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16. Abstract Surface characteristics of portland cement concrete pavement have received much attention in recent years especially as they relate to skid resistance. Seven experimental test sections were constructed in order to quantify the relative effects of the surface textures. Preliminary conclusions reached, after the first year's observation, were: 1. The overall control of concrete quality and uniformity during construction was good to excellent, and there were no appreciable differences in any of the concrete properties as a function of surface finish. 2. During the first year in service, skid values for all experimental textures were higher than the burlap drag texture now generally used by the Texas Highway Department (THD). 3. The change in THD skid trailer values at 40 mph with time as the pavement is subjected to wear is inconsistent and cannot be explained at this time. 4. Under simulated rainfall the skid resistance values for deep-textured pavements are markedly different from values using THD Trailer water. 5. Under "light" rainfall, all of the experimental textures exhibited higher skid resistances than the burlap drag texture. Under "heavy" rainfall, some of the beneficial skid resistance effects of the deeper experimental textures were masked, while the transverse tines exhibited the best overall skid resistance. 6. In general, the greater the texture depth of a concrete surface, the greater the associated skid number as measured using THD trailer water. However, this trend was not as clear when simulated rainfall was used. 7. With an increase in texture depth, there is an associated increase in sound, as measured by sound pressure level.

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FIRST PROGRESS REPORT ON CONCRETE EXPERIMENTAL TEST SECTIONS IN BRAZOS COUNTY, TEXAS

by

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Research Report 141-2

Quality of Portland Cement Concrete Pavement
As Related to Environmental Factors and
Handling Practices During Construction

Research Study 2-6-70-141

Sponsored by

The Texas Highway Department

in cooperation with

U.S. Department of Transportation
Federal Highway Administration

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College Station, Texas

FOREWORD

The information contained herein was developed on Research Study 2-6-70-141 titled "Quality of Portland Cement Concrete Pavement as Related to Environmental Factors and Handling Practices During Construction," in a cooperative research program with the Texas Highway Department and the Federal Highway Administration. The primary purpose of this study is to develop methods whereby the handling of portland cement concrete paving mixtures during construction could be improved.

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The authors wish to acknowledge the assistance given by the advisory committee for this study. They provided valuable guidance in the formulation of the research plan. The members are: (a) Texas Highway Department personnel - Mr. Steve Salek, Study Contact Representative; Mr. W. E. Elmore, Materials and Test Division Representative; Mr. B. R. English, Bridge Division Representative; and Mr. T. R. Kennedy, Highway Design Division Representative; (b) Federal Highway Administration personnel - Mr. Lee Gibbons, Division Representative. The authors also wish to acknowledge the assistance of Ken Hankins in interpretation of the data. The authors also wish to acknowledge the assistance of the following personnel in gathering and summarizing data: Mr. Sidney Greer, Mr. Larry Groth, and Mr. Walt Lehmann.

ABSTRACT

Surface characteristics of portland cement concrete pavement have received much attention in recent years especially as they relate to skid resistance. Seven experimental test sections were constructed in order to quantify the relative effects of the surface textures. Preliminary conclusions reached, after the first year's observation, were:

1. The overall control of concrete quality and uniformity during construction was good to excellent, and there were no appreciable differences in any of the concrete properties as a function of surface finish.

2. During the first year in service, skid values for all experimental textures were higher than the burlap drag texture now generally used by the Texas Highway Department (THD).

3. The change in THD skid trailer values at 40 mph with time as the pavement is subjected to wear is inconsistent and cannot be explained at this time.

4. Under simulated rainfall the skid resistance values for deep-textured pavements are markedly different from values using THD Trailer water.

5. Under "light" rainfall, all of the experimental textures exhibited higher skid resistances than the burlap drag texture. Under "heavy" rainfall, some of the beneficial skid resistance effects of the deeper experimental textures were masked, while the transverse tines exhibited the best overall skid resistance.

6. In general, the greater the texture depth of a concrete surface, the greater the associated skid number as measured using THD trailer

water. However, this trend was not as clear when simulated rainfall was used.

7. With an increase in texture depth, there is an associated increase in sound, as measured by sound pressure level.

Key Words: Concrete, Concrete Pavements, Concrete Finishing, Concrete Construction, Skid Resistance, Pavement Textures, Sound Level

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1. INTRODUCTION AND SUMMARY

1.1 General

The importance of maintaining a safe driving environment on our nation's highways has been an area of increasing concern in recent years. Concern for the prevention of traffic accidents is evidenced by every agency from the Department of Transportation at the federal level to the local highway authorities. Although changes have come about through experience in the field as well as laboratory oriented research, accidents still occur. Trends in the causes of traffic accidents have been discovered, research has been performed, and will continue so that the state-of-the-art will continue to advance.

The importance of the effect of surface finish on the skid resistant properties of the surface of portland cement concrete pavements has for many years been a recognized fact.[1*] Finishing imparts macrotexture to the concrete surface, which in turn affects, but does not control, the surface friction coefficient in wet weather. Researchers have found that channels or escape paths among the asperities aid in the drainage of the lubricating water from the area of tire-pavement contact.[2] The problem of skidding was not considered to be critical when low volumes of traffic and low speeds were prevalent, but with increasing traffic volumes and speeds, the skidding problem has become an increasing matter of priority. Nationally, the average number of wheel passes over the same pavement section increased approximately 62 percent from 1960 to 1969.[3] Indications are that there will be an even more significant increase for the future.

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*Superscript Arabic numbers refer to corresponding items in the list of references (Sec. 4.9).

A recent survey by the Highway Research Board (HRB) Committee D-B4 Task Group, stated that ". . . slippery pavements were recognized as a problem of major concern in 22 states, moderate concern in 24 states, and minor concern in 2 states".[4] The HRB survey, with 48 states reporting, also revealed that ". . . 42 states were using accident data for the detection or selection of slippery pavements, . . . that 32 states were using skid test data as a criterion for resurfacing or deslicking, . . . and that 30 states were presently conducting a research program on pavement slipperiness". As contrast, a 1958 HRB survey conducted on behalf of Highway Research Board Committee D-1 on Mineral Aggregates revealed that ". . . only 10 of 47 state highway departments querried were actively conducting studies involving the measurement of pavement skid resistance".[5] The research that has already been accomplished is continually being added to. For the year 1972 an estimated two million dollars was spent on the area of roadway vehicle interaction, particularly the pavement surface in relation to skidding - causes, effects, and prevention.[6] Studying the construction practices and the effects they have on the concrete pavement surface and their resultant effect on skid resistance is therefore of paramount importance.

1.2 Purpose of Investigation

The purpose of this research was to determine the effects of actual field construction practices on selected surface properties of portland cement concrete pavements.

1.3 Scope

The scope of this report is to report on the results obtained during the first year of a field investigation on:

1. The effects of surface finish variations on the surface properties of concrete pavements.

2. Whether or not the type of surface causes variations in durability and strength properties of the test sections in relation to each other.

3. The relationship between skid number and texture depth.

1.4 Conclusions

1. The overall control of concrete quality and uniformity during construction was good to excellent, and there were no appreciable differences in any of the concrete properties as a function of surface finish.

2. During the first year in service, skid values for all experimental textures were higher than the burlap drag texture now generally used by the Texas Highway Department (THD).

3. The change in THD skid trailer values at 40 mph with time as the pavement is subjected to wear is inconsistent and cannot be explained at this time.

4. Under simulated rainfall the skid resistance values for deep-textured pavements are markedly different from values using THD trailer water.

5. Under "light" rainfall, all of the experimental textures exhibited higher skid resistances than the burlap drag texture. Under "heavy" rainfall, some of the beneficial skid resistance effects of the deeper experimental textures were masked, while the transverse tines exhibited the best overall skid resistance.

6. In general, the greater the texture depth of a concrete surface, the greater the associated skid number as measured using THD trailer

water. However, this trend was not as clear when simulated rainfall was used.

7. With an increase in texture depth, there is an associated increase in sound, as measured by sound pressure level.

1.5 Recommendations

Based on the findings to date the following recommendations are made:

1. Continue to monitor and evaluate the test sections as they age to determine the long term durability of the experimental finishes.

2. Construct experimental test sections on another highway in another part of the state and monitor these test sections over a period of time.*

1.6 Implementation Statement

As a result of this study criteria will be established to modify current specifications for portland cement concrete pavement surface textures. These will be in the form of texture depth, skid number, direction of texture, and method of construction. Implementation is not recommended until additional field tests are completed.

*This recommendation has already been followed. Another test site has been selected and a number of test sections constructed. Details are given in Section 4.8.

2. TEST SECTION CONSTRUCTION

2.1 Test Section Descriptions

The data obtained for this study were taken from 7 test sections of 8 in. continuously reinforced concrete pavement (CRCP). These test sections were constructed by the L. H. Lacy Company for the Texas Highway Department (THD) as an integral part of State Highway 6 (Through Route, Bryan, Texas). Each section was 800 ft long and was prepared using a siliceous gravel, a siliceous sand, Type I portland cement, and an air entrainment admixture. The test sections were constructed in November 1971, utilizing a CMI (Construction Machinery, Inc.) slip-form paver. A tube float was used to prepare the concrete surface for the final characteristic test finish. The locations of the test sections are shown in Figure 2-1, and typical photos of the construction are shown in Figures 2-2 through 2-7.

2.2 Variables

2.2.1 Type of Finish

Seven surface-finish concrete test sections were constructed; a transverse brush, transverse tines, longitudinal brush, longitudinal tines, burlap drag followed by longitudinal tines, transverse natural broom, and a burlap drag as a control finish. The as-constructed finishes on the test sections are shown in Figures 2-8 through 2-14. The finishes are described in Table 2-1.

2.2.2 Construction Sequence and Traffic

The test sections were constructed in November 1971, and the entire main lane pavement was constructed between October 1971 and January 1972. Following the construction of the main lanes, light construction traffic used the main lanes until the roadway was officially opened to traffic in June 1972.

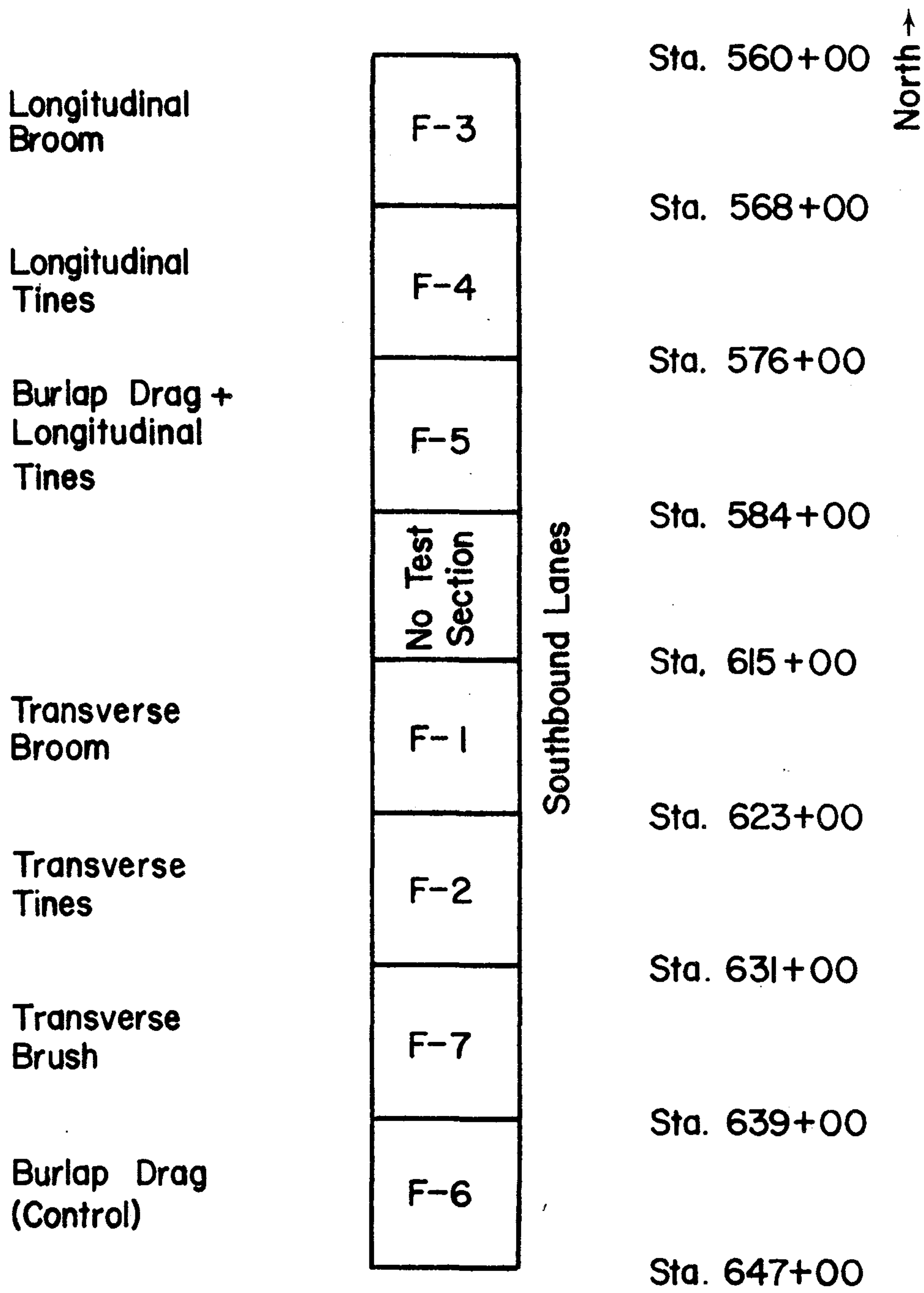

Fig. 2-1 Location of Test Sections

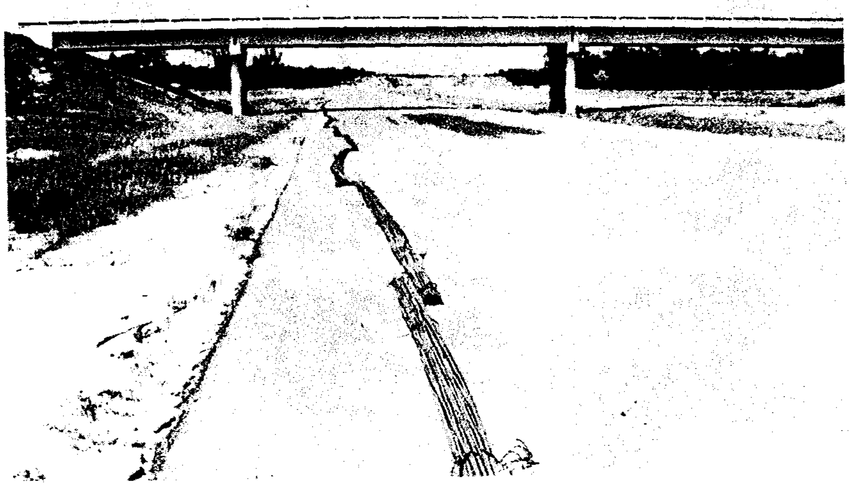

Fig. 2-2 Preliminary Placement of Steel

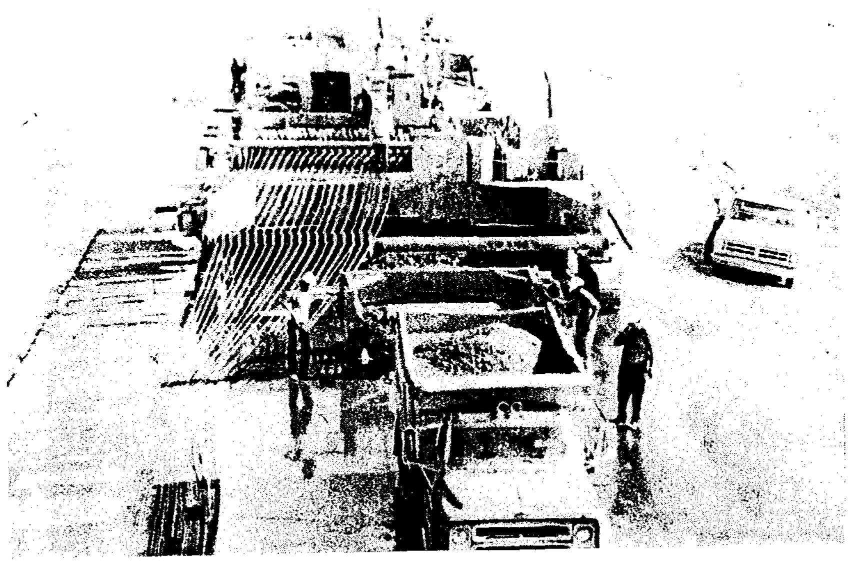

Fig. 2-3 Front View of Paving Operation

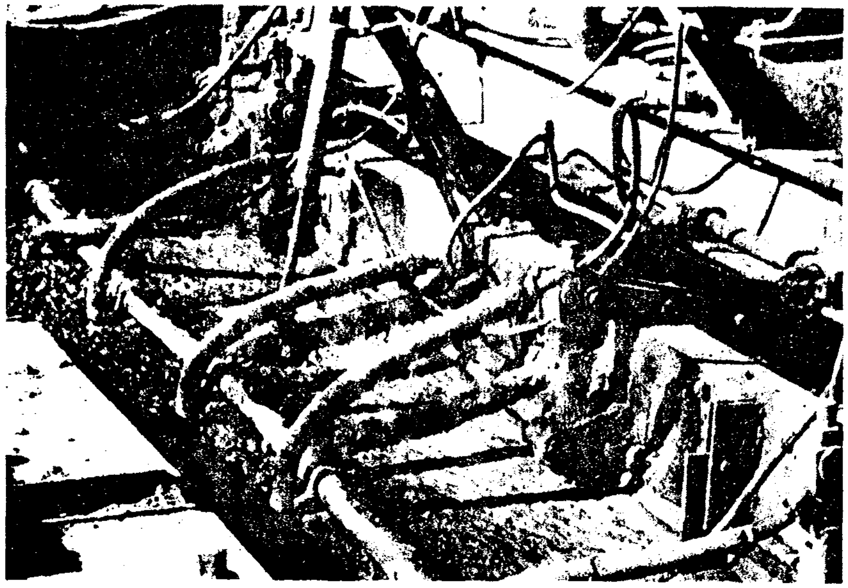

Fig. 2-4 Vibrating Equipment Used to Consolidate Fresh Concrete

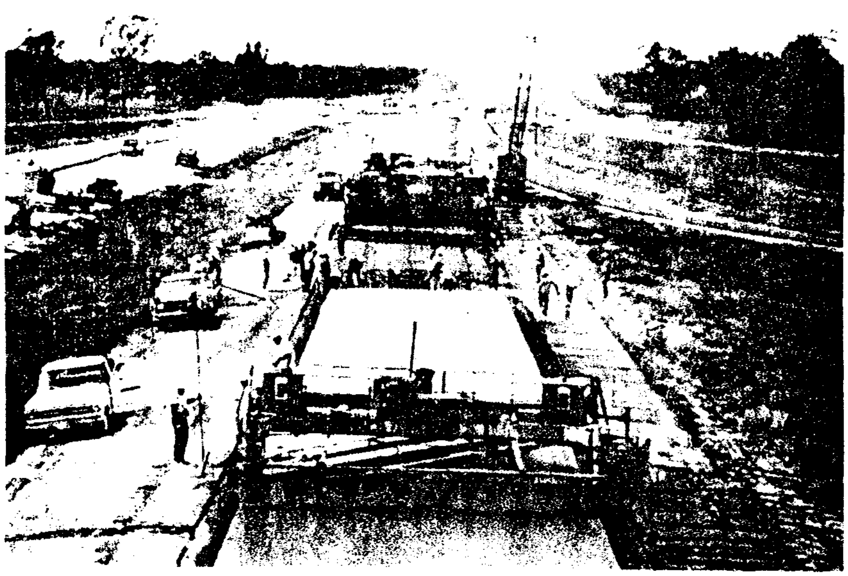

Fig. 2-5 Tube Float

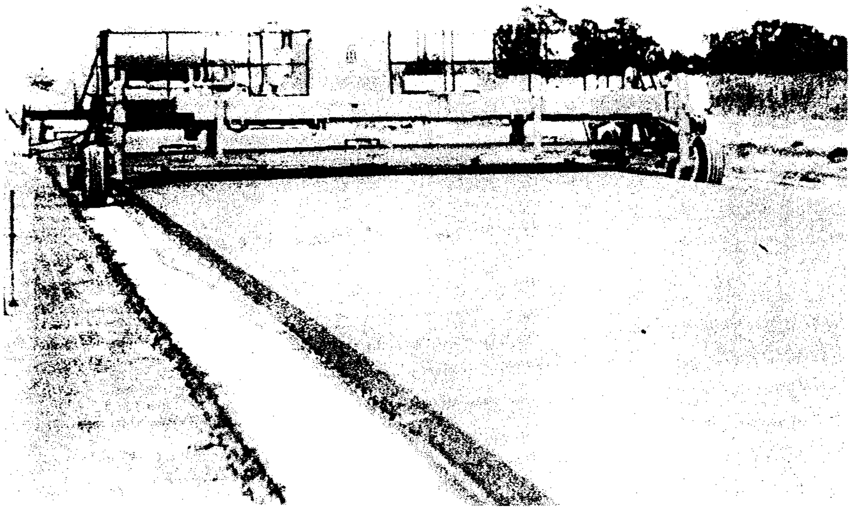

Fig. 2-6 Finishing Machine Applying Longitudinal Tine Finish

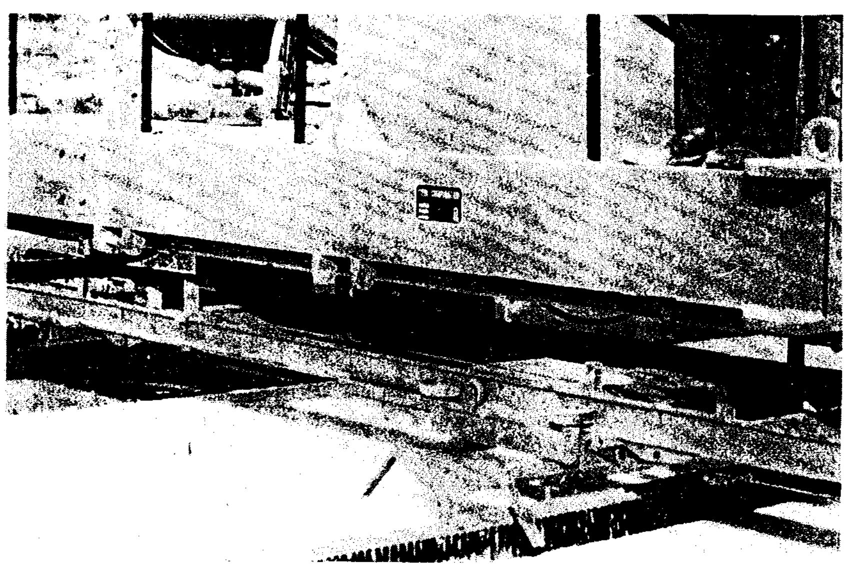

Fig. 2-7 Finishing Machine Applying Transverse Broom Finish

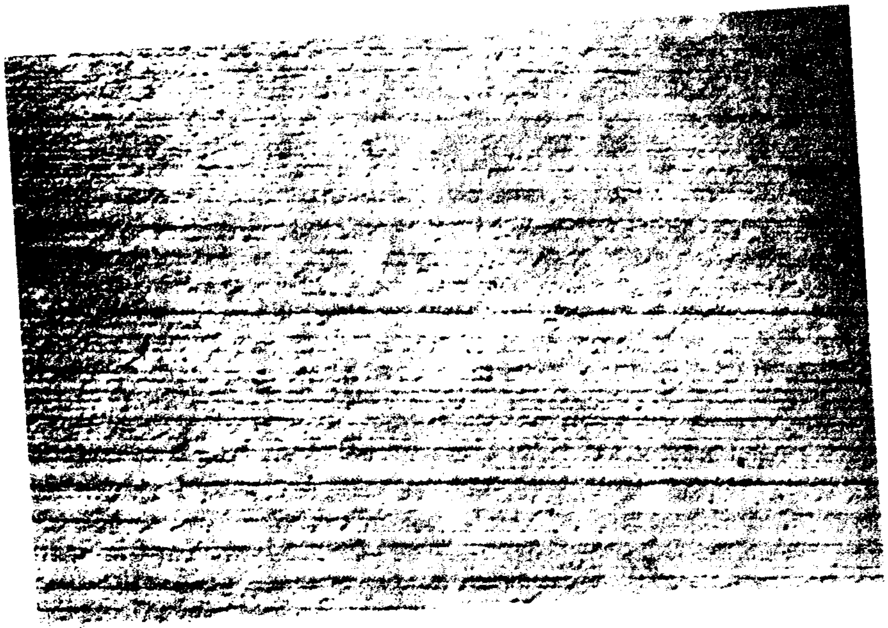

Fig. 2-8 Test Section F-1: Transverse Broom Finish
(As Constructed)

Fig. 2-9 Test Section F-2: Transverse Tine Finish
(As Constructed)

Fig. 2-10 Test Section F-3: Longitudinal Broom Finish (As Constructed)

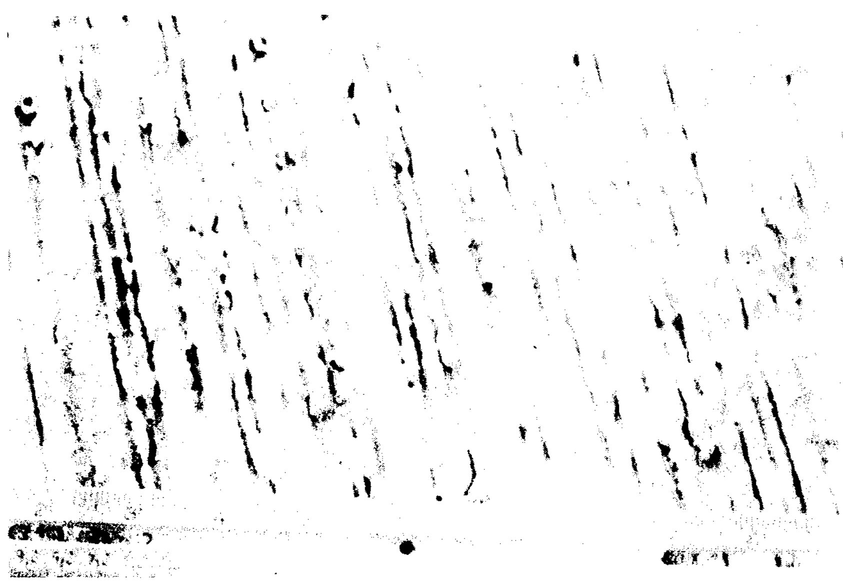

Fig. 2-11 Test Section F-4: Longitudinal Tine Finish (As Constructed)

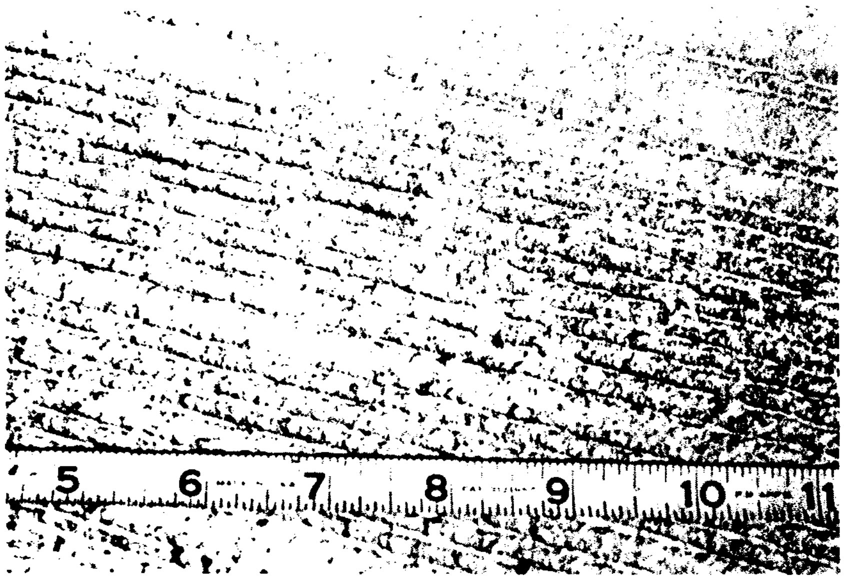

Fig. 2-12 Test Section F-5: Burlap Drag Plus Longitudinal Tines Finish (As Constructed)

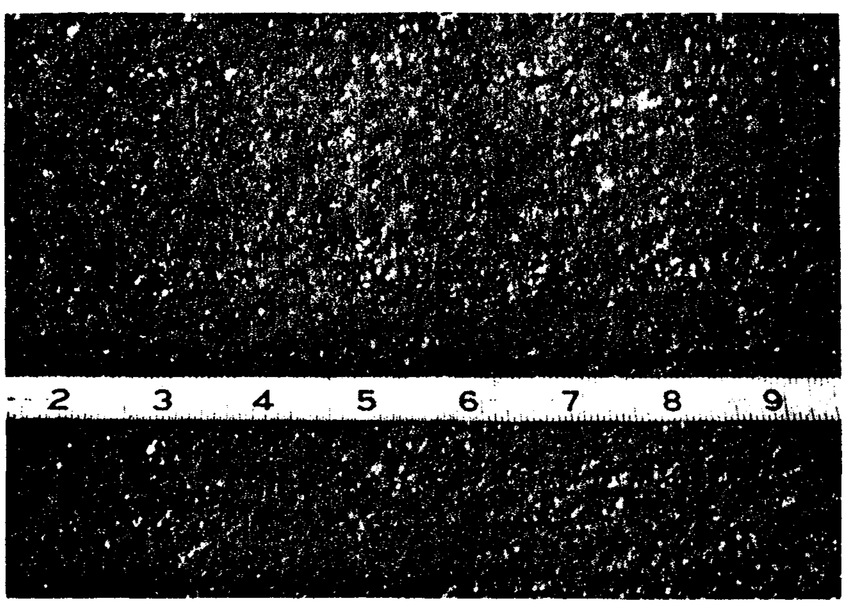

Fig. 2-13 Test Section F-6: Burlap Control Finish (As Constructed)

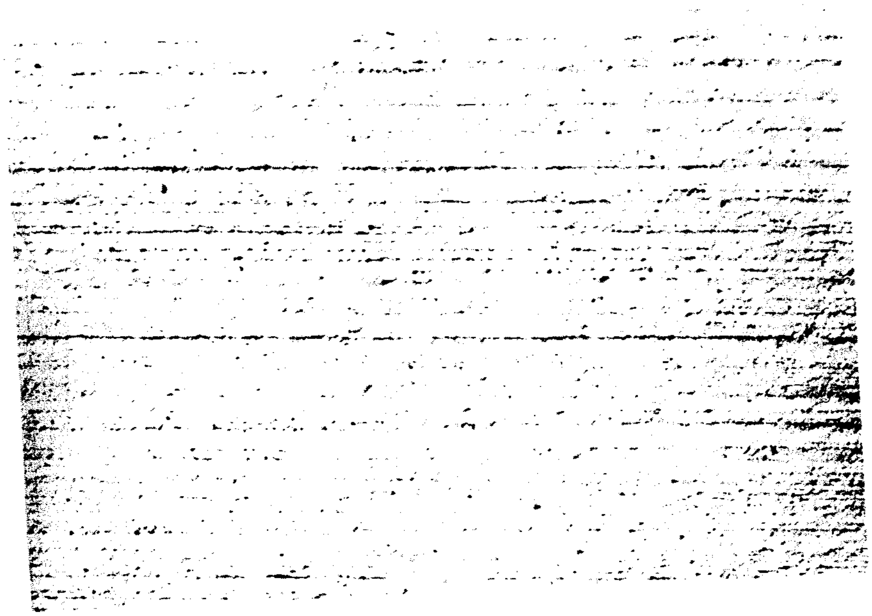

Fig. 2-14 Test Section F-7: Transverse Natural Brush Finish (As Constructed)

TABLE 2-1 Surface Finishes

Finish Type	Description	Test Section No.
Burlap Drag	A burlap drag finish was accomplished by passing a wet burlap cloth, with approximately three ft of burlap in contact with the surface until the desired texture is obtained.	F-6
Broom	Accomplished by passing a plastic-bristle broom over the slab surface, slightly grooving the concrete. The broom was inclined at an angle of approximately 30 degrees to the surface.	F-1, F-3
Tines	Accomplished by passing a series of thin metal strips (tines), 1/8 in. by 5 in. long, over the section surface, producing grooves of approximately 1/8 in. depth in the concrete. The tine spacing was 1/4 in. center-to-center.	F-2, F-4
Brush	Accomplished by the same procedure as the broom. The brush bristles were a naturally occurring material (strawlike).	F-7
Burlap Drag Plus Longitudinal Tines	Accomplished by first passing burlap drag over the section surface, followed by one pass of the longitudinal tines.	F-5

The actual time for the construction for the test sections was two days. Weather during the construction period was cool, averaging approximately 55°, and cloudy.

The traffic over the test sections averaged 868 vehicle passes per day in June 1972, rising to 1360 vehicle passes per day in July 1972.* As of this reporting time the most recent traffic count, in January 1973, shows there to be an average daily traffic count of 1,483 vehicle passes.

2.3 Constants

The mixes were designed under the supervision of the Texas Highway Department personnel using the absolute volume method with a specified cement factor and air entraining admixture. The batches were designed to produce similar strengths based on a cement factor of 4.5 sks per cu yd, a coarse aggregate factor (CAF) of 0.79, a water-cement ratio of 0.53, an air content of 4 percent and a slump of 1 in. $\pm$ 1/2 in.

The concrete test sections used in performing these tests were made utilizing a siliceous fine and coarse aggregate produced by Gifford Hill Company at Benchly, Texas. Aggregate data are given in Table 2-2.

2.4 Control Tests

For control purposes flexural strength tests were performed on two 6 x 6 x 36 in. beams from selected batches of concrete used in each test

*Traffic counts taken by Planning Survey Division of the Texas Highway Department.

TABLE 2-2 Aggregate Data[a]

Fine Aggregate		Course Aggregate	
Sieve Size	Cumulative Percent Retained	Sieve Size	Cumulative Percent Retained
1/4 in.	0	2 1/2 in.	0
No. 4	0	1 3/4 in.	0
No. 8	12	1 in.	7
No. 16	24	3/4 in.	10
No. 20	30	1/2 in.	38
No. 50	84	No. 4	97
No. 100	99		
Fineness Modulus = 249			
Specific Gravity = 2.63		Specific Gravity = 2.65	
Percent Solids = 65.0		Percent Solids = 63.5	
Percent Voids = 35.0		Percent Voids = 36.5	

[a]Data obtained by District 17 of the Texas Highway Department.

section (ASTM C78). The specimens were moist cured at 73°F - 95 percent relative humidity prior to testing. Compressive strength tests were made on two 6 x 12 in. cylinders from selected batches. These specimens were moist cured at 73°F - 95 percent relative humidity and tested in accordance with ASTM C39.

2.5 Data Collection

2.5.1 Core Tests

After a minimum of 28 days, three cores (4 in. diameter) were taken from each test section and subjected to the following diagnostic analyses:

a) Dynamic modulus of elasticity (ASTM C215). The torsional sonic modulus was determined for each core.

b) Impact hammer readings on the cores as a measure of hardness (Section 4.1.7).

c) Bulk density by absolute volume of the top 3 in. and bottom 3 in. of each core (ASTM D1188).

d) Surface Abrasion Coefficient of the finished surface of the cores (ASTM C418).

e) Splitting tensile strengths of the top 3 in. and bottom 3 in. of each core (ASTM C496).

Data are given in Table 2-3.

2.5.2 Field Tests

Surface texture depths were determined in December 1971, just after completion of the test sections, and in August 1972, just after the test sections were open to traffic (Section 4.3). The silicone putty impression method was used to determine these depths.[7] Subsequently it was noted that

TABLE 2-3 Core Test Data

Test Section	Curing Condition	Impact Hammer Reading	Top	Splitting Tensile Strength (psi)	Bottom	Dynamic Modulus of Elasticity (psi x 10^6)	Dens (lb per Top B	y ft) tom	Surface Abrasion Coefficient (in.^{3}/in.^{2})
F-1	Core[a]	22 (34 day)[d]	554	(56 day)	640	6.0	145.8	6.4	.31
Transverse	Moist[b]			429					(55 day)
Broom	WPC/Air[c]			483					
F-2	Core	22 (27 day)	587	(53 day)	734	6.2	144.0	5.9	.27
Transverse	Moist			429					(48 day)
Tines	WPC/Air			483					
F-3	Core	25 (35 day)	567	(56 day)	719	6.3	144.1	5.1	.26
Longitudinal	Moist			395					(56 day)
Broom	WPC/Air			503					
F-4	Core	22 (35 day)	620	(56 day)	738	6.2	145.9	5.7	.24
Longitudinal	Moist			409					(56 day)
Tines	WPC/Air			483					
F-5	Core	23 (35 day)	633	(57 day)	770	5.9	144.7	5.5	.25
Burlap +	Moist			433					(56 day)
Longitudinal	WPC/Air			403					
Tines									
F-6	Core	24 (34 day)	551	(56 day)	733	6.1	144.3	5.0	.33
Burlap	Moist			425					(55 day)
Control	WPC/Air			469					

TABLE 2-3 (Cont'd.)

Test Section	Curing Condition	Impact Hammer Reading	Splitting Tensile Strength (psi) Top	Splitting Tensile Strength (psi) Bottom	Dynamic Modulus of Elasticity (psi x 10^6)	Density (lb per cu) Top	Density (lb per cu) Bott	Surface Abrasion Coefficient (in.^{3}/in.^{2})
F-7	Core	25 (34 day)	638 (56 day)	653	6.1	144.7	145	.27 (55 day)
Transverse	Moist		381					
Natural	WPC/Air		500					
Brush								

[a]Core taken from test section, cured in natural environment until tested.

[b]6 x 12 in. cylinder made from selected batches of concrete used in each test s tion, cured for 7 days at 73°F and 95 percent relative humidity until tested.

[c]Cylinder taken from same batches as (b), surface sprayed with a white pigmente curing compound, cured in natural environment until tested.

[d]Age of specimen at time of test.

the Texas Highway Department had developed a standardized texture depth test called the Sand Patch Test (Tex-436-A). In order to relate these two tests measurements were made on all the test sections in January and June 1973 using both tests and the relationship between the two was determined to be:

Silicone Putty Impression Value = 0.0156 + 0.843 Sand Patch Value (1)

The data and discussion of this relationship are given in Section 4.4. It should be emphasized that this relationship is valid only for these seven test sections and any generalization of the equation to other texture types may not be justified. The determination of the British Portable Number (BPN) of the test section was performed in accordance with ASTM E303. The tests were performed using water and water plus 60 percent glycerine solution as a lubricating medium. Testing was performed in June 1972. Standard skid trailer values were performed using the Texas Highway Department research skid trailer using 14 in. diameter, full tread ASTM standard tires (ASTM E249) inflated to 24 psi (see Section 4.2). Skid measurements were made at 20, 40 and 60 mph. Tests were conducted in December 1971, June 1972, and October 1972. Data are given in Table 2-4.

Simulated rainfall skid trailer values were conducted in June 1972, skid trailer values at this time were determined using the "Rainfall Simulator". The purpose was to evaluate the pavement surface in the presence of varying degrees of simulated rainfall. Data are given in Table 2-5. A preliminary investigation was conducted to see if a relationship might exist between sound pressure level and a surface property of the concrete pavement (Section 4.6). The Texas Highway Department provided the equipment and the test vehicle for these tests. Data are given in Table 2-6.

TABLE 2-4 Field Tests Under Standard Conditions

Test Section	Date	Texture Depth (in.) Putty Impression[a]	Sand Patch[b]	Skid Number 40 mph IL[c]	Skid Number 40 mph OL[d]	British P table Number[g] (N) Water[e] IL[c]	Water[e] OL[d]	Glycerine[f] IL[c]	Glycerine[f] OL[d]
F-1 Transverse Broom	Dec. 71	.064	-	61	63	-	-	-	-
	June 72	-	-	74	69	99	88	93	82
	Aug. 72	.043	-	60	53	-	-	-	-
	Nov. 72	-	-	58	54	-	-	-	-
	Jan. 73	.058	.042	-	-	-	-	-	-
F-2 Transverse Tines	Dec. 71	.070	-	71	75	-	-	-	-
	June 72	-	-	83	78	101	97	98	94
	Aug. 72	.064	-	72	66	-	-	-	-
	Nov. 72	-	-	73	66	-	-	-	-
	Jan. 73	.059	.060	-	-	-	-	-	-
F-3 Longitudinal Broom	Dec. 71	.046	-	57	55	-	-	-	-
	June 72	-	-	61	65	88	87	83	82
	Aug. 72	.028	-	59	52	-	-	-	-
	Nov. 72	-	-	57	50	-	-	-	-
	Jan. 73	.045	.027	-	-	-	-	-	-
F-4 Longitudinal Tines	Dec. 71	.094	-	67	68	-	-	-	-
	June 72	-	-	68	71	93	90	88	86
	Aug. 72	.062	-	67	55	-	-	-	-
	Nov. 72	-	-	66	58	-	-	-	-
	Jan. 73	.065	.059	-	-	-	-	-	-

TABLE 2-4 (Cont'd.)

Test Section	Date	Texture Depth (in.) Putty Impression[a]	Sand Patch[b]	Skid Number 40 mph IL[c]	Skid Number 40 mph OL[d]	British [illegible]table Number[g] (BPN) Water[e] IL[c]	Water[e] OL[d]	Glycerine[f] IL[c]	Glycerine[f] OL[d]
F-5 Burlap + Longitudinal Tines	Dec. 71	.086	–	66	66	–	–	–	–
	June 72	–	–	68	70	84	88	82	84
	Aug. 72	.065	–	64	54	–	–	–	–
	Nov. 72	–	–	63	55	–	–	–	–
	Jan. 73	.083	.074	–	–	–	–	–	–
F-6 Burlap Control	Dec. 71	.039	–	33	36	–	–	–	–
	June 72	–	–	54	45	80	81	72	70
	Aug. 72	.032	–	44	34	–	–	–	–
	Nov. 72	–	–	43	37	–	–	–	–
	Jan. 73	.040	.024	–	–	–	–	–	–
F-7 Transverse Natural Brush	Dec. 71	.042	–	62	64	–	–	–	–
	June 72	–	–	71	69	94	92	89	87
	Aug. 72	.033	–	60	55	–	–	–	–
	Nov. 72	–	–	63	59	–	–	–	–
	Jan. 73	.044	.026	–	–	–	–	–	–

[a]As measured by Silicone Putty Impression Test.[7]

[b]As measured by Method Tex-436-A (See Section 4.4).

[c]IL - Inside lane (east side of southbound direction).

[d]OL - Outside lane (west side of southbound direction).

[e]Water used as lubricating medium.

[f]Water + 60 percent glycerine solution used as lubricating medium.

[g]Utilizing ASTM standard pad.

TABLE 2-5 Field Tests Under Simulated Rain

Test Section	Texture Depth (in.) Aug. 72 Putty Impression (Sand Patch)[a]		Water Depth[b] (mm)		Skid Numb (IL Only 20	40	0
F-1			Light[d]	-.5	69	56	1
Transverse Broom	.043	(.033)	Heavy[e]	.62	67	51	3
F-2			Light	.0	74	62	9
Transverse Tines	.064	(.057)	Heavy	.9	82	62	7
F-3			Light	-.2	71	49	3
Longitudinal Broom	.028	(.015)	Heavy	1.2	75	53	6
F-4			Light	-.65	80	61	5
Longitudinal Tines	.062	(.055)	Heavy	.7	75	64	8
F-5 Burlap + Longitudinal			Light	-.35	67	59	2
Tines	.065	(.059)	Heavy	1.0	73	56	3
F-6			Light	-.25	57	41	6
Burlap Control	.032	(.020)	Heavy	.4	62	41	6
F-7 Transverse Natural			Light	.0	83	63	3
Brush	.033	(.021)	Heavy	.5	78	55	8

[a]As measured by Silicone Putty Impression Test. Numbers in parenthesis are calculated THD Sand Patch values (see Section 4.4).

[b]Texture depth becomes reference point for measurement.

[c]IL - Inside lane (east side of southbound direction).

[d]Approximately an 1.5 in./hr rainfall.

[e]Approximately an 6 in./hr rainfall.

TABLE 2-6 Noise Level Data

Test Section	20 mph Dec. 71	20 mph Sept. 72	40 mph Dec. 71	40 mph Sept. 72	60 mph Dec. 71	60 mph Sep[illegible] 72	Texture Depth (in.) Aug. 72 Putty Impression (Sand Patch)[b]
	Noise Level[a] - dBA (decibels)						
F-1 Transverse Broom	-	86	74	97	-	10[illegible]	.043 (.033)
F-2 Transverse Tines	-	82	72	92	-	9[illegible]	.064 (.057)
F-3 Longitudinal Broom	-	79	77	90	-	9[illegible]	.028 (.015)
F-4 Longitudinal Tines	-	81	79	94	-	10[illegible]	.062 (.055)
F-5 Burlap + Longitudinal Tines	-	83	77	94	-	10[illegible]	.065 (.059)
F-6 Burlap Control	-	81	68	91	-	9[illegible]	.032 (.020)
F-7 Transverse Natural Brush	-	81	69	93	-	9[illegible]	.033 (.021)

[a]Tests performed on inside lane of southbound direction only.

[b]As measured by silicone Putty Impression test. Numbers in parenthesis a[illegible] calculated THD Sand Patch values (see Section 4.4).

3. DISCUSSION OF RESULTS TO DATE

3.1 General

The results which follow were obtained from the previously described test sections. The test sections which were investigated had the same coarse aggregate type, mix design, base type, method of vibration, and curing environment. These constituents were held as constant as possible by the quality control personnel of the Texas Highway Department. Where possible, any data scatter is illustrated and analyzed.

From an examination of the results presented in Table 3-1, it can be seen that the job control exhibited in the concrete used for the test sections was good to excellent.

The data gathered from the cores (see Table 2-3) were analyzed statistically and are presented in Table 3-2. From an examination of this data the following comments are offered:

1. The Impact Hammer Reading was obtained from an average of six values of hardness of the cored specimens. Locations for evaluation by the Impact Hammer were chosen at random, so that the value determined was representative of the entire core.

2. The Splitting Tensile Strength of the cores is an indirect method of determination of the actual tensile strength of the concrete. Examination of the strengths of the cored specimens shows, as expected, the top with a lower mean value of strength than the bottom, although all strengths are considered to be satisfactory. Job control as measured by the Splitting Tensile Strength Test was good for both top and bottom, indicating uniformity in the concrete placed in the test sections.

3. The lower splitting tensile strengths exhibited by both the moist cured and the curing compound test cylinders is due to the age of the specimen at testing. The average age of the cores was 56 days, and the cylinders were tested at 7 days age. The higher value of splitting tensile strength exhibited by the moist cured specimen was due to the "ideal" conditions under which it was kept until testing. Control was excellent in both cases.

4. The density of the top was slightly less than the bottom, probably due to the consolidation practices. In general, it can be concluded that the density of the mix was satisfactory throughout the pavement.

5. From an examination of the Abrasion Coefficient, it can be concluded that there is no significant difference in the abrasion properties of the surface of the cores due to the surface finish.

If the Abrasion Resistance of Concrete test is a laboratory determination of how these test finishes should perform in the field, then the test finishes should have the same abrasion resistance, or wear rates, in the field. This will be evaluated in subsequent tests.

6. From an examination of the data as a whole, it can be seen that the overall control exhibited was good to excellent, so that there is no appreciable difference in any of the concrete properties as a function of surface finish.

3.2 Surface Related Results

3.2.1 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

TABLE 3-1 Job Control

Property	Number Used in Calculation	Mean (psi)	Standard Deviation (psi)	Coefficient of Variation (Percent)	Cont l[a]
Compressive Strength (f'_c)[b]	21	3800	440	12	Good
Modulus of Rupture (3rd pt.)[c]	14	600	50	8	Exce ent
Modulus of Rupture (center pt.)[d]	14	690	40	6	Exce ent

[a]Taken from Reference 8.

[b]ASTM C39.[31]

[c]ASTM C78.[31]

[d]ASTM C293.[31]

TABLE 3-2 Comparison of Control of Concrete Properties

Property	Number Used in Calculation	Mean (psi)	Standard Deviation (psi)	Coefficient of Variation (Percent)	Contro
Splitting Tensile Strength[b] (top) (psi)	30	600	90	15	Good - air
Splitting Tensile Strength[b] (bottom) (psi)	30	700	100	14	Good
Splitting Tensile Strength[c]	30	420	20	4	Excell t
Splitting Tensile Strength[d]	30	480	30	7	Excell t
Modulus of Elasticity (psi x 10^6)	30	6.0	0.0	<1	Excell t
Density (top) (lb per cu ft)	30	145	1	<1	Excell t
Density (bottom) (lb per cu ft)	30	146	1	<1	Excell t

TABLE 3-2 (Cont'd.)

Property	Number Used in Calculation	Mean (psi)	Standard Deviation (psi)	Coefficient of Variation (Percent)	Contro
Impact Hammer Reading	54	24	2	8	Excell t
Surface Abrasion Coefficient ($in.^3/in.^2$)	30	.30	.03	10	Good

[a]Taken from Reference 8.

[b]As determined from cored specimen.

[c]6 x 12 in. cylinder made from selected batches of concrete used in each est section, cured for 7 days at 73°Fahrenheit and 95 percent relative humidity u il tested.

[d]Cylinder taken from same batches as (c), surface sprayed with a white p mented curing compound, cured in natural environment until tested.

in textures 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.

The evaluation of the pavement surface in terms of texture depth was taken in December 1971 and August 1972. The test surfaces that were evaluated in December had little or no traffic on them. Conversely, the same test surfaces evaluated in August had been subjected to construction traffic for eight months. Table 3-3 shows the effect of the texturing method on both initial texture depth and texture depth measured 8 months later. The table was constructed from the mean values for all seven test sections. The tine finishes produced the deepest textures. The transverse tine finish proved to be the most resistant to abrasion (as determined by the Abrasion Resistance of Concrete test); however, none of the other texturing methods or associated losses seemed to follow any set pattern. For these materials and construction techniques, measures of texture depth have shown that the finishes applied to the test sections wore at a rate dependent on the level of traffic and the method of texturing employed. Variations in the level of texture depth that occurred from site to site for the same texturing method have not yet been fully studied and thus are not included here. Their importance, however, should not be minimized.

The only consistency which is evidenced by the data is that all the textures wore down, some more than others. The important question is will all the textures wear down to a level above that of burlap, or will one or more of the test finishes retain a higher level of texture as time passes? It has been shown that the transverse tine finish lost the least texture in

TABLE 3-3 Texture Depths

Test Section	Texture Depth (in.)[a] Dec. 71	Aug. 72	Percent[b] Loss
F-1 Transverse Broom	.064 (.057)	.043 (.033)	33 (44)
F-2 Transverse Tines	.070 (.064)	.064 (.057)	9 (14)
F-3 Longitudinal Broom	.046 (.036)	.028 (.015)	39 (58)
F-4 Longitudinal Tines	.094 (.093)	.062 (.055)	34 (41)
F-5 Longitudinal Tines + Burlap	.086 (.083)	.065 (.059)	24 (29)
F-6 Burlap Control	.039 (.028)	.032 (.020)	18 (29)
F-7 Transverse Natural Broom	.042 (.031)	.033 (.021)	21 (32)

[a]As measured by the Silicone Putty Impression Test (Section 4.3). Numbers in parenthesis are calculated THD Sand Patch values (Section 4.4).

[b]Loss of texture depth over 8 month period from December 1971 to August 1972.

the 8 month period between texture depth evaluations. Will the transverse tine finish continue this trend of low loss, or will it eventually drop to the level reached by the burlap drag finish? Only the continuation of this investigation will answer these questions.

3.2.2 Skid Number

One immediate observation from the data in Table 2-4 is the apparent inconsistency of the skid numbers with time. This is shown in Figures 3-1 and 3-2.

Laboratory data indicate that as various surfaces wear down (texture depths become less) the skid numbers would initially drop but finally level off.[9] Figures 3-1 and 3-2 do not indicate this and several possibilities exist toward explaining this behavior. They are:

1. Initial readings of skid resistance were influenced by the presence of the curing compound.

2. Initial readings of skid resistance were influenced by a weak coating of mortar present on the surface, covering the stronger, rough textured, asperities comprised of coarse and fine aggregate. When the initial evaluation of the surface was made, the skid trailer (utilizing the locked wheel mode) caused this weak portion to be sheared off and this resulted in low readings.

3. The pavement section actually exhibited this behavior.

4. A combination of one or more of the above.

Possibility No. 1 was investigated by running the skid trailer over a freshly cured concrete pavement with the curing compound still present, then scrubbing off a major portion of the curing compound with soap and water and running the skid trailer again. In this test no significant differences in skid numbers were found. Possibility No. 2 has not been (perhaps can-

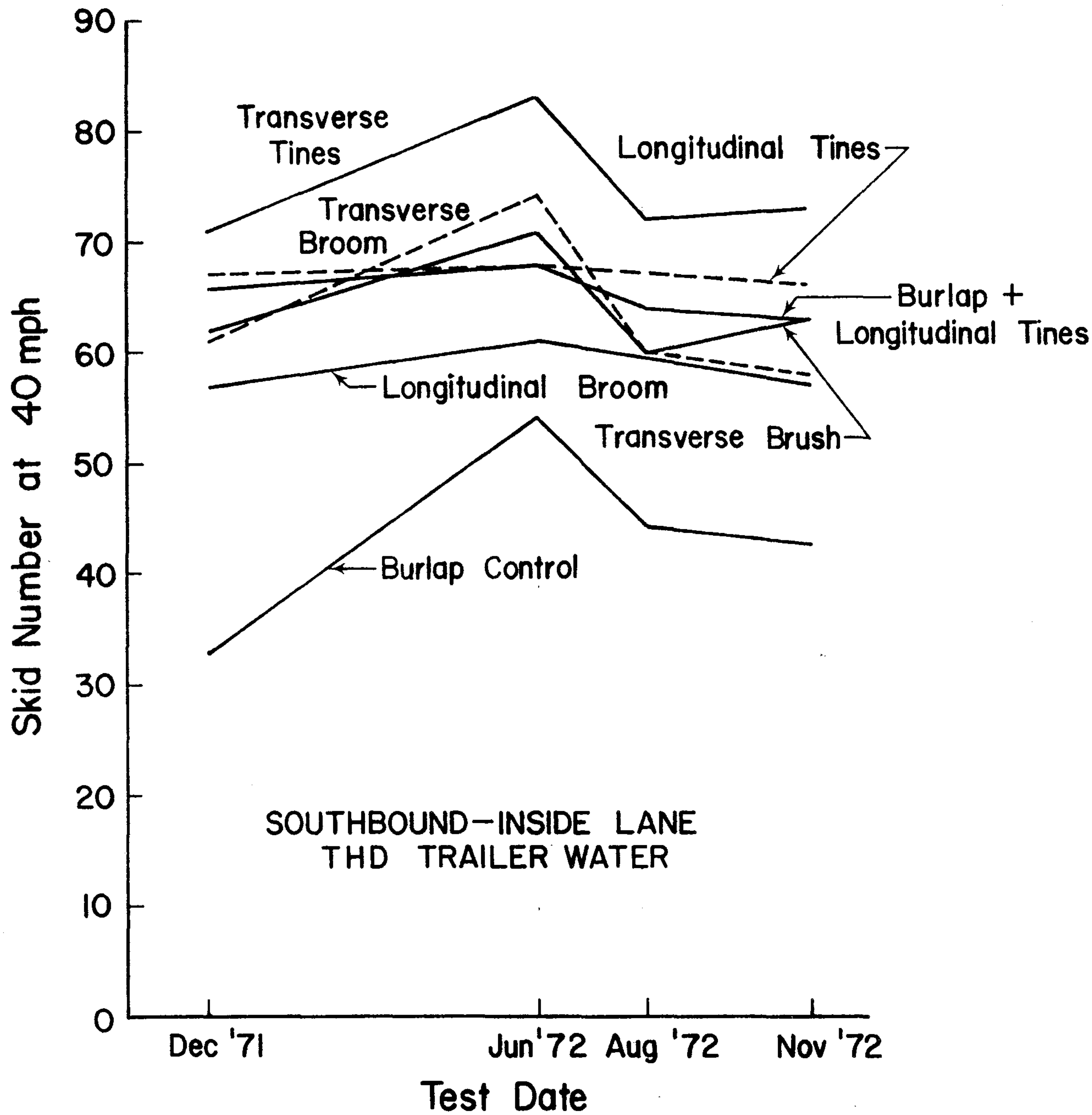

Fig. 3-1 Effect of Test Date on Skid Number

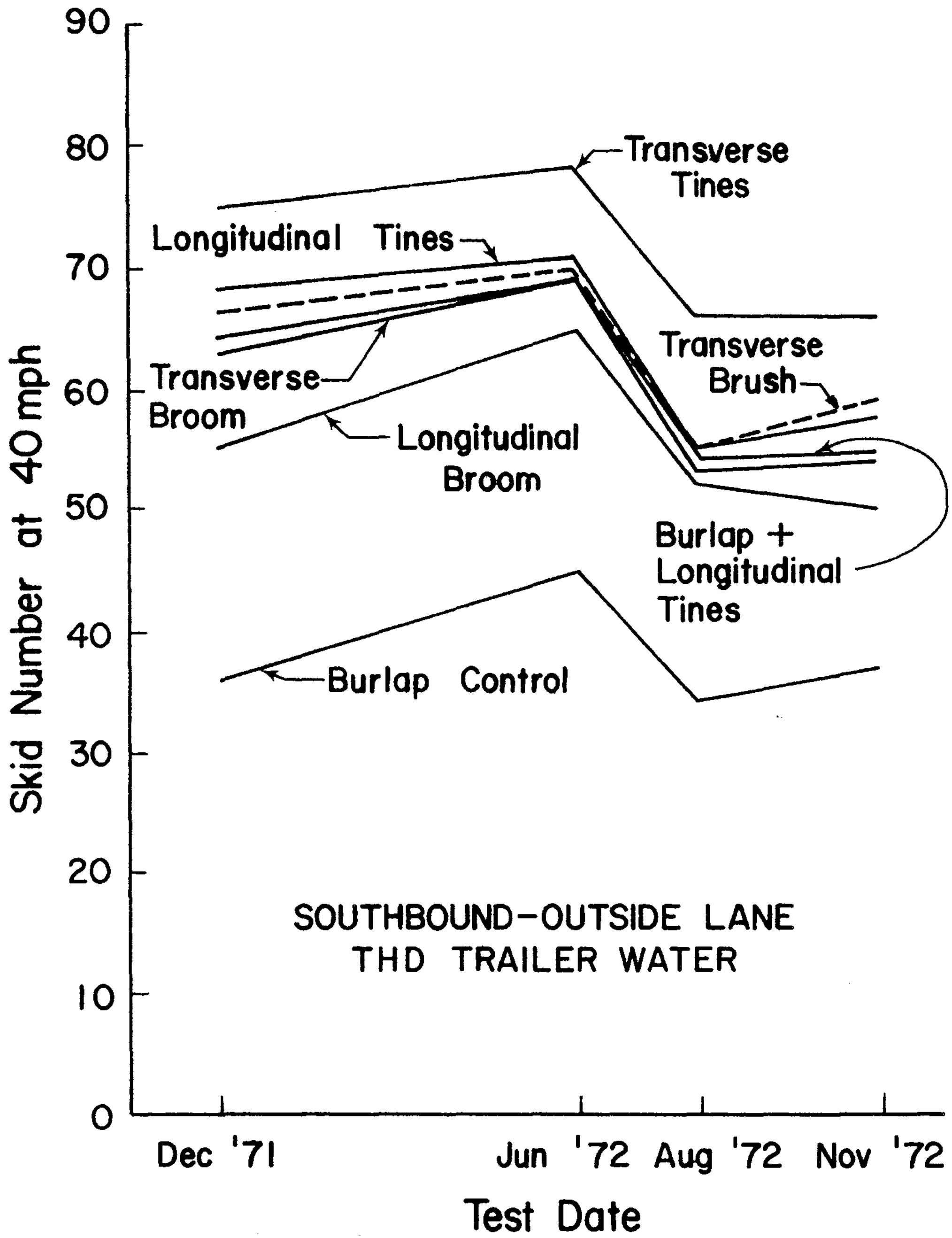

Fig. 3-2 Effect of Test Date on Skid Number

not be) verified by other field skid tests or in the laboratory testing program. However, it does not seem plausible since the finishing operations would tend to break up any weak mortar coating.

Though Possibility No. 3 appears doubtful it cannot, at this point, be ignored. The data obtained may be representative of the type of data scatter to be expected in field operations. Thus the apparent inconsistencies cannot be explained at this time.

From an examination of Table 2-4 the finishes that exhibited the greatest capacity for skid resistance were the tine finishes - transverse, longitudinal, or longitudinal followed by a burlap drag. This relationship not only holds true for the initial values of skid resistance, but also for subsequent values at later ages.

Figures 3-3 through 3-9 illustrate the effect of velocity on skid number. The data are presented for skid numbers determined by the utilization of the internal watering system of the THD skid trailer and by use of the "Rainfall Simulator" - "light" and "heavy" rain. Light rain refers to an approximately 1.5 in. per hour intensity, while heavy rain refers to approximately 6 in. per hour intensity.

In general, as vehicle speed increases, the skid number decreases. The entrapment of water between a sliding tire and a wetted pavement surface is responsible for the development of hydrostatic pressure. This pressure decreased tire-pavement friction in direct proportion to its magnitude. To the extent that this water cannot drain during the tire contact period, tire-pavement friction is decreased. If this pressure develops to the extent that the tire is supported almost entirely by the water film, hydroplaning results.

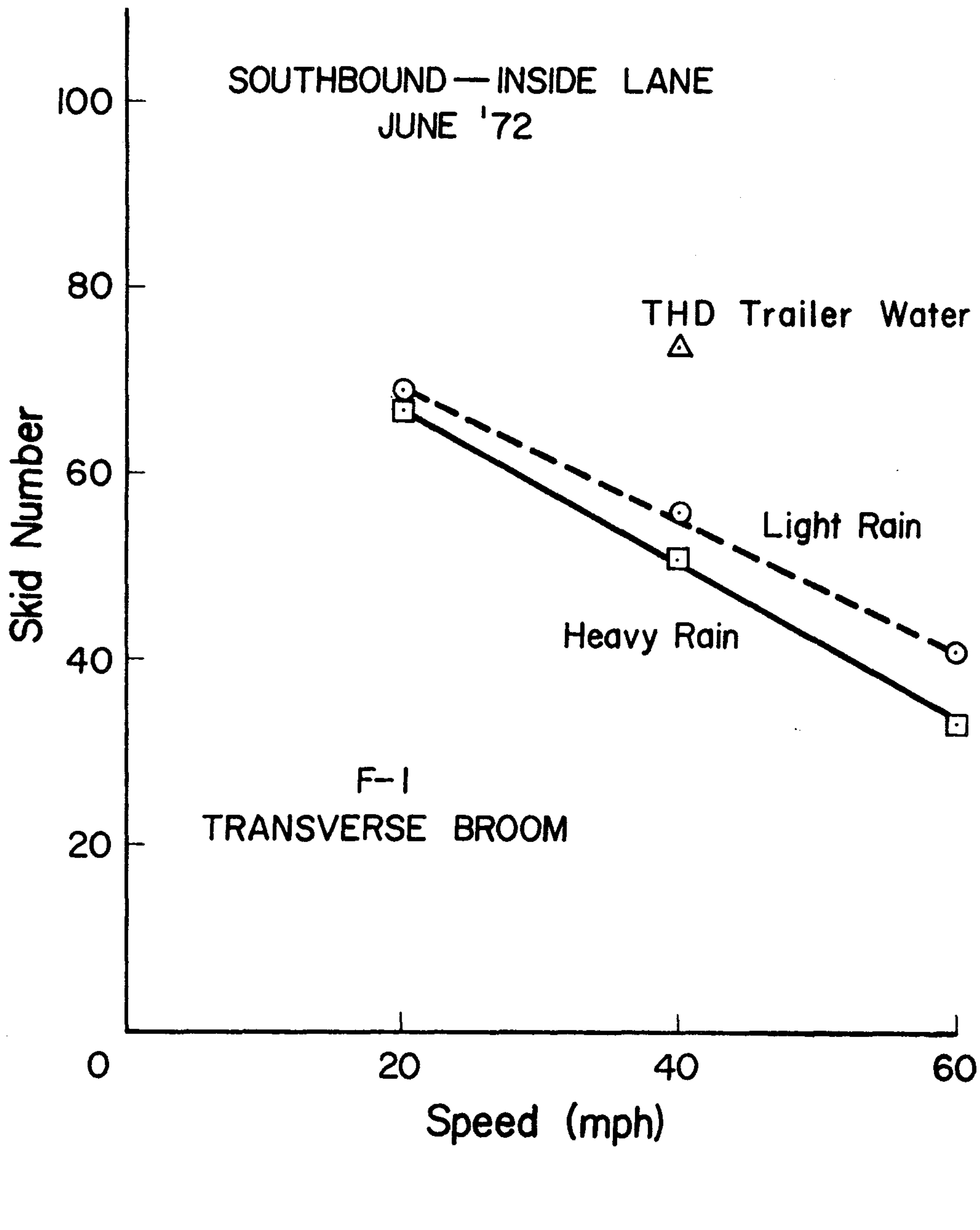

Fig. 3-3 Effect of Vehicle Speed on Skid Number

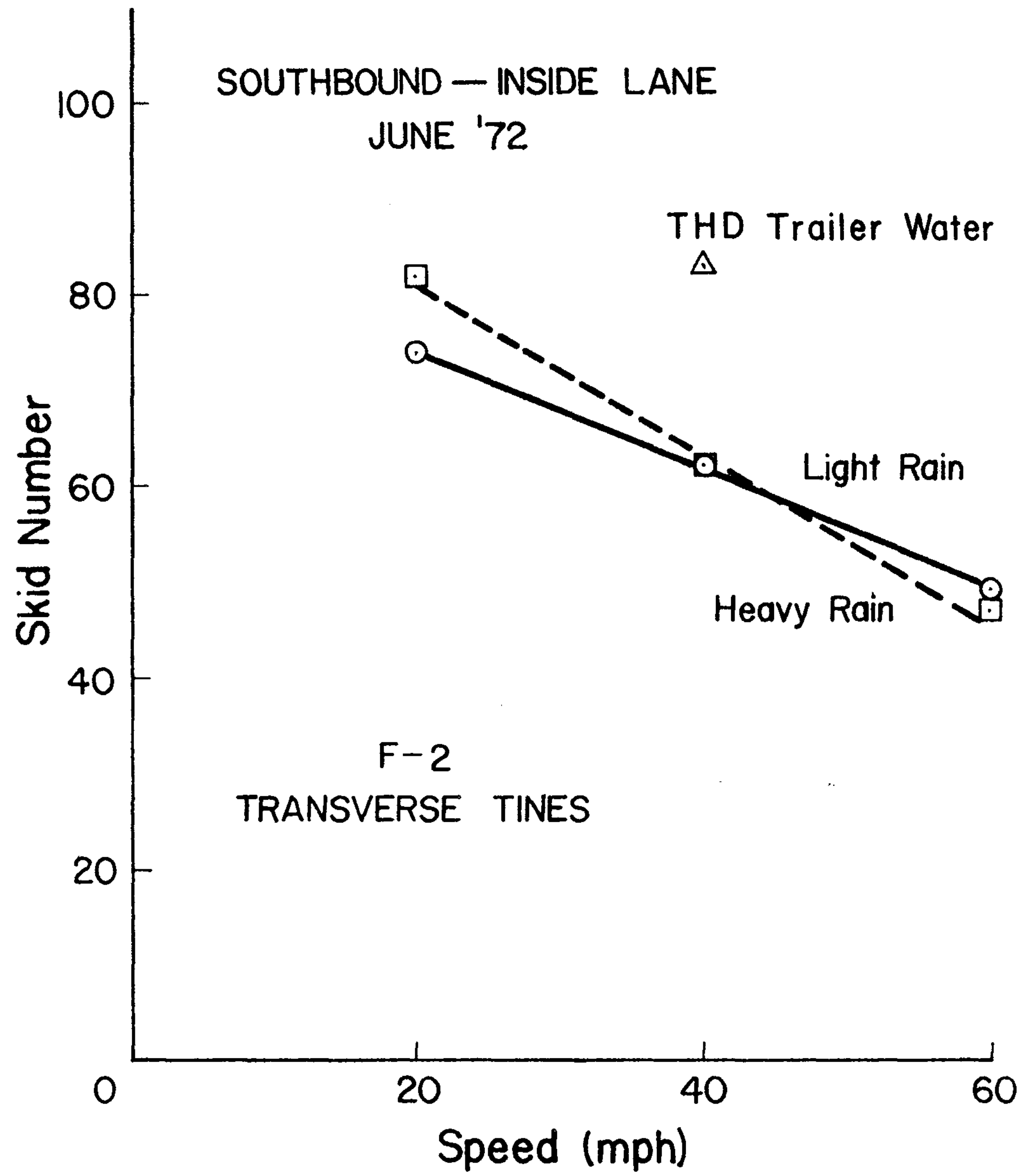

Fig. 3-4 Effect of Vehicle Speed on Skid Number

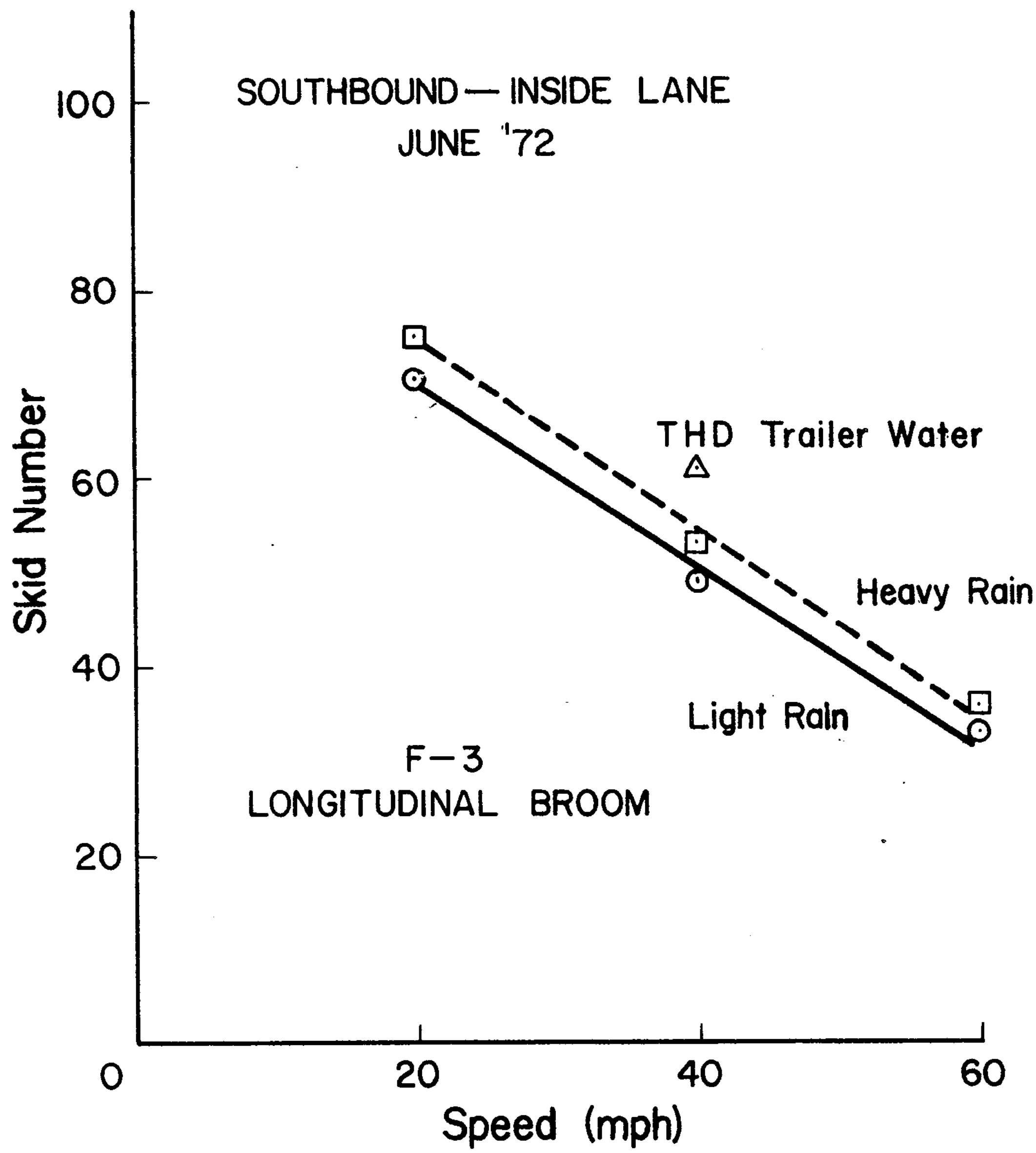

Fig. 3-5 Effect of Vehicle Speed on Skid Number

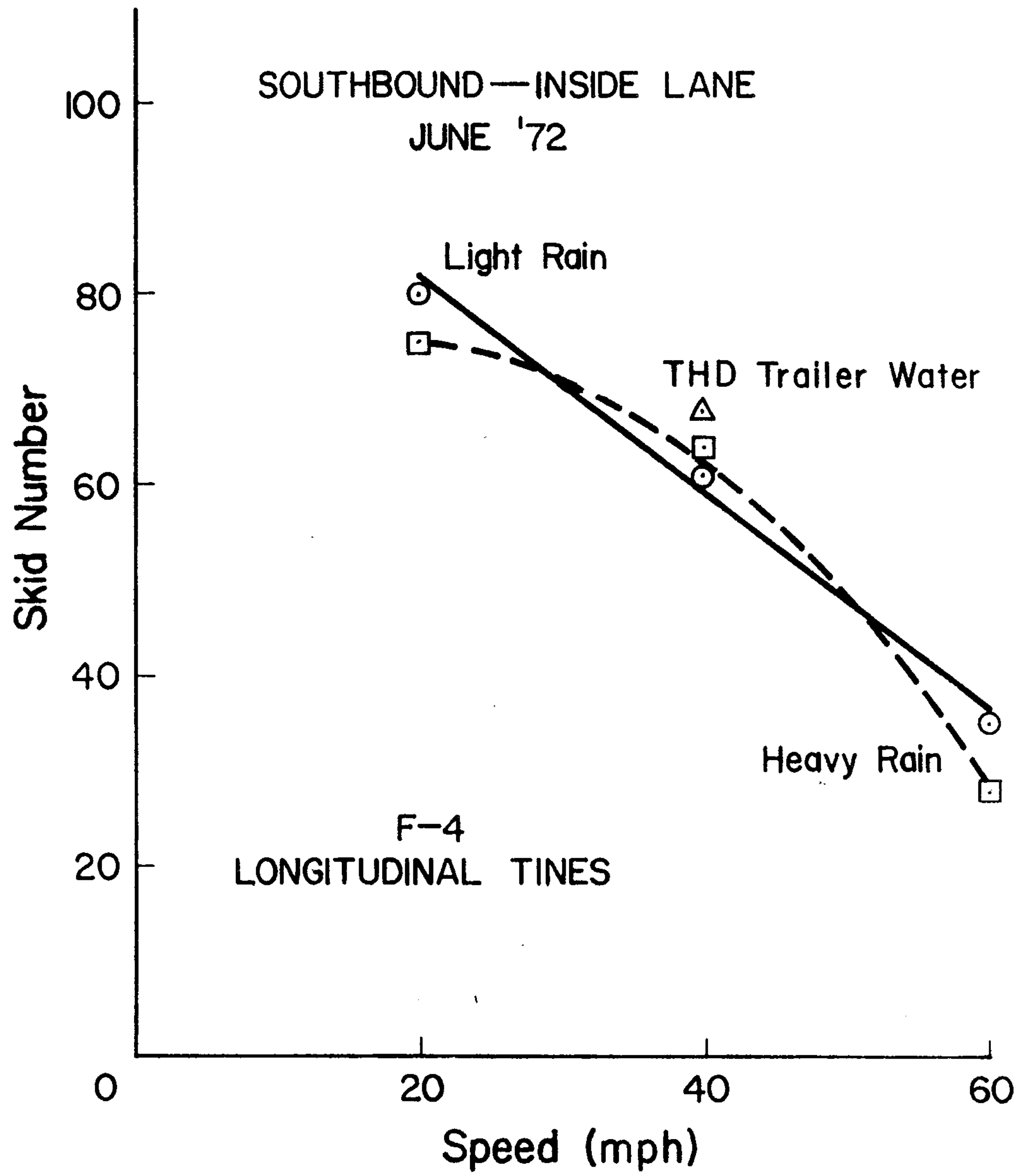

Fig. 3-6 Effect of Vehicle Speed on Skid Number

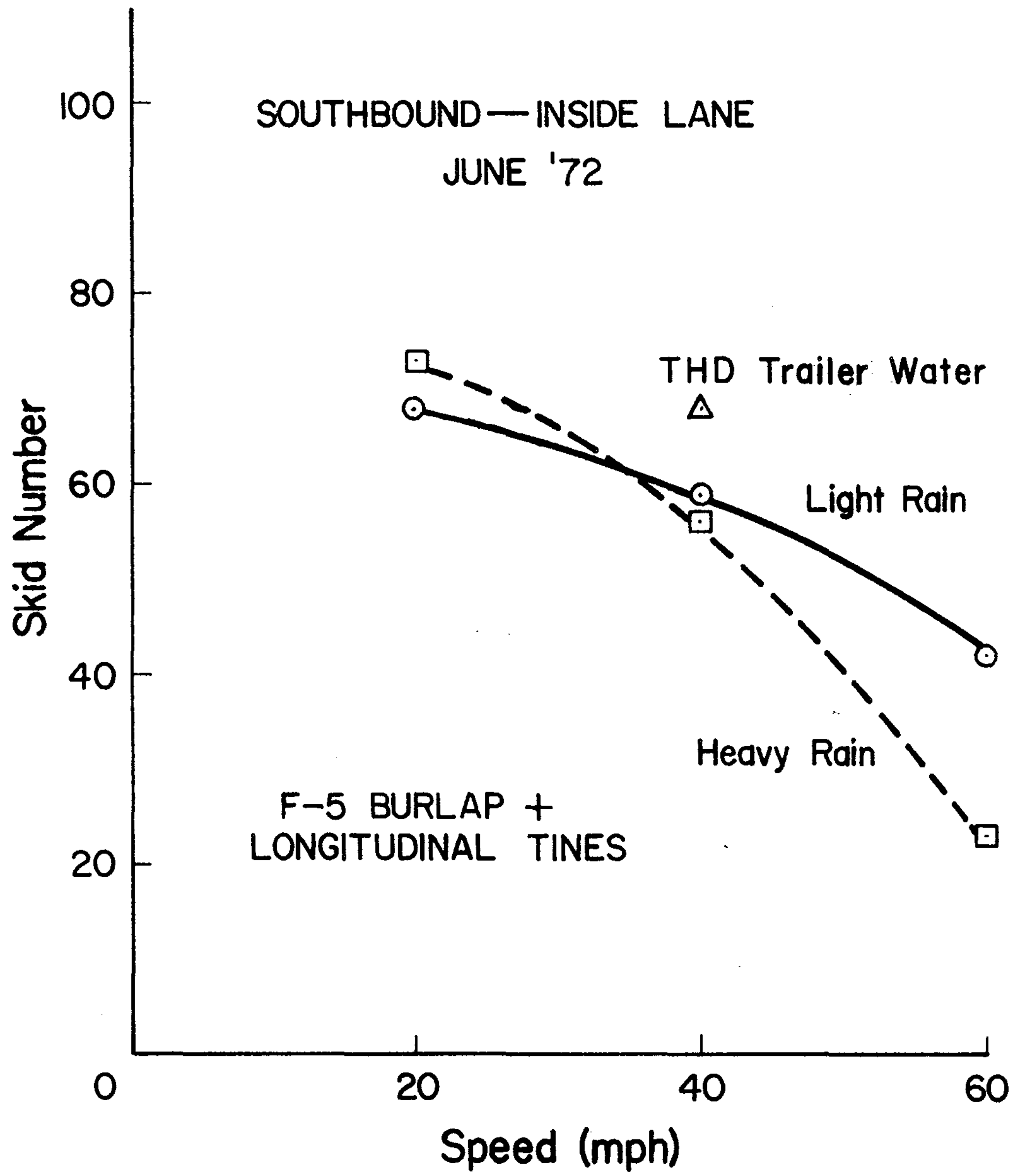

Fig. 3-7 Effect of Vehicle Speed on Skid Number

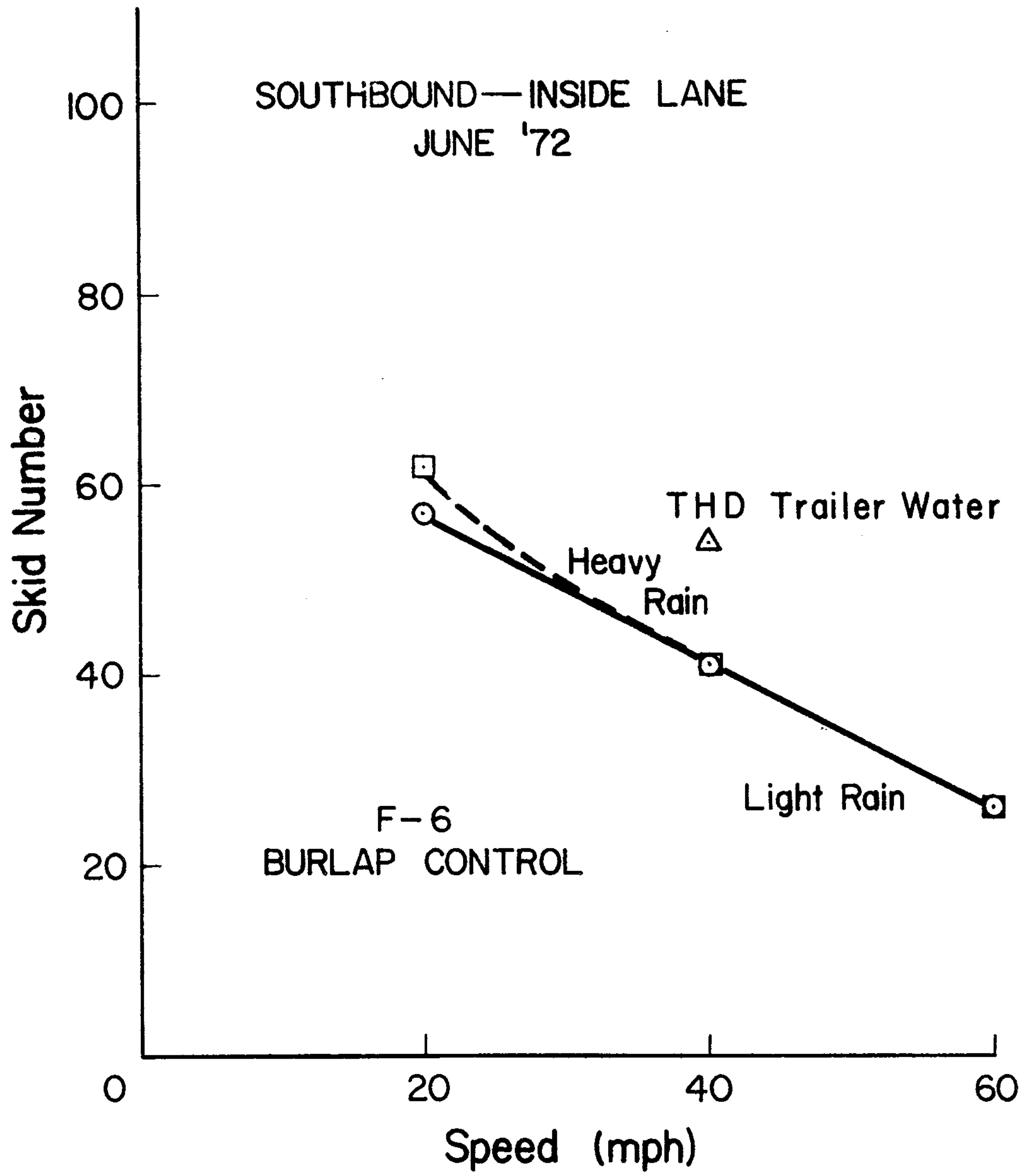

Fig. 3-8 Effect of Vehicle Speed on Skid Number

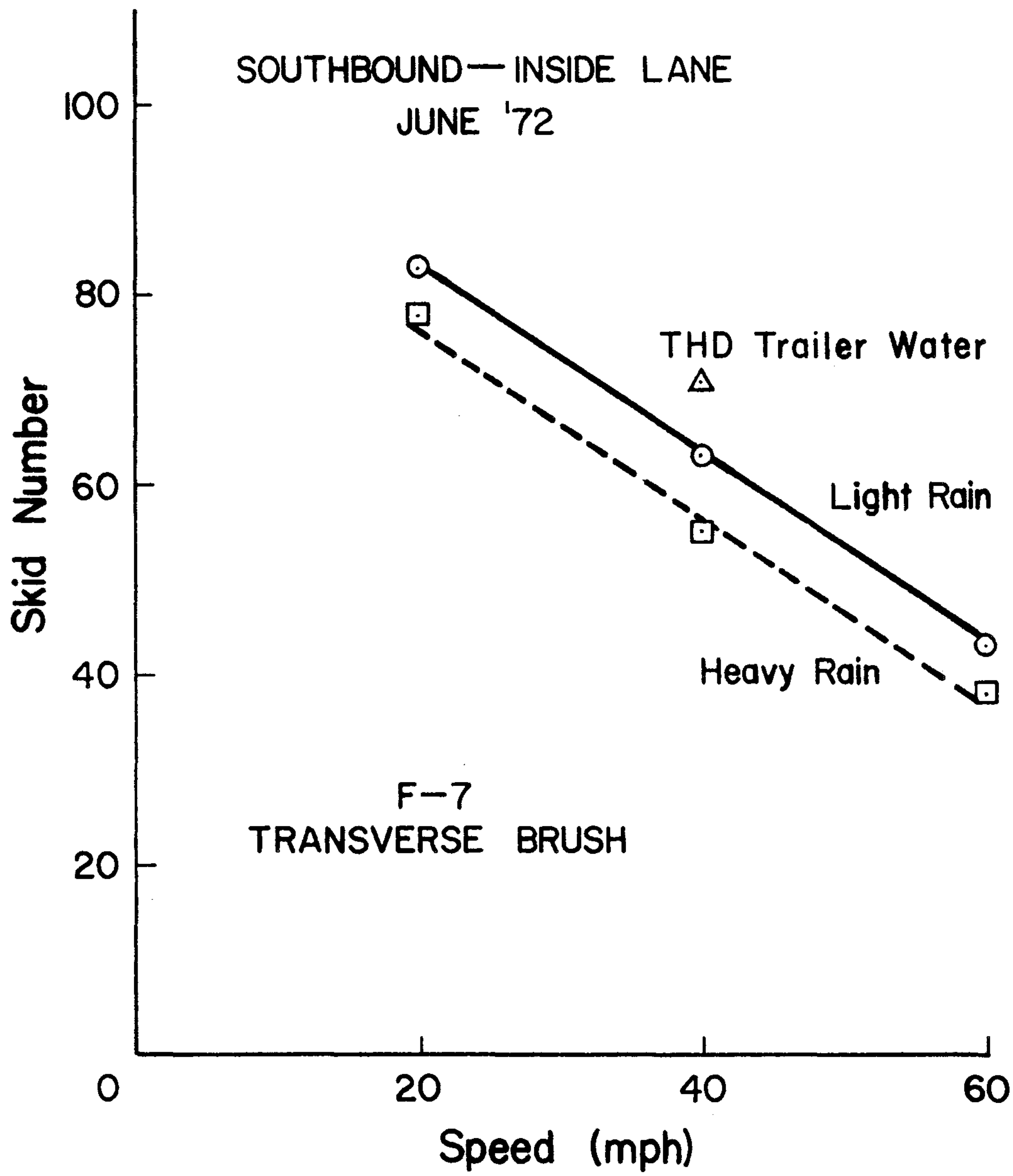

Fig. 3-9 Effect of Vehicle Speed on Skid Number

At the varying test speeds, the tire-pavement interface becomes wetted to varying degrees. This fact, in part, may account for some of the anomalies that occur during the testing of a pavement surface. The most obvious of these is an apparent increase in skid number (as indicated by the THD skid trailer utilizing the internal watering system - Figure 3-4) with an increase in velocity. This can partly be explained by the hypothesis that there is a certain inability of the water to fully wet the tire-pavement interface at higher velocities, especially on the deep textured finishes.

Figures 3-10 and 3-11 represents a summary of the effects of simulated rainfall. Under a "light" rainfall - approximately 1.5 in. per hour (Figure 3-10) - all of the experimental textures exhibited higher skid resistances (10 to 20 skid numbers) at every speed checked, although the skid gradients were similar (around 0.6 SN drop per mph). Under a "heavy" rainfall - approximately 6 in. per hour - the beneficial skid effects of the deeper textures were somewhat masked, especially at higher speeds (Figure 3-11). The longitudinal tines finishes were no better than the burlap drag at 60 mph, although they were significantly better at 40 mph. Under heavy rainfall the transverse tines appeared to exhibit the best overall skid resistance.

3.2.3 Effect of Texture Depth on Skid Number

THD Trailer Tests

Analysis of the data presented by Figure 3-12 shows the relationship between texture depth (as measured by the putty impression method) and skid resistance. The data are representative only of skid numbers at 40 mph, although similar relationships were established at 20 and 60 mph.

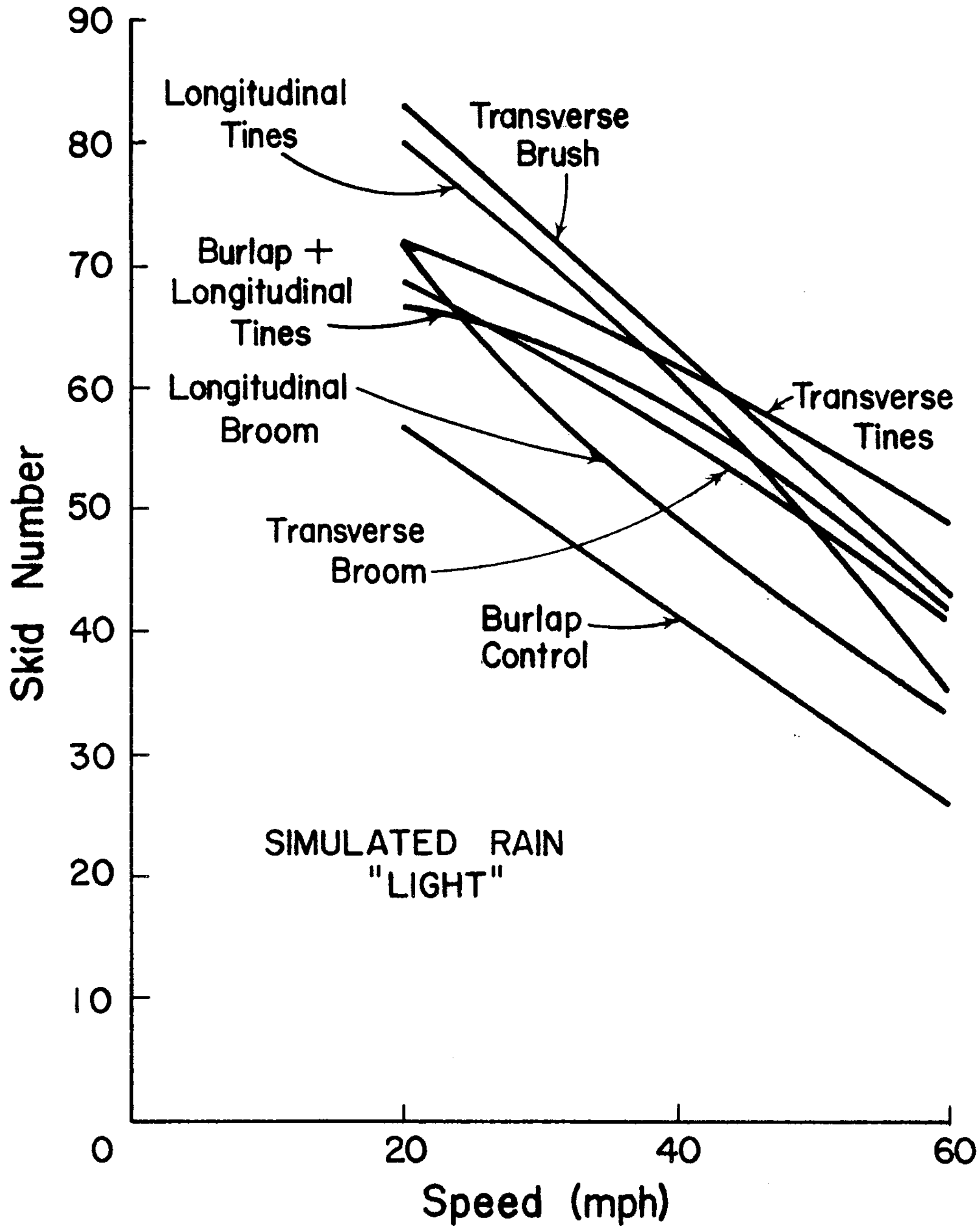

Fig. 3-10 Effect of Vehicle Speed on Skid Number of Test Sections in Presence of Simulated Rain

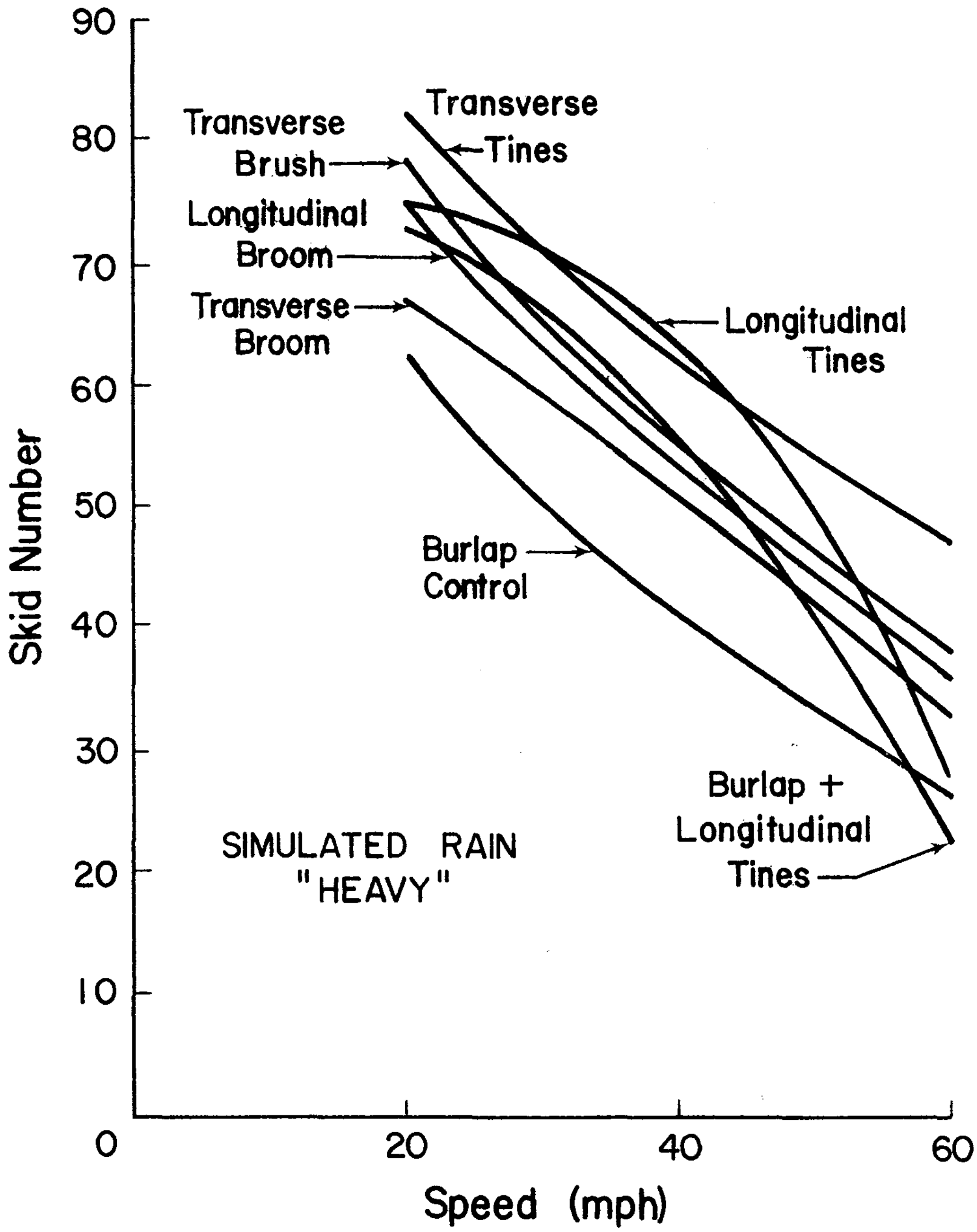

Fig. 3-11 Effect of Vehicle Speed on Skid Number of Test Sections in Presence of Simulated Rain

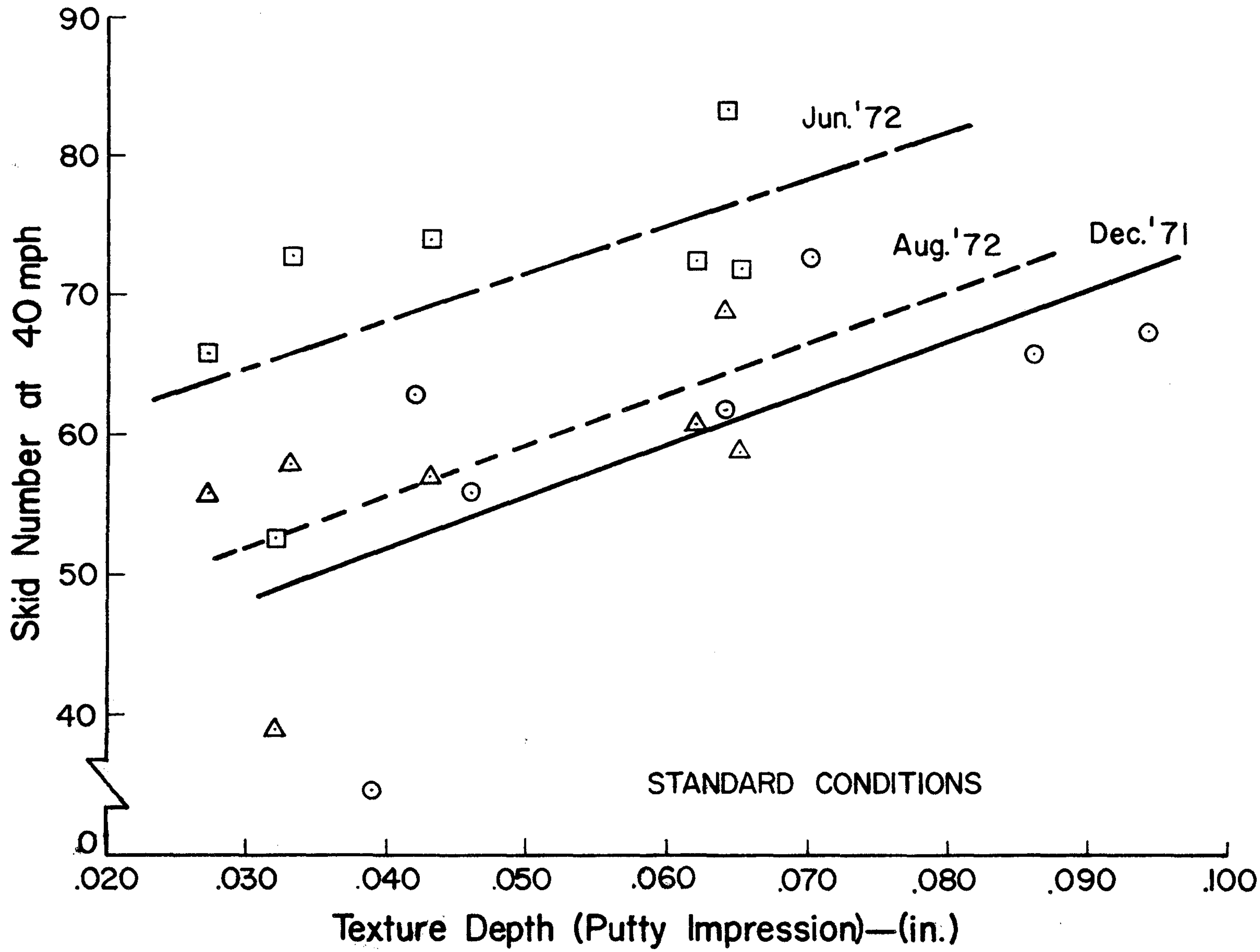

Fig. 3-12 Effect of Texture Depth on Skid Number (Standard Conditions)

The tentative conclusion that can be drawn from Figure 3-12 is that the greater the texture depth of the test section, the greater the associated skid number. The relationship between skid resistance and texture depth in pavements, as measured by the sand patch test, has been demonstrated by others.[1] This is the first time, however, to the authors' knowledge, that the relationship has been shown to hold for a variety of textures produced in concrete by different methods. This tends to reinforce the significance of texture depth as one of the important determinants of overall skid resistance.

The finish types that give rise to greater texture depths and resulting greater skid numbers (the right end of the June and August correlations) are the transverse tines, longitudinal tines, and the burlap drag plus longitudinal tines. Without respect to the direction of the applied finish, it appears that the tine finish may be the best for producing a high textured, high skid-resistant pavement. This statement assumes that the tine finish (as it wears down) will reach a plateau higher than that of any other finish (based on standard trailer measurements utilizing internal watering system).

Simulated Rain Tests

Figures 3-13 and 3-14 illustrate texture depth versus skid number under simulated rainfall.

Under the influence of rainfall the effects of texture depth on skid resistance are minimized. Under the "light" rain (Figure 3-13), some increase in skid number can be seen with an increase in texture depth, but not nearly as much as was measured under "standard trailer water" conditions (Figure 3-12). Under "heavy rain" conditions the effect of texture depth is even further negated (Figure 3-14).

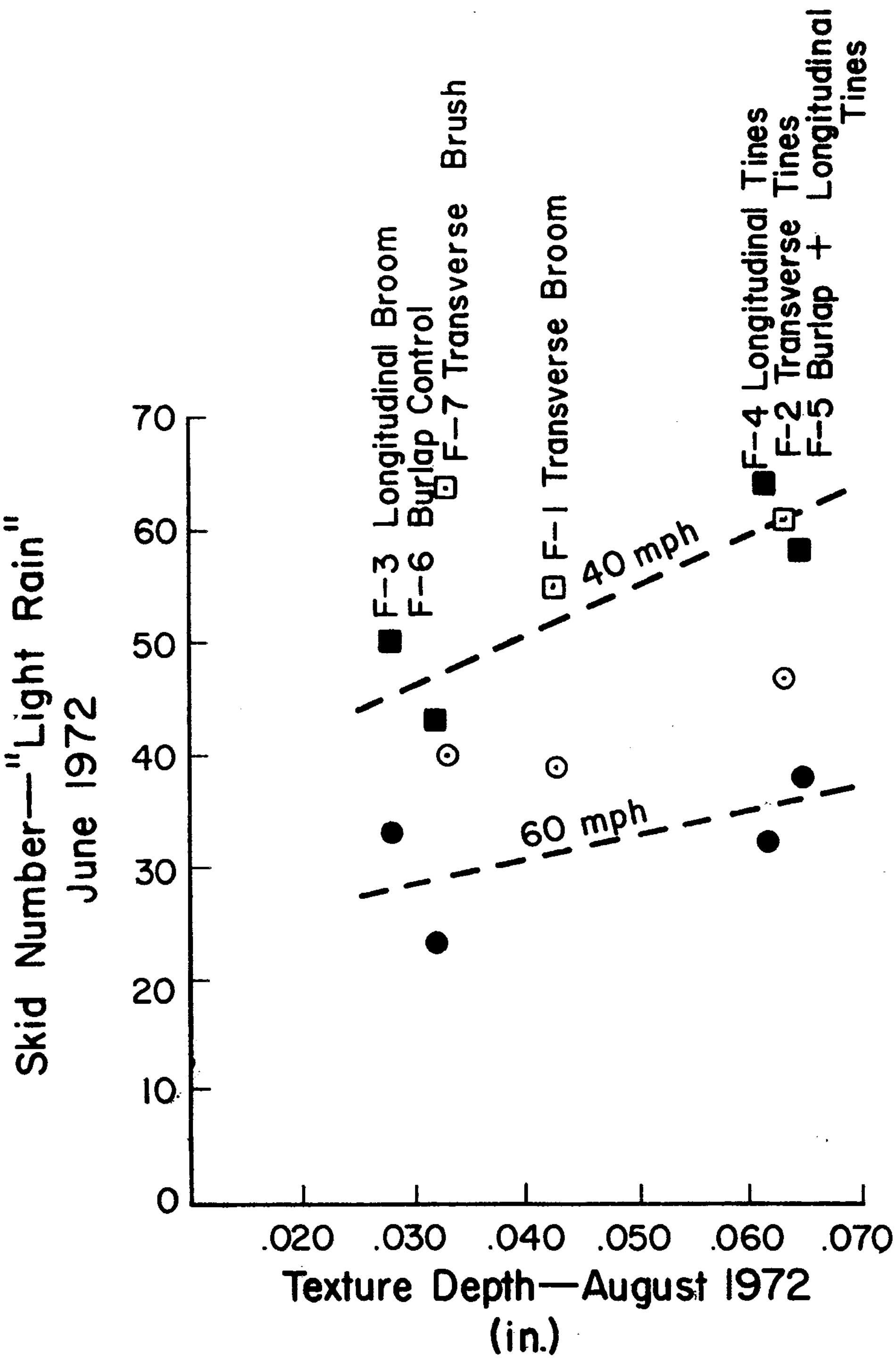

Fig. 3-13 Effect of Texture Depth on Skid Number

(Light Rain)

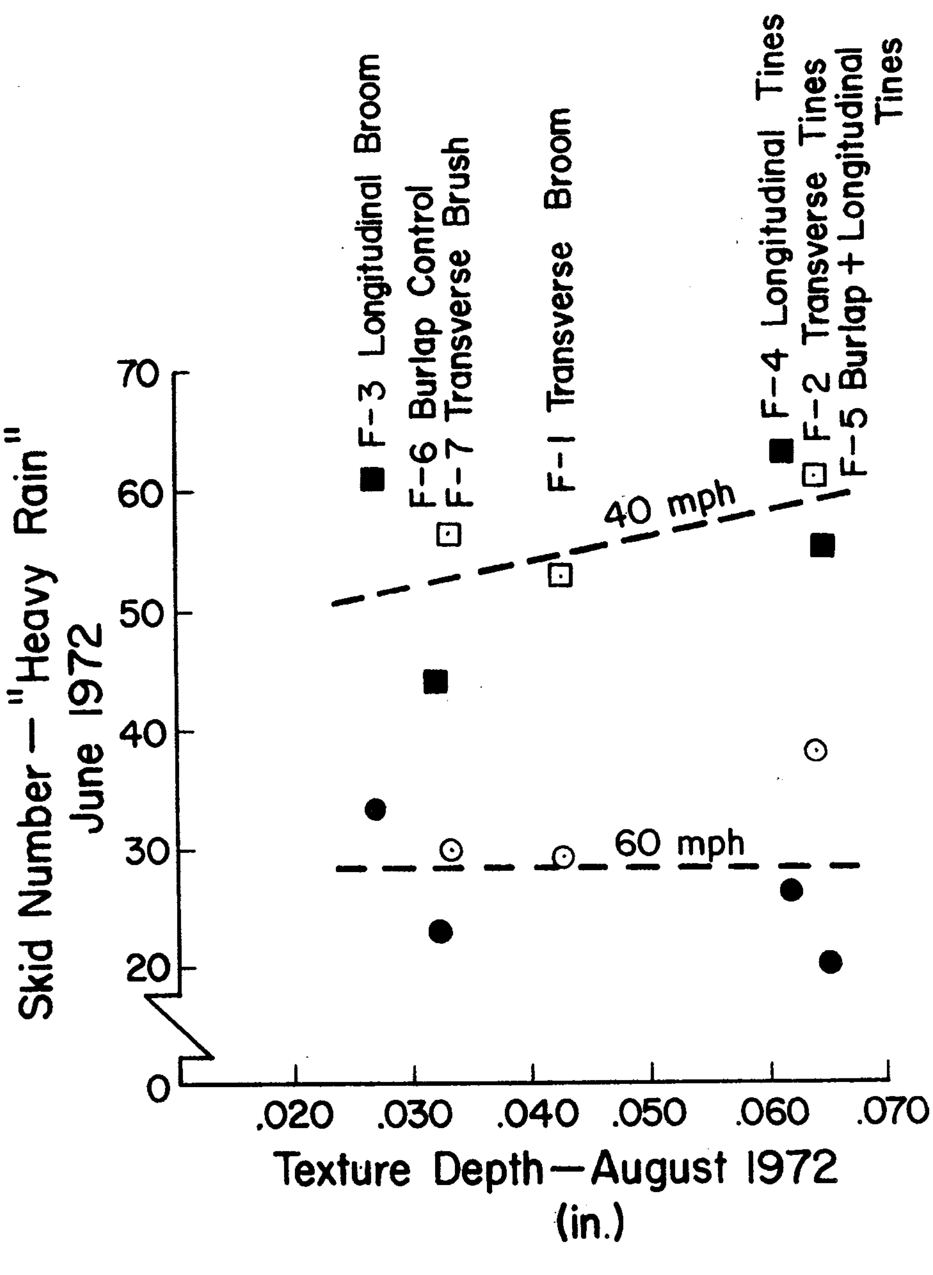

Fig. 3-14 Effect of Texture Depth on Skid Number

(Heavy Rain)

3.2.4 Effect of Texture Depth on Sound Pressure Level

Examination of the data presented by Figure 3-15 reveals that with an increase in texture depth, within the range observed, there is an associated increase in sound, as measured by sound pressure level.

The purpose of this segment of the study was to attempt to establish a relationship between sound pressure level and pavement surface texture depth. If such a relationship could be clearly established between texture depth and the associated sound pressure level generated by the tires, then it might be possible to evaluate the overall surface texture of a pavement without resorting to many, many, time-consuming texture depth measurements. Utilizing this evaluation of the texture along with standard measures of skid resistance could yield important information for a fuller evaluation of pavement surfaces.

The definite relationship found in December 1971 (Figure 3-15) was very encouraging and indicates an approach of this kind may be very valuable.

Sound pressure level measurements were repeated in August 1972, after the pavement had been worn somewhat and the sound level vs. texture depths are plotted on Figure 3-16. Here again a trend was established.

3.2.5 Effect of Skid Number on Sound Pressure Level

Figure 3-17 indicates the relationship between skid number and the sound pressure level. For the particular variables under investigation in this study skid numbers correlated very poorly with the sound pressure level. This is not surprising, as texture and skid resistance are not always directly relatable. It must also be remembered that the sound pressure level information was taken on an arbitrary basis, making use of existing

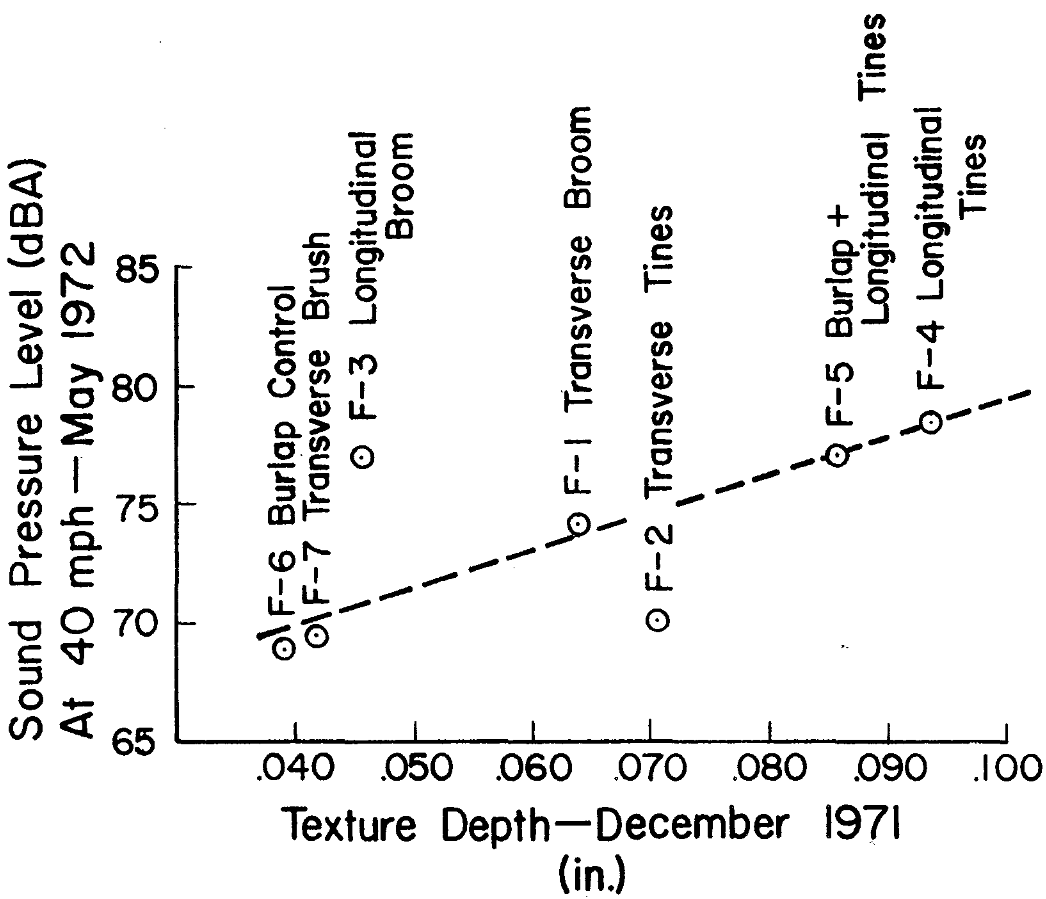

Fig. 3-15 Effect of Texture Depth on Sound Pressure Level
(Initial)

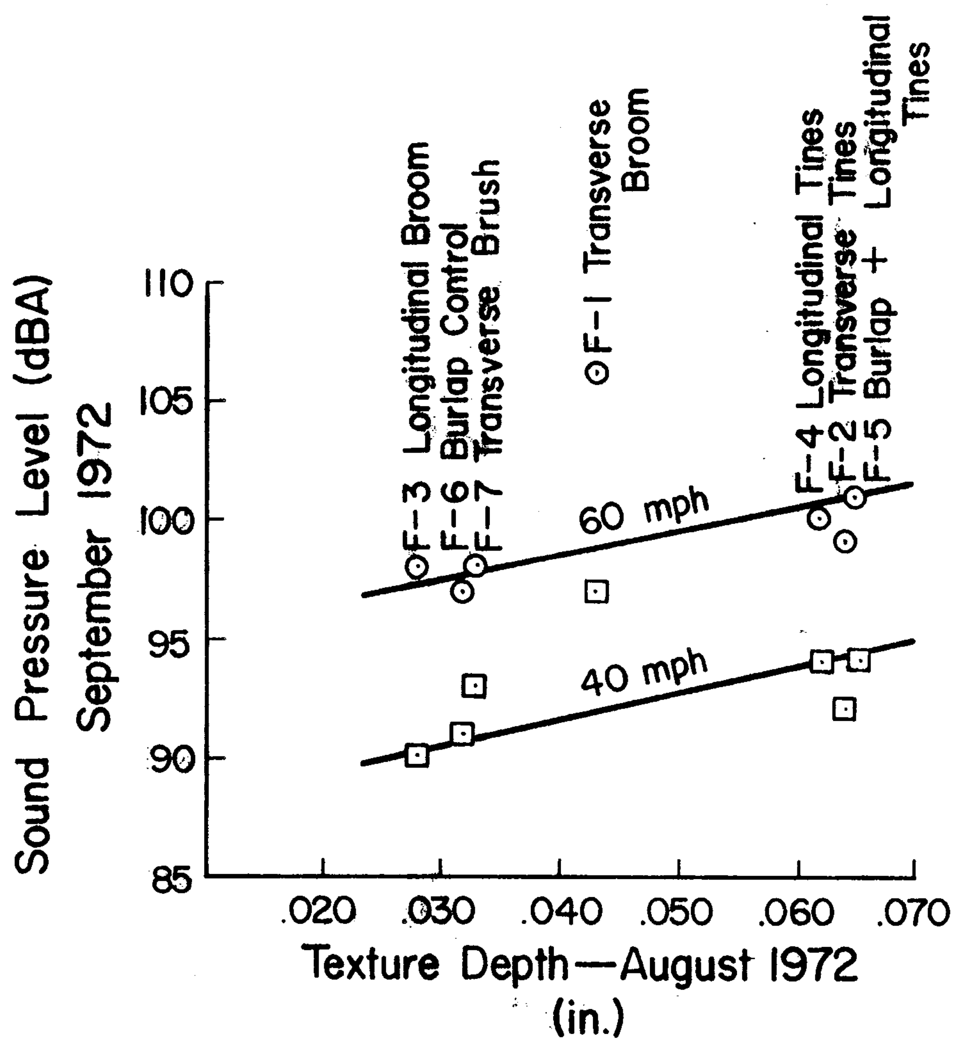

Fig. 3-16 Effect of Texture Depth on Sound Pressure Level

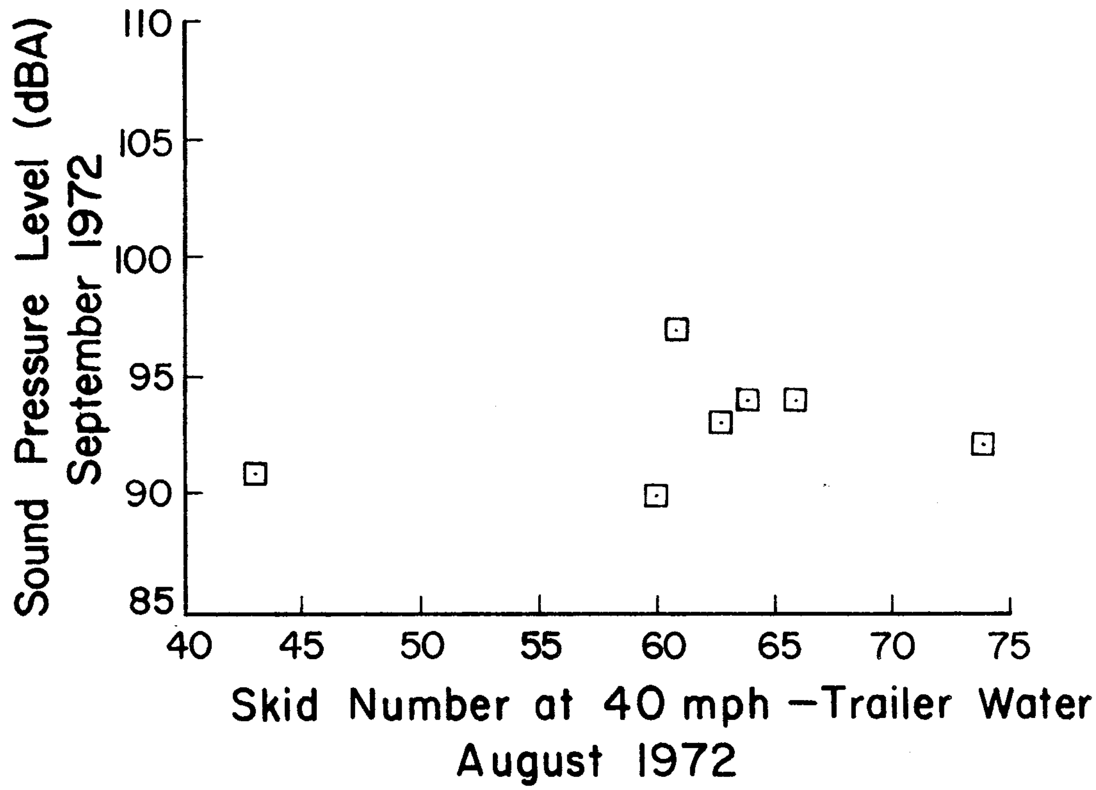

Fig. 3-17 Effect of Skid Number on Sound Pressure Level

equipment (see Section 4.6), and thus the data are too preliminary to draw any significant conclusions.

3.2.6 British Portable Tester

No relationships were apparent when the British Portable Number (BPN) was used for comparison.

4. APPENDIX

4.1 Rain Simulator

A general view of the equipment used for wetting the surfaces is shown in Figure 4-1. The basic framework of the rain simulator was composed of 4 in. wide by 1 in. deep channel iron. A 4 in. diameter pipe served as

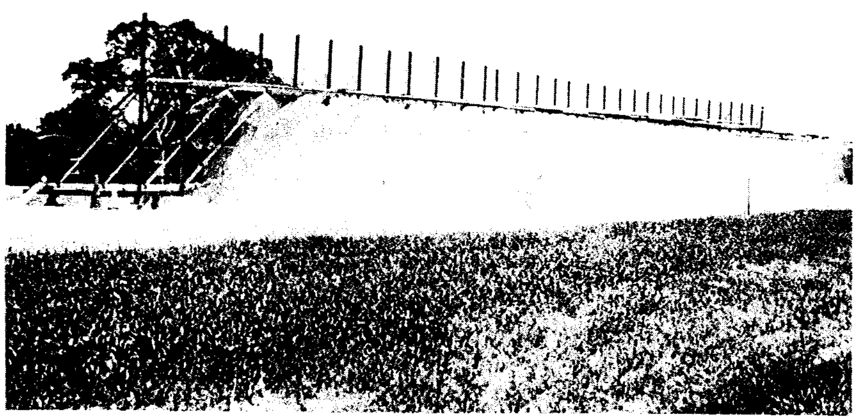

Fig. 4-1 Rain Simulator

the manifold with 2 in. diameter pipes used as feeder lines for the nozzles. Eight 20 ft long sections of the rain simulator wetted an area approximately 210 ft long by 30 ft wide. The spacing of the nozzles was decreased along the length of the spray bar such that the rainfall intensity could be increased along the spray bar. Under areas where spacing of the nozzles was closer, greater water depths could be obtained. Hose type nozzles were attached to the upper side of the spray bar and used for low rainfall intensity.

A 4000 gallon water truck equipped with a high pressure pump was used for supplying water to the system. Water depths were measured at various distances along the drainage path.

Rainfall intensities were deduced from the amount of water caught in metal cans during a twelve minute interval. Twelve cans were placed at random locations under the rain simulator. Results were then recorded in in. per hr.

Water depth measurements were taken with a Leupold and Stevens point gauge. The metric vernier can be read directly to the nearest 0.2 mm. Zero measurements were taken at each test spot. These were necessary in order to establish a datum plane at the top of the texture from which subsequent water-depth measurements could be referenced.

A total of 16 measurements were taken for a given reported average water depth.

4.2 Skid Trailer

The friction measurements reported were obtained with the Texas Highway Department research skid trailer which conforms substantially to ASTM standards (E274) and utilizes 14 in. ASTM standard tires (E249) inflated to 24 psi. The drag forces are measured with straingauges and the self-watering system, when used, utilizes a centrifugal pump which applies a volume of water equivalent to a water film approximately 0.020 in. in thickness on the surface of the pavement. The development and calibration of the trailer may be reviewed in departmental research reports published earlier by the Texas Highway Department.[10,11] Friction measurements were taken at 20, 40, and 60 mph with ASTM E247 designation treaded tires. The self-watering system was used for only a portion of the measurements, as indicated.

4.3 Silicone Putty Impression Test[7]

A known volume of silicone putty is formed into an approximate sphere and placed on a pavement surface. A 6 in. plate with a 4 in. diameter by 1/16 in. deep recess is centered over the putty and pressed down in firm contact with the surface. The average diameter of the resulting flat topped ring of putty is recorded. The volume of putty is selected so that on a smooth, flat surface with no texture, the silicone putty will completely fill the recess giving a 4 in. diameter flat topped circle. A decrease in diameter of the deformed putty is related to an increase in texture depth thus giving a rapid and simple index of pavement macrotexture.

The putty ball and plate are shown in Figure 4-2.

Fig. 4-2 Silicone Putty Impression Test

4.4 Relationship Between Silicone Putty Impression Test and Sand Patch Test

The relationship between the previously described Silicone Putty Impression Test (Section 4.3) and the Sand Patch Test (Tex-436-A) was based on the average of ten values of ATD taken by each method for each texture. The measurements were taken in January and June of 1973. The data were obtained from the experimental texture sections on the State Highway 6 through route near Bryan, Texas. The relationship for these data is:

Silicone Putty Impression Value = 0.0156 + 0.843 Sand Patch Value

as graphically illustrated in Figure 4-3. These data yield a correlation coefficient of .94. Caution should be exercised when calculating ATD values in the low range. Putty Impression values below about .025 in. will yield erroneous calculated sand patch values.

4.5 British Portable Tester

The instrument was developed by the British Road Research Laboratory. The instrument consists of a pendulum arm with a spring-loaded rubber slider on the foot of the pendulum. It can be used on both flat roads and those with camber or gradient.

The portable skid resistant tester is placed on the portion of the road to be tested, leveled, and the height of the center of suspension of the pendulum adjusted by a system of screws to a fixed value which is read on a special gauge. The pendulum is then released from the horizontal position and swings freely until the rubber slider meets the surface being tested. The slider moves over the surface for a fixed distance, slowing the pendulum down. A frictionally constrained pointer affixed to the pendulum arm measures the highest point in the pendulum arc. The position is then read on a measuring arc graduated from 0 to 150. The pointer leading measures the resistance to skidding of the surface being tested.

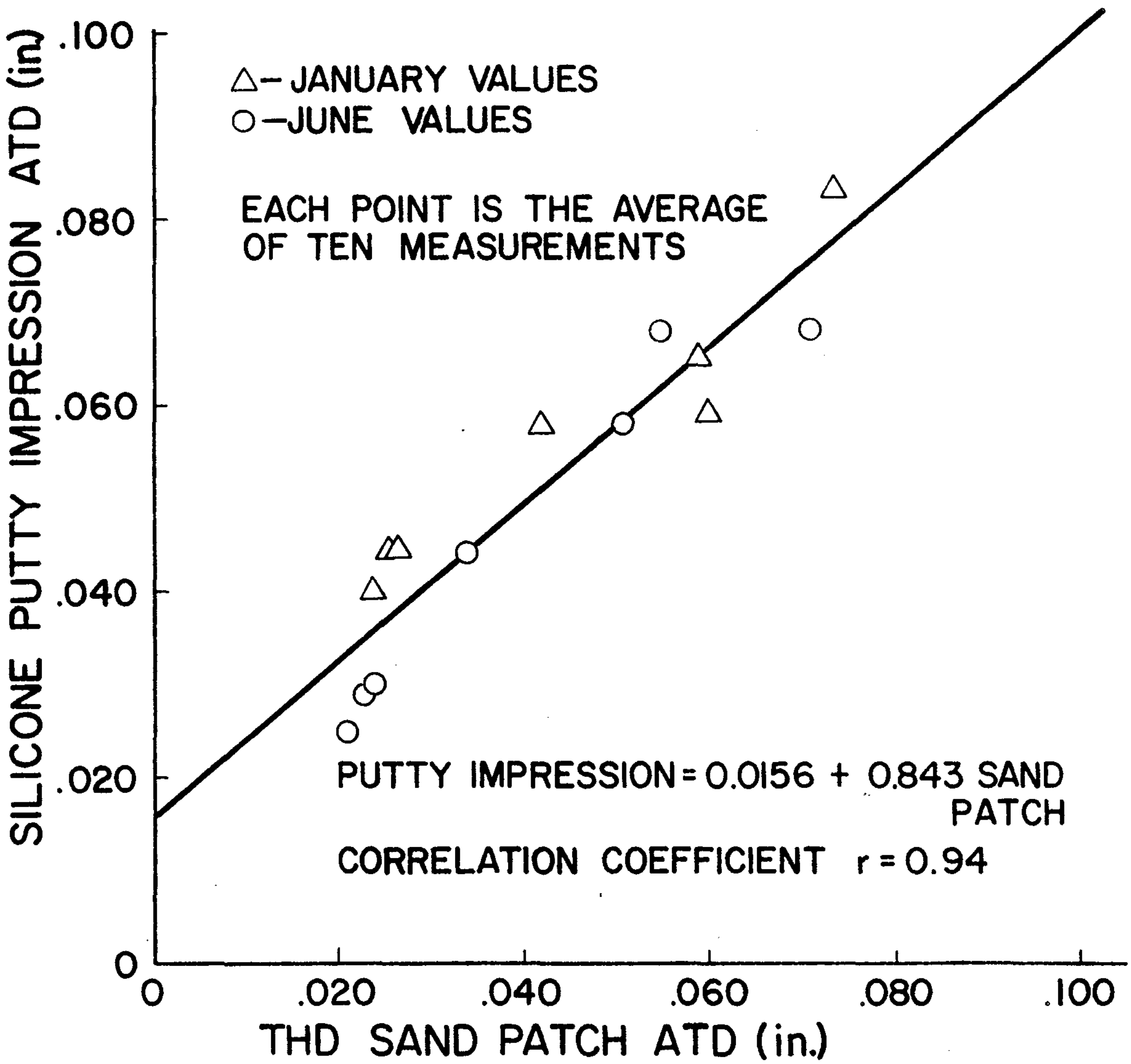

Fig. 4-3 Relationship Between Silicone Putty Impression Test and THD Sand Patch Test

4.6 Sound Level Investigation

The equipment listed below was purchased by the Texas Highway Department for the purpose of sound level investigations. General Radio Company, West Concord, Massachusetts, was the supplier for the sound associated equipment.

a) Type 1560-P5, 1 in. Ceramic Microphone - Designed for flat random incidence response. Typically flat, $\pm$ 1 dB, from 5 Hertz to 20 Hertz with respect to the 500 Hertz level.

b) Type 1562-A Sound Level Calibrator - A self contained unit for making accurate field calibrations on sound-measuring instruments. It generates a precisely known sound-pressure level at five ANSI - preferred frequencies (125, 250, 500, 1000, and 2000 Hertz, $\pm$ 3 percent).

c) Type 1558 Octave Band Noise Analyzer - Instrument used for a rapid analysis of broadband noise where a knowledge of individual frequency is not desired. It is particularly useful for studies of measurement of vehicle noise.

d) Type 1521-B Graphic Level Recorder - The recorder is a completely transistorized, single-channel, servo-type recorder. It produces a permanent, reproducible strip cart record of AC - voltage level as a function of time or some other quantity. Used in conjunction with a sound level meter, such as Type 1558, the recorder can plot sound levels over a side dynamic range as a function of time.

e) Ford Econoline Van - 1972 model.

f) Goodyear Polyglas - belted tires.

4.7 Impact Hammer (Schmidt Rebound Hammer)

The Concrete Test Hammer is used as a control and test instrument for measuring the quality and indicating the strength of the concrete in place. This quick and inexpensive test is not intended as a substitute for control testing of concrete cylinders.

The Concrete Test Hammer is valuable for use in the field for trouble shooting to determine when test cores are needed and where they should be drilled. The device is also used to determine the rate of increase in strength of concrete with time and may be used to determine when forms can be removed or loads applied.

Other users have employed the test hammer to estimate the extent of damage done to structures by freezing or by fire and to estimate the quality of concrete in old structures. There are many other applications.

The lightweight, portable instrument operates on an impact-rebound principle. To operate, the plunger is pressed against the surface of the concrete applying a gradually increased pressure until the hammer impacts. After the impact, the rebound number is read on the indicator scale. The rebound number has been calibrated to indicate concrete compressive strength when referenced to a set of calibration curves which are supplied.

The calibration curves have been developed on the basis of actual comparison tests of the rebound number and compressive strength of thousands of concrete test specimens. The compressive strength of concrete can be determined to within approximately 15 percent.

4.8 Culberson County Test Sections

A total of eleven (11) experimental test sections have been constructed on IH 10 in Culberson County near Van Horn, Texas. Project I10-1(66)142 is an eleven mile section of interstate highway consisting of four lane, divided, continuously reinforced concrete pavement, 8 in. thick. The sections of experimental finishes, constructed in August 1973 are:

Sec F-11	Burlap Drag + 1/4 in. Longitudinal Tines
Sec F-12	Burlap Drag + 1/2 in. Longitudinal Tines
Sec F-13	Burlap Drag + 1 in. Longitudinal Tines
Sec F-14	Burlap Drag + 3/4 in. Longitudinal Tines
Sec F-15	1/4 in. Longitudinal Tines
Sec F-16	1/8 in. Longitudinal Tines
Sec F-17	Burlap Drag (Control)
Sec F-18	1/8 in. Transverse Tines
Sec F-19	1/4 in. Transverse Tines
Sec F-20	Transverse Brush
Sec F-21	Burlap Drag + 1 in. Transverse Tines

Evaluation of these test sections will be carried out in a similar manner to the evaluation reported herein.

4.9 References

1. Fleming, E. M., "Coefficients of Friction Between Rubber Tires and Concrete Road Surfaces," Proceedings, Highway Research Board, Vol. 14, 1934, pp. 178-188.

2. Csathy, T. I., Burnett, W. C., Armstrong, M. D., "State of the Art of Skid Resistance Research," National Cooperative Highway Research Program, Report 39, 1967, 13 pp.

3. Traffic Speed Trends, U. S. Department of Transportation, March 1969.

4. Highway Research Board Committee D-B4 Task Group, "An Inventory of Existing Practices and Solutions to Slippery Pavements-1969," Presented at the 49th Annual Meeting, January 1970.

5. Correlation Service Circular 363 Highway Research Board, National Academy of Sciences, 1958, 38 pp.

6. "Highway Skid Resistance," ASTM STP 456, American Society for Testing and Materials, 1968, 176 pp.

7. Rose, J. G., Hutchinson, J. W., and Gallaway, B. M., "Summary and Analysis of the Attributes of Methods of Surface Texture Measurement," Skid Resistance of Highway Pavements, ASTM STP 530, American Society for Testing and Materials, 1973, pp. 60-77.

8. ACI Committee 214, " ACI Standard Recommended Practice for Evaluation of Compression Test Results of Field Concrete," ACI Manual of Concrete Practice, Part 1, 1970, pp. 214-1 thru 214-25.

9. Rose, J. G., and Ledbetter, W. B., "Summary of Surface Factors Influencing the Friction Properties of Concrete Pavements," Highway Research Record Number 357, National Research Council, 1971, pp. 53-63.

10. McCullough, B. F., and Hankins, K. D., "Skid Resistance Guideline for Surface Improvements on Texas Highways," Record 131, Highway Research Board, National Academy of Sciences, 1966.

11. McCullough, B. F., and Hankins, K. D., "Texas Highway Department Skid Test Trailer Development," Research Report 45-1, Texas Highway Department, April 1965, 72 pp.