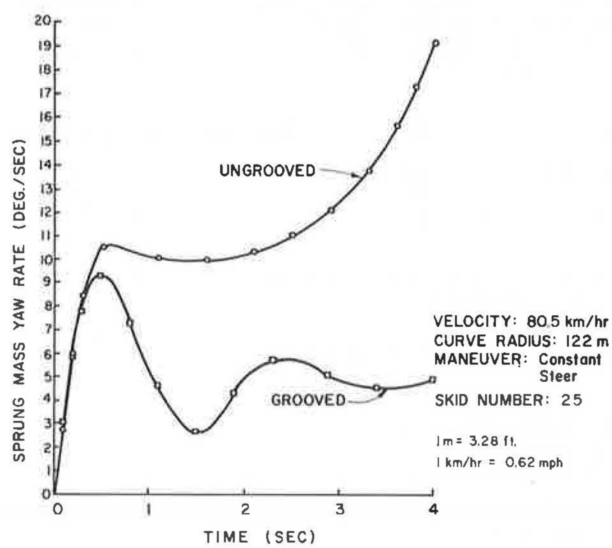
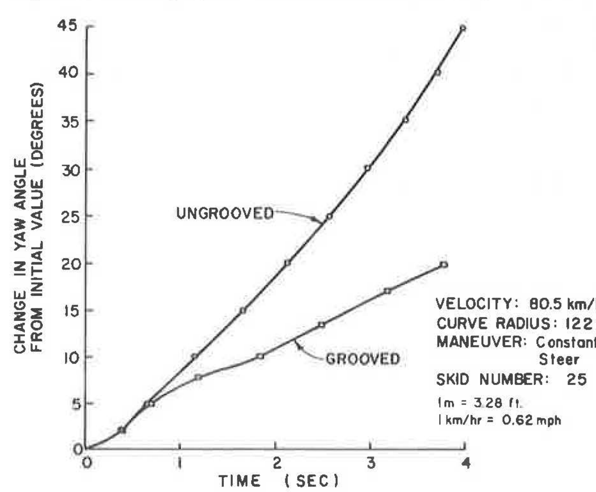


Figure 4. Yaw angle in HVOSM computer simulation.



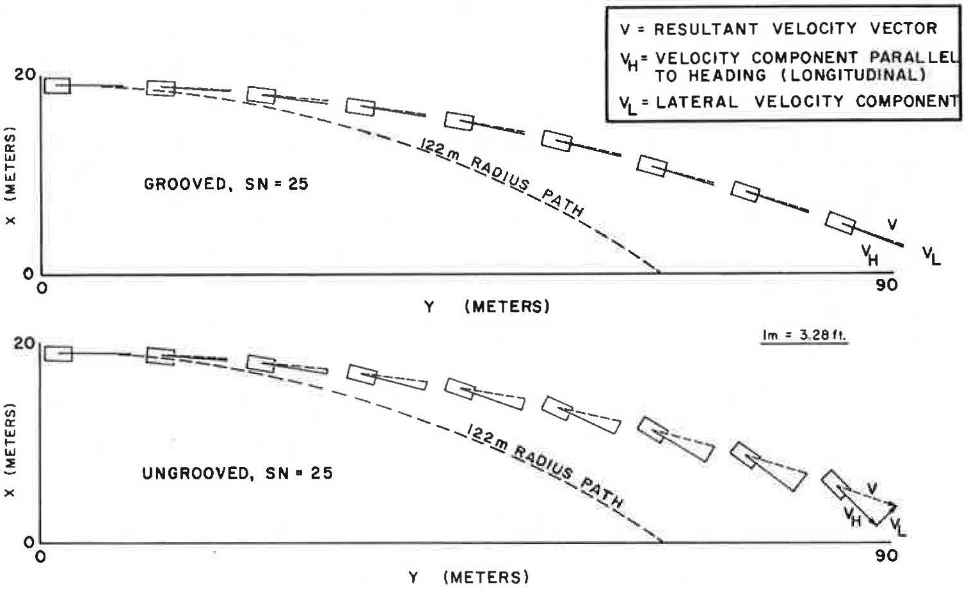


Figure 5. Constant steer maneuver at 80.5 km/h (50 mph) on low-friction pavement in HVOSM simulation.

THEORETICAL APPROACH

A regression analysis was performed on the data, and equations were developed to describe the effects of the pavement grooving. The equations considered the effect of the following parameters: side force and circumferential force for smooth pavement, side-slip angle, camber angle, grooving approach angle, normal load, groove width, groove depth, groove spacing, pavement, tire, circumferential slip, and velocity. The two equations that were developed for automobile tires considered free-rolling and braking effects, and the one equation that was developed for motorcycle tires considered only free-rolling effects.

The computer simulation was carried out by using three distinct vehicle-handling computer models: a highway-vehicle-object simulation model (HVOSM) (7), a motorcycle-handling model developed by CALSPAN Corporation (6), and a model for articulated vehicles developed by HSRI (8). These models incorporated the results of the regression analysis.

DISCUSSION OF RESULTS

The results obtained by the HSRI computer simulation of an articulated vehicle in free-rolling and braking conditions on both grooved and smooth (ungrooved) pavements closely match results obtained by HSRI in tests in which a new B. F. Goodrich Silvertown belted 8.25 × 14 tire inflated to 165.5 kPa (24 lbf/in^2) was driven on a smooth TTI test pad (9). The computer runs were made for a 1636.5-kg (3600-lb) vehicle towing a 954.6-kg (2100-lb) trailer at 48.3 km/h (30 mph) on dry, grooved concrete pavement. Results from 12 computer runs show that the smooth and grooved roads do not differ significantly (5).

The results of the motorcycle study were inconclusive. The model simulated a motorcycle following the line of the roadway on a section of grooved pavement. Steering torque data were obtained in full-scale tests by a torque sensor located between the handlebars and front fork of the test motorcycle. The data were digitized and used as a disturbance input to the motorcycle computer simulation. The steer angle was also recorded and used in comparisons. The front and rear tire side forces resulting from the disturbance were modified by using the grooving function.

Since steer angle was the only parameter that could be used in comparisons, no firm conclusions could be reached on how well the simulation results compare with full-scale test results. The agreement between simulated and experimental steer responses was not close. No oscillations of the motorcycle that could be termed weave or wobble were noted either in the simulated or experimental steering time histories. One conclusion that can be reached is that pavement grooving has little effect on motorcycle response under the conditions studied.

Several computer runs made with HVOSM considered different pavements (SN = 75 and SN = 25) and constant steer maneuvers for a medium-weight vehicle traveling on a 122-m (400-ft) radius curve at 80.5 km/h (50 mph). Grooving caused a slight increase in lateral force on the high-friction pavement and had a significantly beneficial effect on the low-friction pavement. Figures 1 through 5 show that the vehicle is considerably more stable on the grooved pavement than on the ungrooved pavement. The vehicle attains its maximum available lateral force on all four tires during the 4-s maneuver on the ungrooved pavement; only the front two tires saturate on the grooved pavement. Figures 1 and 5 indicate that the grooves provide vehicle directional control as evidenced by the small lateral velocity component. Figure 2 shows that lateral acceleration is dependent on steer input on grooved pavements and indepdendent of steer input on ungrooved pavements. Figure 3 shows that the oscillations in yaw rates seem to decay to a steady-state value on grooved pavements and diverge rapidly after 2 s on ungrooved pavements. Figure 4 shows that the yaw angle is larger on ungrooved pavements than on grooved pavements and continues to increase throughout the simulation. These results seem to indicate that the beneficial effects of pavement grooving are greater for the low-friction pavements. However, the results at the low skid number represent an extrapolation of measured data.

CONCLUSIONS

Pavement grooving helps to drain pavements, provides directional stability, and consequently reduces the number of accidents during wet-weather periods. However, some motorcyclists have expressed concern about riding on grooved pavements. This study could find no detrimental effects of pavement grooving on motorcycle handling. At high speed, the motorcycle rider did have an insecure feeling because of the presence of the grooved pavement. The testing, theoretical hypotheses, and riding experiments suggest that the tire-groove interaction does excite certain resonant frequencies in motorcycles; the effect is so subtle as to be almost undetectable except at very high speeds or for a poorly damped motorcycle.

The results of the HSRI computer simulation of the articulated vehicle did not show much difference between the smooth and grooved pavements. The braking results revealed that slightly higher friction is available on grooved than on smooth pavements. The full-scale testing of the instrumented automobile-trailer combination revealed that the effects of the grooving could not be detected by the instrumentation used.

The study showed that variations in the groove dimensions and approach angle do not produce a significant difference between grooved and ungrooved pavement.

Specific conclusions drawn are given below, some of which are based on analyses contained in another report (5).

Motorcycle

Rider Evaluation

1. Worn grooves are not so evident to the rider as are unworn or newly cut grooves.
2. Grooves have no detrimental effects at speeds no higher than 88.5 km/h (55 mph).
3. At speeds approaching 112.6 km/h (70 mph), the rider experiences a perceptible wobble (side-to-side, front-wheel movement) when he does not follow the grooves and only a slight wobble when he does.
4. The effect of the grooves does not occur immediately and is more evident when the testing is performed over a 0.8-km (0.5-mile) length of pavement.
5. The effect of a steering damper on the response of the motorcycle to the grooves could not be clearly detected.
6. The effect of grooves on motorcycle response is more noticeable for knobby tires than for factory-equipped, street tires.
7. Riding over transverse grooves (perpendicular to approach direction) does not produce undesirable effects.
8. Lowering the tire-inflation pressure by 68.9 kPa (10 lb/in^2) from the recommended pressure does not affect the motorcycle response on grooves.
9. A more noticeable disturbance is produced on steel-time, longitudinally textured pavement than on grooved pavements.
10. Pavement grooving cannot be considered hazardous for speeds under 112.6 km/h (70 mph) except perhaps to the most inexperienced rider.

Electronic Instrumentation and Computer Simulation

1. The effects of pavement grooving cannot be detected.
2. Motorcycle response is almost the same on grooved and smooth pavements.
3. No motorcycle oscillations that could be termed weave or wobble were noted.

Small Automobile and Towed-Vehicle Combination

1. Based on instrumented full-scale testing, the effects of grooving cannot be detected at different speeds for various trailer and tongue loads.
2. Based on driver evaluation, a slight vibration occurs in the steering wheel at a speed of 80.5 km/h (50 mph) even though the system remains extremely stable.
3. Based on full-scale testing and driver evaluation, pavement grooving is not detrimental.
4. Based on computer simulation in which grooving function resulting from single-tire test data is used, no significant difference is observed for cornering maneuvers on smooth and grooved pavements.

Automobile (HVOSM Simulation)

1. In a braking situation, grooving is quite beneficial at higher speeds (data were only collected at skid numbers of 60 and above).
2. In a free-rolling situation, grooving is more beneficial on the low-friction pavements (Figure 4), the effect of the grooving approach angle (angle between wheel velocity vector and the grooves) is minor, and the side forces are larger on grooved than on smooth pavement.
3. At 80.5 km/h (50 mph) on a 122-m (400-ft) radius curve, grooves have a slightly beneficial effect for a constant steer maneuver on a high-friction pavement (SN = 75) and significant beneficial effect for a turning maneuver on a low-friction pavement (SN = 25).

ACKNOWLEDGMENTS

This study was conducted by the Texas Transportation Institute and sponsored by the Federal Highway Administration, U.S. Department of Transportation. I wish to express my appreciation to R. R. Hegmon, contract manager, for his guidance and helpful advice during the course of the study. His continual interest assured the successful execution of the objectives of the research. The opinions, findings, and conclusions expressed in this paper are mine and not necessarily those of the sponsor.

REFERENCES

1. E. Farnsworth and D. Johnson. Reduction of Wet Pavement Accidents on Metropolitan Freeways. SAE, Rept. 710574, June 1971.
2. R. J. Rasmussen. Pavement Surface Texture and Restoration for Highway Safety. Paper presented at the 53rd Annual Meeting, HRB, 1974.
3. B. M. Gallaway and J. G. Rose. Macro-Texture, Friction, Cross Slope and Wheel Track Depression Measurements on 41 Typical Texas Highway Pavements. Texas Transportation Institute, Texas A&M Univ., College Station, Research Rept. 138-2, June 1970.
4. D. L. Ivey, H. E. Ross, G. G. Hayes, R. D. Young, and J. C. Glennon. Side Friction Factors Used in the Design of Highway Curves. Texas A&M Research Foundation, Texas Transportation Institute, College Station, Final Rept. 628-2, revised June 1971; NCHRP, Project 20-7.
5. J. E. Martinez. Effects of Pavement Grooving on Friction, Braking and Vehicle Control. Texas Transportation Institute, Texas A&M Univ., College Station, Final Rept., Aug. 1976.
6. R. Roland. Simulation Study of Motorcycle Stability at High Speed. Second International Congress on Automotive Safety, San Francisco, Paper 73020, July 1973.
7. R. R. McHenry and N. J. Deleys. Automobile Dynamics: A Computer Simulation of Three-

Dimensional Motions for Use in Studies of Braking Systems and of the Driving Task. CALSPAN Corp., Buffalo, CAL Rept. VJ-2251-V-7, Aug. 1970.
8. J. E. Bernard and others. A Computer Based Mathematical Method for Predicting the Directional Response of Trucks and Tractor-Trailers. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, Technical Rept. UM-HSRI-PF-73-1, June 1973.
9. J. E. Bernard and others. Vehicle in Use Limit Performance and Tire Factors: The Tire in Use. Highway Safety Research Institute, Univ. of Michigan, Ann Arbor, Rept. DOT-HS-801-439, March 1975.

Publication of this paper sponsored by Committee on Surface Properties-Vehicle Interaction.

Photographic Technique for Estimating Skid Number and Speed Gradients of Pavements

L. Bruce McDonald,* Allen Corporation, Alexandria, Virginia
Robert R. Blackburn, Midwest Research Institute, Kansas City, Missouri
Donald R. Kobett,* Black and Veatch Engineers, Kansas City, Missouri

A technique has been developed for determining skid number and speed gradients of pavements from a moving vehicle. Photographs were made of the pavement by using a light at low-incidence angle to project shadows across the peaks and valleys of pavement macrotexture. The photographs were compared to standard photographs of pavements with known gradients. The ratings were converted to estimated skid number and speed gradient by using a regression equation. The technique is economical, valid, and reliable.

A study was made to determine the relations between skid number (coefficient of friction × 100) and wet-pavement accident rates. Wet-pavement accident records and the matching skid-number measurements provided by the states participating in the study were used. Skid number measurements are needed that correspond to the operating speed of the roadway.

The skid number data collected by the states are generally measured at a speed of 64 km/h (40 mph), and the skid number is known to decrease as speed increases. Thus, to determine skid number at the operating speed of the roadway at the time of the accident, we must know the skid number-speed gradient ($G = \Delta$ skid number/Δ speed). For example, if we know that the skid number at 64 km/h (40 mph) is 45 and the speed gradient is 0.50, then the skid number at an operating speed of 97 km/h (60 mph) is $45 - (0.50 \times 60 - 40) = 45 - 10 = 35$.

The most obvious method of obtaining the gradient for a section of pavement is to measure the skid number at various speeds and determine the gradient empirically. Because this is an expensive procedure and states have only limited budgets for skid measurement, the gradients have been determined for only a small number of pavement sections. A review of previous work was thus made to determine the technique best suited to estimate gradients.

PREVIOUS WORK

Several research projects have been directed toward alternate methods of determining the skid number-speed gradient of selected pavements. The most productive study was done by Schulze and Beckman (1), who found that the skid number-speed gradient from 20 to 60 km/h (12 to 37 mph) is correlated with the mean width of surface voids. The larger void width produces a flatter speed gradient primarily because of better water drainage.

The method for obtaining the mean void width is described by Schulze (2). Stereophotographs were taken of pavement sections and magnified 25 to 1. The outline of each individual void was then traced onto paper, and the width of each void was measured. Needless to say, this procedure would be much too expensive for any major speed-gradient inventory.

Gillespie (3) found mean void widths from pavement profile traces by using an electromechanical roughness meter. The mean void width was defined as the mean distance between peaks on the trace. When mean void width was compared to the known skid number-speed gradient from 60 to 80 km/h (37 to 50 mph), the comparison with the extrapolated Schulze and Beckmann curve was excellent.

Goodman (4) developed several techniques for measuring pavement texture from a moving vehicle; his validation, however, was limited to stationary, laboratory studies. One proposed technique involved photography. A narrow slit of light was projected vertically onto the surface of the pavement, and the resulting line was photographed from an angle of 30° to horizontal. In the resulting photograph, the strip of light delineated the peaks and valleys along the strip. The number of peaks per centimeter, inverse of mean void width, from this photographic technique agreed well with the results from an electromechanical roughness meter applied to the same strip of pavement.