Wear and Skid Resistance of Full-Scale Experimental Concrete Highway Finishes

W. B. Ledbetter and A. H. Meyer, Texas Transportation Institute, Texas A&M University

Results on an evaluation of two sets of full-scale experimental concrete test sections are summarized. Eighteen experimental concrete finishes were evaluated in terms of skid resistance under standard trailer water conditions and under simulated rainfall conditions. In addition the changes in texture depths and skid values with time were measured. Results indicate that (a) texture depths of 0.15 cm (0.06 in) or greater can be constructed easily and economically with 0.32-cm (1/8-in) metal tines spaced closer than 1.27 cm (½ in) apart; (b) under normal traffic conditions, all concrete textures can be expected to wear down approximately 25 to 35 percent during the first half year and then remain relatively unchanged for a prolonged period; (c) skid measurements made under standard trailer water conditions may not be indicative of real-life conditions in wet weather; (d) low skid values could be obtained in almost any rainfall in which the pavement is completely wetted regardless of texture; and (e) under simulated rain condition, deep transverse texturing will result in the greatest improvement in skid values.

The purpose of this investigation was to determine the effects of various experimental concrete surface finishes on the skid resistance and durability of portland cement concrete (PCC) pavement.

The scope of this paper is to report on the changes in skid resistance under various simulated rainfall conditions on two sets of full-scale experimental test section surfaces constructed on concrete pavements in different parts of the state of Texas. Also reported are the changes in texture depths and skid resistances as the pavements wore down under traffic.

BACKGROUND

The safety and durability of concrete pavement surfaces have long been of importance to highway engineers. Concrete pavements are often selected because they are supposed to last a long time and their surfaces are supposed to provide high skid resistances. At the time of this study the Texas Department of Highways and Public Transportation required the use of a longitudinal burlap drag finish with an initial minimum texture depth of 0.064 cm (0.025 in). During this time, three questions were raised.

1. Should deeper textures be required, and, if so, will these deeper textures result in less durable surfaces or have any other undesirable effects?
2. Are there better types of textures than the burlap drag?
3. Does the direction of texturing—longitudinal or transverse—influence safety or durability?

In attempting to answer these questions, we examined the literature. Currently, a number of excellent reports have been prepared on PCC surface textures. Among them are the state-of-the-art summaries by Ray and Norling (2) and Rose and Ledbetter (3). They point to the need for deeper textures and attest to the fact that durable concrete surfaces can be easily constructed.

A survey of 69 PCC pavements in 27 states has been conducted (4). The data on the change in average texture depth (ATD) were limited, but, for those reporting initial and present values of ATD, they did show a drop of about 30 to 40 percent in 3 to 4 years. In terms of skid values, an average loss of 20 percent was observed in 5 years.

An excellent summary of the research work done in England is reported by Murphy and Maynard (5). This report shows that transverse grooves provide the highest resistance to skidding at high speeds, and England now requires transverse grooving of their highways. Concerning tire wear they state that "the rate of wear depends upon the harshness, or microtexture, of the surface, the macrotexture being of little importance."

From the evidence reported, it appears that deeper textures would be advantageous from a safety standpoint, provided that there were no undesirable effects created. Undesirable effects could include increased noise, increased cost, decreased life, adverse driver effect, and increased tire wear.

The possibility of increased noise was investigated by the Texas Transportation Institute (6), and only one texture (the transverse plastic broom) appeared to generate objectionable noises.

The possibility of increased construction cost and de-

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

creased pavement life were investigated in this study and are discussed in this paper. Driver effects and tire wear are beyond the scope of this study.

TEST SECTION CONSTRUCTION

Seven test sections, each 244 m (800 ft) long, were constructed on Tex-6 in College Station, Texas, in November 1971 (Table 1, sections F-1 through F-7). A complete description and discussion of the construction of these 7 test sections are given elsewhere (6). Traffic on these sections averaged 868 vehicle passes/day (VPD) in June 1972, 1483 vehicle passes/day in January 1973, and 1530 vehicle passes/day in July 1974.

Eleven test sections were constructed in September 1973, on I-10 near Van Horn, Texas. The average length of each section was 183 m (600 ft) and was prepared by using a granite gravel and granite sand, type II portland cement, and an air entrainment admixture. A description of construction conditions, mix design constraints, control tests, and original batch data is given elsewhere (7).

A burlap drag finish was accomplished by passing a wet burlap cloth, with approximately 0.5 m (2 ft) of burlap in contact with the surface until the desired texture was obtained. The brush finish was accomplished by passing a natural-bristle (strawlike) brush over the slab surface, which slightly grooved the concrete. The broom was inclined at an angle of approximately 30 deg to the surface. The tine finish was accomplished by passing a series of thin metal strips (tines), 0.32 by 12.7 cm (1/8 by 5 in) long, over the section surface, which produced grooves that were approximately 0.32 cm (1/8 in) in depth in the concrete. The tine spacing was varied from 0.32 to 0.64 cm (1/8 to 1/4 in) (clear distance between tines). The burlap-drag-plus-tine finish was accomplished by first passing the burlap drag over the section surface, followed by one pass of the tines as previously described. The tine spacing was varied from 0.64 to 2.54 cm (1/4 to 1.0 in) (clear distance between tines).

RESULTS TO DATE

Texture Depth

The texture of a pavement surface is the character of the surface profile consisting of a series of abrupt changes in elevation. Variations in texture can result from the different sizes of aggregates on the surface and from various pavement finishing operations. The textures resulting from construction can be altered by the effects of traffic, wear, and environment.

One major finding of this study was that all of the experimental textures were easily constructed. No increase in construction cost would be expected if any of the experimental textures were specified.

Texture measurements were initially made by using the putty impression method (8) and later by using the sand patch method as well (Tex 436-A) (9). To develop the correlation between these two tests, we made a linear regression analysis of 276 observations on the Tex-6 test sections, 124 observations on the I-10 test sections, and 44 observations on laboratory blocks of various finishes (10). The resulting equation is

$$TXD_s = 0.8185\ TXD_p \qquad (1)$$

where

TXD_s = sand patch value and
TXD_p = putty impression value.

The square of the correlation coefficient for equation 1 = 0.96.

For Tex-6, texture depth measurements were taken at various intervals between December 1971 and July 1974. The test surfaces evaluated in December 1971 had little or no traffic on them. Conversely, the same surfaces, tested in July 1974, had been subjected to 8 months of construction traffic and 23 months of public use. The texture depths decrease rapidly at first and then appear to level off.

Evaluation of each surface finish on I-10 was conducted in essentially the same manner. The initial textures were measured in December 1973 before any traffic movement. The second measurements were made in July 1974 after the 11 different textures had been subjected to approximately 3 months of construction traffic and 5 months of public traffic.

The average wearing down for the Tex-6 textures was 32 percent, which is in substantial agreement with data taken from accelerated wear testing of 98 laboratory-constructed concrete finishes on the Texas Department of Highways and Public Transportation circular test track. The average wearing down of these 98 surfaces was 24 percent with a standard deviation of 13 percent (10). The average wearing down for the I-10 textures was 34 percent. Therefore, it can be concluded that concrete pavement textures, regardless of type, may be expected to wear down a minimum of 25 to 35 percent under normal southern United States traffic conditions, based on initial texture depth.

Skid Measurements Under Standard Conditions

For the outer lane of the Tex-6 test sections, the variations in skid resistance at 64 km/h (40 mph) with time are shown in Figure 1. Following an initial period of anomalous behavior, all sections appear to be exhibiting lower skid resistances with time. However, every experimental texture exhibited a higher initial skid resistance than that for the burlap control.

On I-10, only two sets of skid resistance measurements have been made to date. The longer term behavior of the I-10 test sections is unknown at this time.

Skid Measurements Under Simulated Rainfall

Skid measurements under light simulated rainfall conditions on the Tex-6 test sections are summarized in Figure 2. The data are given in Table 2. Under rainfall intensities of approximately 3.8 cm/h (1.5 in/h) (Figure 2), all of the experimental textures exhibited higher skid resistances [10 to 20 skid numbers (SNs)] than the burlap control, although skid gradients were similar [about 0.97 SN drop per km/h (0.6 SN drop per mph)]. Under rainfall intensities of approximately 15 cm/h (6 in/h), the beneficial skid effects of the deeper textures were somewhat masked, especially at higher speeds. A more complete discussion of these conditions can be found elsewhere (6).

For the I-10 test sections, skid measurements under simulated rainfall are shown in Figures 3 and 4 for selected test sections on I-10. The data are given in Table 3. For comparison purposes, skid values that use standard trailer water are also shown. These data and figures again show that, at elevated speeds [64 and 97 km/h (40 and 60 mph)], skid measurements under standard trailer water were significantly higher than under simulated rainfall.

Before discussing these results in detail, it should be pointed out that all the simulated rainfall data were

gathered on relatively new pavement surfaces that had neither been worn nor contaminated by road films and the like. If worn pavements had been used, lower skid values would be expected.

In general, as vehicle speed increases, SN decreases. The entrapment of water between a sliding tire and a wet pavement surface is responsible for the development of hydrostatic pressure. This pressure decreases tire pavement friction in direct proportion to its magnitude. If this pressure develops to the extent that the tire is supported almost entirely by the water film, hydroplaning results (11).

At the different test speeds, the tire-pavement interface becomes wet to various degrees. This fact, in part, may account for some of the anomalies that occur during the testing of pavement surfaces, as can be seen by comparing skid values for standard trailer water with skid values for various depths of water on the pavement surface.

These data seem to indicate that skid measurements under standard trailer water conditions may not be indicative of real-life conditions in rainy weather. If we assume that the simulated rainfall conditions represent more closely real-life conditions, then the lack of skid resistance under these rainfall conditions is alarming at speeds in excess of about 64 to 80 km/h (40 to 50 mph), regardless of texture.

Table 1. Test section surface treatments.

Test Section Number	Surface Treatment
F-1	Transverse broom
F-2	0.32-cm transverse tines
F-3	Longitudinal broom
F-4	0.32-cm longitudinal tines
F-5	Burlap drag + 0.32-cm longitudinal tines
F-6	Burlap drag (control)
F-7	Transverse brush
F-11	Burlap + 0.64-cm longitudinal tines
F-12	Burlap + 1.27-cm longitudinal tines
F-13	Burlap + 2.54-cm longitudinal tines
F-14	Burlap + 1.91-cm longitudinal tines
F-15	0.64-cm longitudinal tines
F-16	0.32-cm longitudinal tines
F-17	Burlap drag (control)
F-18	0.32-cm transverse tines
F-19	0.64-cm transverse tines
F-20	Transverse brush
F-21	Burlap + 2.54-cm transverse tines

Note: 1 cm = 0.394 in.

Figure 1. Skid measurement results at 64 km/h (40 mph) on the outside lane of Tex-6 in College Station.

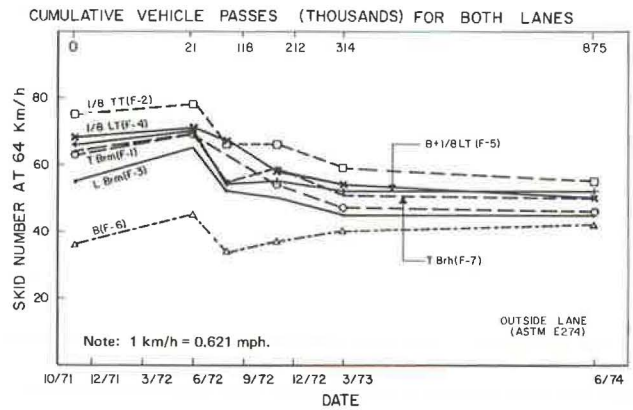


Table 2. Skid measurements under simulated rainfall on Tex-6 in College Station, August 1972.

Test Section Number	Description	Bald Tire Water Depth (cm)	Bald Tire 32-km/h SN	Bald Tire 64-km/h SN	Bald Tire 97-km/h SN	Treaded Tire Water Depth (cm)	Treaded Tire 32-km/h SN	Treaded Tire 64-km/h SN	Treaded Tire 97-km/h SN
F-1	Transverse broom	-0.051	64	40	28	-0.051	69	56	41
	(TXD_a = 0.084 cm,	0.010	67	36	23	0.010	75	54	37
	TXD_p = 0.109 cm)	0.061	57	39	24	0.061	74	55	25
		0.122	58	28	16	0.122	74	55	25
F-2	Transverse tines	-0.150	72	48	36	-0.150	77	59	45
	(TXD_a = 0.145 cm,	-0.089	77	47	32	-0.089	82	62	47
	TXD_p = 0.163 cm)	0.000	72	56	43	0.000	74	62	49
		0.061	84	47	28	0.061	84	59	34
F-3	Longitudinal broom	-0.020	53	32	19	-0.020	71	49	33
	(TXD_a = 0.038 cm,	0.051	61	29	22	0.051	75	53	28
	TXD_p = 0.071 cm)	0.079	54	29	19	0.079	71	51	33
		0.107	55	26	19	0.107	75	53	36
		0.130	66	28	21	0.130	74	51	27
		0.155	58	25	19	0.155	75	62	29
F-4	Longitudinal tines	-0.066	75	50	29	-0.066	80	61	35
	(TXD_a = 0.140 cm,	0.020	76	47	23	0.020	84	67	28
	TXD_p = 0.157 cm)	0.071	69	35	20	0.071	75	64	28
		0.150	74	30	18	0.150	75	63	24
F-5	Burlap + longitudinal tines	-0.036	69	40	23	-0.036	67	59	42
	(TXD_a = 0.150 cm,	0.030	68	42	20	0.030	72	58	34
	TXD_p = 0.165 cm)	0.130	72	46	20	0.130	73	56	23
		0.180	74	46	18	0.180	76	55	18
F-6	Burlap drag (control)	-0.025	46	26	16	-0.025	57	41	26
	(TXD_a = 0.051 cm,	0.010	50	28	16	0.010	61	45	21
	TXD_p = 0.081 cm)	0.041	54	26	16	0.041	62	41	26
		0.140	60	31	16	0.140	64	47	20
F-7	Transverse natural brush	0.000	64	35	25	0.000	83	63	43
	(TXD_a = 0.053 cm,	0.051	56	30	25	0.051	78	55	38
	TXD_p = 0.084 cm)	0.079	66	32	23	0.079	85	65	36
		0.127	49	29	23	0.127	70	56	26

Note: 1 cm = 0.394 in. 1 km/h = 0.621 mph.

Figure 2. Effect of vehicle speed on skid values of Tex-6 test sections under simulated light rainfall.

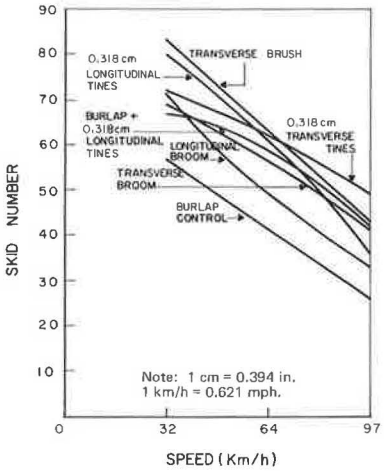


Figure 3. Effect of vehicle speed on skid values of section F-11 on I-10 under simulated rainfall.

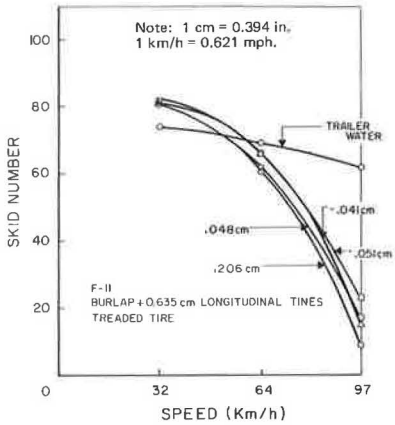


Figure 4. Effect of vehicle speed on skid values of section F-19 on I-10 under simulated rainfall.

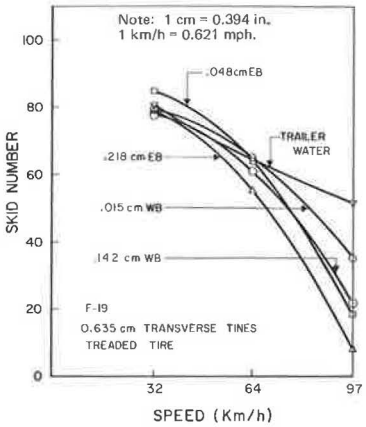


Table 3. Skid measurements under simulated rainfall on I-10 near Van Horn, October 1973.

Test Section Number	Description	Bald Tire: Water Depth (cm)	Bald Tire: 32-km/h SN	Bald Tire: 64-km/h SN	Bald Tire: 97-km/h SN	Treaded Tire: Water Depth (cm)	Treaded Tire: 32-km/h SN	Treaded Tire: 64-km/h SN	Treaded Tire: 97-km/h SN
F-11	Burlap + 0.64-cm longitudinal tines	-0.135	78	51	16	-0.051	82	66	23
	(TXD_s = 0.178 cm,	-0.117	77	56	26	-0.041	81	66	15
	TXD_p = 0.206 cm)	-0.018	78	46	12	0.048	81	62	17
		0.165	80	52	9	0.206	81	61	9
F-12	Burlap + 1.27-cm longitudinal tines	-0.018	79	46	18	-0.033	80	61	34
	(TXD_s = 0.155 cm,	0.005	81	45	12	-0.023	79	59	16
	TXD_p = 0.191 cm)	0.074	78	40	7	0.028	83	61	14
		0.160	78	38	3	0.132	79	59	9
F-13	Burlap + 2.54-cm longitudinal tines	-0.030	66	33	13	-0.041	71	52	18
	(TXD_s = 0.114 cm,	0.163	60	32	11	0.025	69	51	18
	TXD_p = 0.157 cm)	0.036	70	30	5	0.061	70	48	8
		0.107	68	27	4	0.127	71	46	8
F-14	Burlap + 1.91-cm longitudinal tines	0.036	73	33	11	0.061	81	63	14
	(TXD_s = 0.132 cm,	0.069	74	29	6	0.089	78	54	8
	TXD_p = 0.163 cm)	0.132	75	33	6	0.142	78	50	7
		0.135	69	22	3	0.183	82	60	11
F-16	0.32-cm longitudinal tines	0.046	75	43	13	0.033	81	66	25
	(TXD_s = 0.165 cm,	0.051	75	36	4	0.058	82	65	17
	TXD_p = 0.173 cm)	0.114	79	44	11	0.102	84	65	20
		0.175	77	42	4	0.165	85	68	10
F-17	Burlap drag (control)	-0.028	65	31	10	-0.023	77	57	16
	(TXD_s = 0.069 cm,	-0.005	62	25	4	-0.008	71	52	16
	TXD_p + 0.086 cm)	0.081	67	28	8	0.076	78	49	14
		0.135	65	21	4	0.165	77	48	9
F-18	0.32-cm transverse tines	-0.015	73	33	21	0.156	88	64	22
	(TXD_s = 0.132 cm,	0.145	73	25	7	0.137	94	65	9
	TXD_p = 0.127 cm)	0.0005	79	32	20	0.023	89	65	28
		0.013	78	34	15	0.041	88	65	17
F-19	0.64-cm transverse tines	0.188	65	23	9	0.218	79	55	8
	(TXD_s = 0.079 cm,	0.137	63	21	9	0.142	78	61	22
	TXD_p = 0.079 cm)	0.048	61	24	13	0.048	85	64	18
		0.015	60	25	14	0.015	79	65	35
F-20	Transverse brush	0.114	59	20	5	0.114	76	51	16
	(TXD_s = 0.059 cm,	0.099	60	20	5	0.099	74	49	15
	TXD_p = 0.053 cm)	0.081	56	24	10	0.081	85	56	19
		0.013	58	29	16	0.013	85	62	31
F-21	Burlap + 2.54-cm transverse tines	0.112	67	22	10	0.112	77	55	14
	(TXD_s = 0.079 cm,	0.117	67	19	7	0.117	75	50	9
	TXD_p + 0.076 cm)	0.033	61	28	13	0.030	73	49	16
		0.015	62	23	11	0.013	78	60	21

Note: 1 cm = 0.394 in. 1 km/h = 0.621 mph.

Statistical Analysis of Skid Measurements Under Simulated Rain Conditions

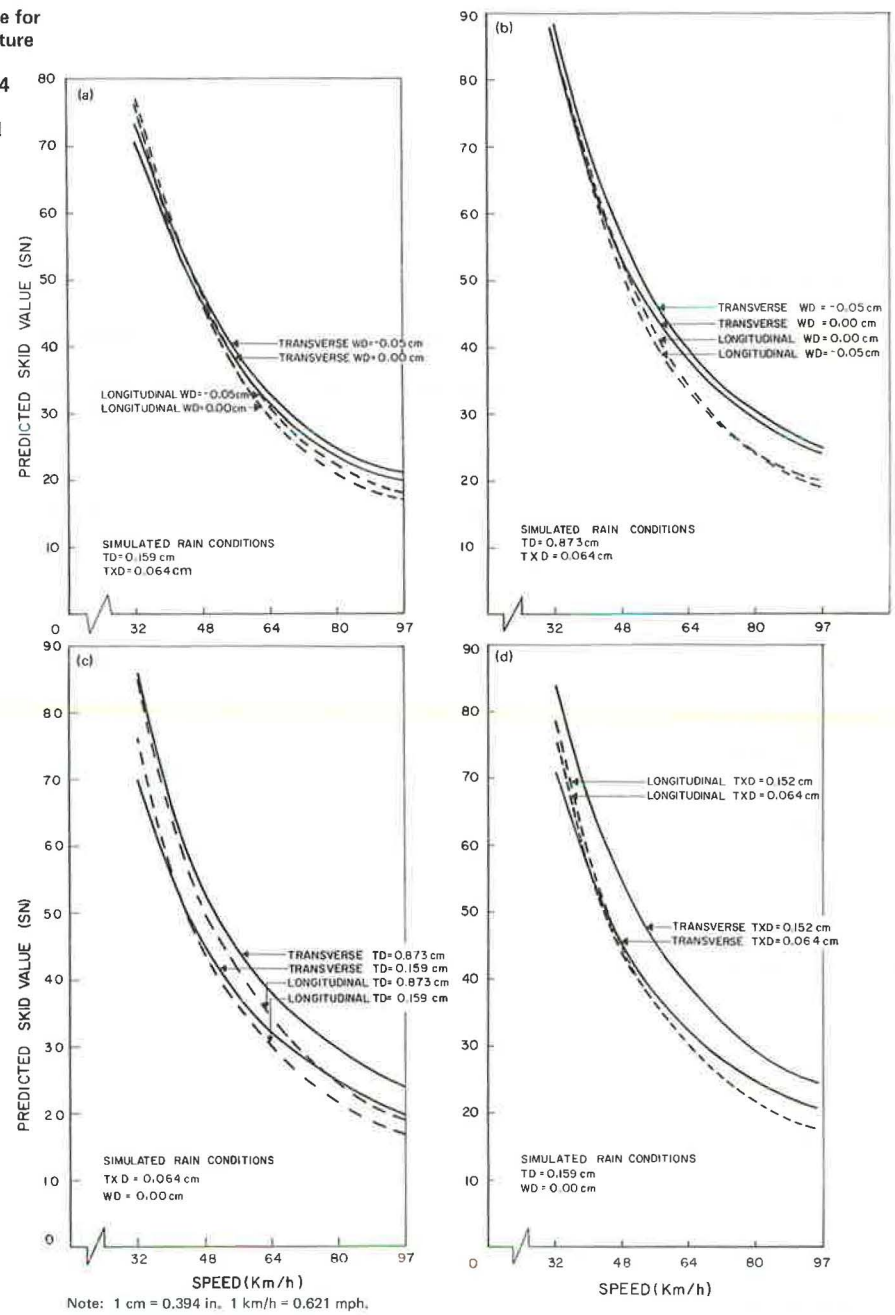
All the data (Tables 2 and 3) from the test sections on Tex-6 and I-10, including the bald tire data, were statistically analyzed by using a two-step select regression analysis technique where best fit models of the following form were developed (these models are designed for U.S. customary units only; therefore, values are not given in SI units):

$$SN = \frac{C_1}{MPH^{C_2}}\left[C_3(TD+1)^{C_4}\ TXD^{C_5} + \frac{1}{(WD+0.1)^{C_6}}\right] \quad (2)$$

Table 4. Regression models.

Texture Direction	Equation Number	Regression Model	Number of Data Points	Square of Correlation Coefficient	Standard Error[a]
Transverse	24	$SN = \frac{205}{MPH^{1.15}}\left[17.92\ (TD+1)^{0.18}\ TXD^{0.29} + \frac{1}{(WD+0.1)^{0.53}}\right]$	168	0.79	11.88
Longitudinal	25	$SN = \frac{910}{MPH^{1.37}}\left[3.06\ (TD+1)^{0.14}\ TXD^{0.04} + \frac{1}{(WD+0.1)^{0.31}}\right]$	252	0.76	13.56

Note: TD is measured in 32nds of an inch; TXD and WD are measured in inches.
[a]In terms of skid number.



Note: 1 cm = 0.394 in. 1 km/h = 0.621 mph.

Figure 5. Effect of vehicle speed on skid value for (a) tread depth of 0.159 cm (0.06 in) and texture depth of 0.064 cm (¼ in), (b) tread depth of 0.873 cm (0.33 in) and texture depth of 0.064 cm (¼ in), (c) water depth of 0.00 cm (0.00 in) and texture depth of 0.064 cm (¼ in), and (d) tread depth of 0.159 cm (0.06 in) and water depth of 0.00 cm (0.00 in).

where

SN = skid number,
MPH = vehicle speed in miles per hour,
TD = skid tire tread depth in 32nds of an inch,
TXD = pavement texture depth in inches,
WD = water depth on the pavement surface in inches measured from the top of the pavement asperities, and
$C_1, \ldots, C_6$ = constants.

A complete description of this technique is given elsewhere (12, 13). The regression analyses yielded two equations—one for transverse textures and one for longitudinal textures—that are summarized in Table 4. The correlation coefficients obtained through the use of this statistical technique are satisfactory. However, the standard errors in terms of SN are somewhat high. There is considerable data scatter because many variables, such as type of finish, location of test section, and type of aggregate, were not considered in this analysis. Therefore, at best, these models for the prediction of SN must be used with engineering judgment because considerable variability may be expected. The results have been plotted in Figures 5, 6, 7, and 8 by using the models.

Figure 5a shows the effect of increasing speed on skid value, of both transverse and longitudinal texturing, assuming a tread depth of 0.16 cm (1/16 in) (the legal minimum in Texas) and a texture depth of 0.064 cm (0.025 in) (the specified as-constructed minimum in Texas) (1) for two water depths: -0.05 cm and 0.00 cm (-0.02 in and 0.00 in) as measured from the top of the pavement asperities. The significant influence of vehicle speed on available friction (SN) can be immediately seen because the SN value drops very rapidly as speed is increased. At low speeds very high SN values are obtained, but, at high speeds [above 64 km/h (40 mph)], the SN values drop below 30 and here transverse texturing results in higher skid values regardless of water depth. This becomes very important at speeds of 97 km/h (60 mph) because the SNs are very low (around 20) and even small increases in skid values become significant on a relative basis.

Figure 5b shows the same type of plot but for a tire depth of 0.87 cm (11/32 in), which represents a new tire. From this figure, it can be seen that, even for a deep tread, the loss in skid value becomes alarmingly high as vehicle speed is increased. Here again, at speeds in excess of 48 km/h (30 mph), the transverse textures exhibit higher skid values than longitudinal textures exhibit. For example, at 97 km/h (60 mph) and -0.05-cm (-0.02-in) water depth, there is a 24 percent greater skid value for transverse texturing over longitudinal texturing (24 versus 20 SN). Another interesting finding shown in Figure 5b is the relatively small influence of water depth on measured skid value, only 1 SN difference for a change in water depth from 10.05 cm to 0.00 cm (-0.02 in to 0.0 in). Examination of all the data reveals that, for the range of conditions evaluated, this is a general finding regardless of texture direction, tread depth, water depth, and vehicle speed. If it were carried further, it would seem to indicate that low skid values could be obtained in almost any rainfall in which the pavement surface was completely wet.

The effect of tread depth on skid values for a water depth of 0.00 cm (0.00 in) and a texture depth of 0.064 cm (0.025 in) is shown in Figure 5c. At speeds approaching 97 km/h (60 mph), the relative differences in SN values between full tread, 0.87 cm (11/32 in), and minimum tread, 0.16 cm (1/16 in), become very significant. Full tread results in 20 percent more available skid resistance than minimum tread does (SN values of 24 versus 20).

The effects of texture depth and texture direction are shown in Figure 5d for a tread depth of 0.16 cm (1/16 in) and a water depth of 0.00 cm (0.00 in). For this water depth, at 97 km/h (60 mph), transverse texturing is again significantly better than longitudinal texturing, and a 0.15-cm (0.06-in) texture depth is significantly better than 0.064-cm (0.025-in) texture depth (20 percent for transverse texturing—24 versus 20). Figure 5d summarizes the effects of vehicle speed on skid value for conditions that may reasonably be expected to exist on Texas highways in almost any rainfall in which the pavement is completely wet.

CONCLUSIONS

Six conclusions relate to the findings of this study and are subject to the limitations involved in the study. Generalizations beyond the parameters investigated may not be warranted.

1. Texture depths of 0.15 cm (0.06 in) or greater were easily and economically constructed in PCC pavement in either the longitudinal or transverse direction by using 0.32-cm-wide (1/8-in-wide) metal tines spaced closer than 1.27 cm (1/2 in) apart.
2. Based on initial texture depth, all textures wore down between 25 and 35 percent under traffic and appeared to have leveled off.
3. At speeds of 64 and 97 km/h (40 and 60 mph), locked-wheel skid measurements using trailer water were significantly different from the same measurements made under simulated rain conditions. The simulated rain conditions indicated much lower skid values regardless of measured water depths. This indicates that skid measurements made under standard trailer water conditions may not be indicative of real-life conditions in wet weather.
4. Statistical analysis of the skid measurements under simulated rainfall conditions indicate that, for the rainfall conditions evaluated, extremely low skid values occurred at speeds greater than 64 km/h (40 mph) regardless of water depths. This means that low skid values could be obtained in almost any rainfall in which the pavement was completely wet.
5. Under simulated rain conditions, deep transverse texturing will result in the greatest improvement in skid values.
6. Statistical analysis is needed of the data required in regression models that can predict skid values for a selected vehicle speed, tire tread depth, pavement texture depth (with an appropriate factor for expected wearing down) and texture direction, and pavement water depth.

RECOMMENDATION

Transverse tine textures, with the tines spaced less than 1.27 cm (1/2 in) apart, should be required for concrete pavements. These textures should be significantly deeper than now required. Furthermore, any required initial texture depth should consider expected wearing down and subsequent loss of texture, and the regression models should be used to determine required texture depths. This recommendation has been successfully applied by the Texas Department of Highways and Public Transportation on two recent construction projects and will be the standard practice for current projects.

ACKNOWLEDGMENTS

The information contained here was developed in Research Study 2-6-70-141, Quality of Portland Cement Concrete Pavement as Related to Environmental Factors and Handling Practices During Construction, in a cooperative research program with the Texas Department of Highways and Public Transportation and the Federal Highway Administration.

The contents of this paper reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration.

REFERENCES

1. 1972 Standard Specifications. Texas Highway Department, Austin, Item 360.8.
2. G. K. Ray and L. T. Norling. More Microtexture in Concrete Pavement for Greater, Longer-Lasting Skid Resistance. Portland Cement Association, Skokie, Ill., 1974, 18 pp.
3. J. G. Rose and W. B. Ledbetter. Summary of Surface Factors Influencing the Friction Properties of Concrete Pavements. HRB, Highway Research Record 357, 1971, pp. 53-63.
4. Surface Wear of Portland Cement Concrete Pavements. TRB, Transportation Research Circular 170, Sept. 1975.
5. W. E. Murphy and D. P. Maynard. Surface Texture of British Concrete Pavements. Journal of Highway Division, Proc., ASCE, Vol. 101, No. TE1, Feb. 1975, p. 115.
6. J. L. Davis, W. B. Ledbetter, and A. H. Meyer. First Progress Report on Concrete Experimental Test Sections in Brazos County, Texas. Texas Transportation Institute, Texas A&M Univ., College Station, Research Rept. 141-2, Aug. 1973, 63 pp.
7. W. B. Ledbetter, A. H. Meyer, and D. E. Ballard. Evaluation of Full-Scale Experimental Concrete Highway Finishes. Texas Transportation Institute, Texas A&M Univ., College Station, Research Rept. 141-4F, Sept. 1974, 81 pp.
8. J. G. Rose and others. Summary and Analysis of the Attributes of Methods of Surface Texture Measurement. In Skid Resistance of Highway Pavements, ASTM, Philadelphia, STP 530, 1973, pp. 60-77.
9. Manual of Testing Procedures. Texas Highway Department, Austin.
10. K. D. Hankins, J. P. Underwood, O. Darnaby, and W. B. Ledbetter. Pavement Surface Polishing Characteristics: A Circular Track Test. Texas Transportation Institute, Texas A&M Univ., College Station, Research Rept. 126-3F, June 1974, 118 pp.
11. R. W. Yeager. Tire Hydroplaning: Testing, Analysis, and Design. In The Physics of Tire Traction, Plenum Press, New York, 1974, pp. 25-63.
12. R. R. Hocking and R. N. Leslie. Selection of the Best Subset in Regression. Technometrics, Vol. 9, 1967, pp. 531-540.
13. L. R. Lamotte and R. R. Hocking. Computational Efficiency in Selection of Regression Variables. Technometrics, Vol. 12, 1970, pp. 83-93.