TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

EVALUATION OF FULL-SCALE EXPERIMENTAL CONCRETE HIGHWAY FINISHES

5. Report Date
September, 1974

6. Performing Organization Code

7. Author(s)
W. B. Ledbetter, A. H. Meyer, D. E. Ballard

8. Performing Organization Report No.
Research Report 141-4F

9. Performing Organization Name and Address
Texas Transportation Institute
Texas A&M University
College Station, Texas 77843

10. Work Unit No.

11. Contract or Grant No.
Research Study 2-6-70-141

12. Sponsoring Agency Name and Address
Texas Highway Department
11th & Brazos
Austin, Texas 78701

13. Type of Report and Period Covered
Final-September 1969
September 1974

14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with DOT, FHWA.
Research Study Title: Quality of Portland Cement Concrete Pavement as Related to Environmental Factors and Handling Practices During Construction.

16. Abstract

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 change in texture depths and skid values with time were measured. Results indicate that (1) texture depths of 0.060 in. or greater can easily and economically be constructed with 1/8 in. metal tines spaced closer than 1/2 in. apart, (2) under normal traffic conditions all concrete textures can be expected to wear-down approximately 25 to 35 percent during the first 1/2 year and then remain relatively unchanged for a prolonged period, (3) skid measurements made under standard trailer water conditions may not be indicative of real life conditions in wet weather, (4) low skid values could be obtained in almost any rainfall in which the pavement is completely wetted, and (5) under simulated rain conditions deep transverse texturing will result in the greatest improvement in skid values.

17. Key Words
Concrete Pavement, Concrete Finish, Concrete Texture, Skid Measurement, Highway, Concrete Surface

18. Distribution Statement

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
81

22. Price

Form DOT F 1700.7 (8-69)

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D. E. Ballard

Research Report 141-4F

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

The U.S. Department of Transportation
Federal Highway Administration

September, 1974

Texas Transportation Institute
Texas A&M University
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.

This is the fourth and final report on this study. The other three are:

141-1 "Laboratory Study of Effects of Environment and Construction Procedures on Concrete Pavement Surfaces"

141-2 "First Progress Report on Concrete Experimental Test Sections in Brazos County, Texas"

141-3 "Effects of Temperature, Wind and Humidity on Selected Curing Media".

ACKNOWLEDGEMENTS

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, Planning and Research Division Representative; (b) Federal Highway Administration personnel - Mr. Lee Gibbons, Division Representative. The authors also wish to acknowledge the assistance of Ken Hankins and Jon Underwood in the gathering and interpretation of the skid data. The authors also wish to acknowledge the assistance of the following personnel in gathering and summarizing data: Mr. Sidney Greer, Miss Deborah Fisher and Mr. Walt Lehmann. Finally, special thanks are due Dr. Danny Lu for performing the statistical analysis of the data and developing the models for predicting skid values.

ABSTRACT

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 change in texture depths and skid values with time were measured. Results indicate that (1) texture depths of 0.060 in. or greater can easily and economically be constructed with 1/8 in. metal tines spaced closer than 1/2 in. apart, (2) under normal traffic conditions all concrete textures can be expected to wear-down approximately 25 to 35 percent during the first 1/2 year and then remain relatively unchanged for a prolonged period, (3) skid measurements made under standard trailer water conditions may not be indicative of real life conditions in wet weather, (4) low skid values could be obtained in almost any rainfall in which the pavement is completely wetted, and (5) under simulated rain conditions deep <u>transverse</u> texturing will result in the greatest improvement in skid values.

Key Words: Concrete Pavement, Concrete Finish, Concrete Texture, Skid Measurement, Highway, Concrete Surface.

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1. INTRODUCTION AND SUMMARY

1.1 Purpose of Investigation

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 pavement.

1.2 Scope

The scope of this report 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.

1.3 Background

The safety and durability of concrete pavement surfaces have long been of importance to the highway engineer. Concrete pavements are often selected because they are supposed to last a very long time and their surfaces are supposed to provide high skid resistances. Currently the Texas Highway Department requires the use of a longitudinal burlap drag finish with an initial minimum texture depth of 0.025 in. (1).* The questions that have been raised are:

1. Should deeper textures be required, and if so, will these deeper textures result in less durable surfaces or have any other undesirable effects?

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*Numbers in parentheses refer to references contained in Sec. 4.1.

2. Are there better texture types than the burlap drag?

3. Does the direction of texturing - longitudinal or transverse - influence safety or durability?

In attempting to answer these questions the literature has been examined. At the present time a number of excellent reports have been prepared on portland cement concrete (pcc) surface textures. Some of them are the state-of-the-art summaries by Ray, et al. (2) and Rose, et al. (3). They point to the need for deeper textures and attest to the fact that durable concrete surfaces can be easily constructed.

HRB Committee A2F01 recently conducted a survey (4) of 69 pcc pavements in 27 states. The data on the change in average texture depth (ATD) was limited, but for those reporting initial and present values of ATD it did show a drop of about 30 to 40 percent in three to four years. In terms of skid values, a loss of 20 percent was observed in five years on the average.

An excellent summary of the research work done in England is reported by Murphy, et al . (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:

> .... 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 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 in Research Report 141-2 (6) and only one texture (the transverse plastic broom) appeared to generate objectionable noises.

The possibility of increased cost and decreased life were investigated in this study and are discussed in this report.

1.4 Conclusions

The following 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 0.060 in. or greater were easily and economically constructed in portland cement concrete pavement, in either the longitudinal or transverse direction, using 1/8 in. wide metal tines spaced closer than 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 40 and 60 mph, locked wheel skid measurements using trailer water were significantly different than the same measurements made under simulated rain conditions, with the simulated rain conditions indicating 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 40 mph regardless of water depth. This means that low skid values could be obtained in almost any rainfall in which the pavement were completely wetted.

5. Under simulated rain conditions deep transverse texturing will result in the greatest improvement in skid values.

6. Statistical analysis of the data resulted in regression models which can predict skid values for a selected vehicle speed, tire tread depth, pavement texture depth (with an appropriate factor for expected wear-down) and texture direction, and pavement water depth.

1.5 Recommendations

The following recommendations are offered:

1. All experimental textures should be monitored for skid values and texture depths for at least 5 years and the results analyzed and reported.

2. Research should be initiated to attempt to relate skid values obtained under standard trailer water conditions with skid values obtained in wet weather.

3. Research should be initiated on other texturing methods such as plastic grooving to see if they should be used.

1.6 Implementation Statement

Transverse tine textures, with the tines spaced less than 1/2 in. apart, should be required for concrete pavements. And these textures

2. TEST SECTION CONSTRUCTION

2.1 SH 6, College Station, Texas

Seven test sections, each 800 ft long, were constructed in November 1971 (see Fig. 2-1 for location of the test sections). A complete description and discussion of the construction of these 7 test sections is given in Research Report 141-2 (6).

Traffic on these sections averaged 868 vehicle passes per day (VPD) in June 1972, 1483 VPD in January 1973, and 1530 VPD in July 1974.*

2.2 IH 10 Near Van Horn, Texas

2.2.1 Test Section Description

The data obtained for this study were taken from 11 test sections of 8 in. thick continuously reinforced concrete pavement (CRCP). These test sections were constructed by the Dahlstrom Corporation for the Texas Highway Department (THD) as an integral part of IH 10 (near Van Horn, Texas). The average length of each section was 600 ft and was prepared using a granitic gravel and granitic sand, Type II portland cement, and an air entrainment admixture. Test sections were constructed in September 1973 utilizing a slip form paver. A tube float was used to prepare the concrete surface prior to the final characteristic test finish. The locations of the test sections are shown in Fig. 2-2, and typical photographs of the construction operation are shown in Figs. 2-3 through 2-9.

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*Traffic data supplied by the Planning Survey Division of the Texas Highway Department.

should be significantly deeper than now required. Furthermore, any required initial texture depth should consider expected wear-down and subsequent loss of texture, and the regression models should be used to determine required texture depths.

This statement is made concurrently by the authors and the study Contact Representative.

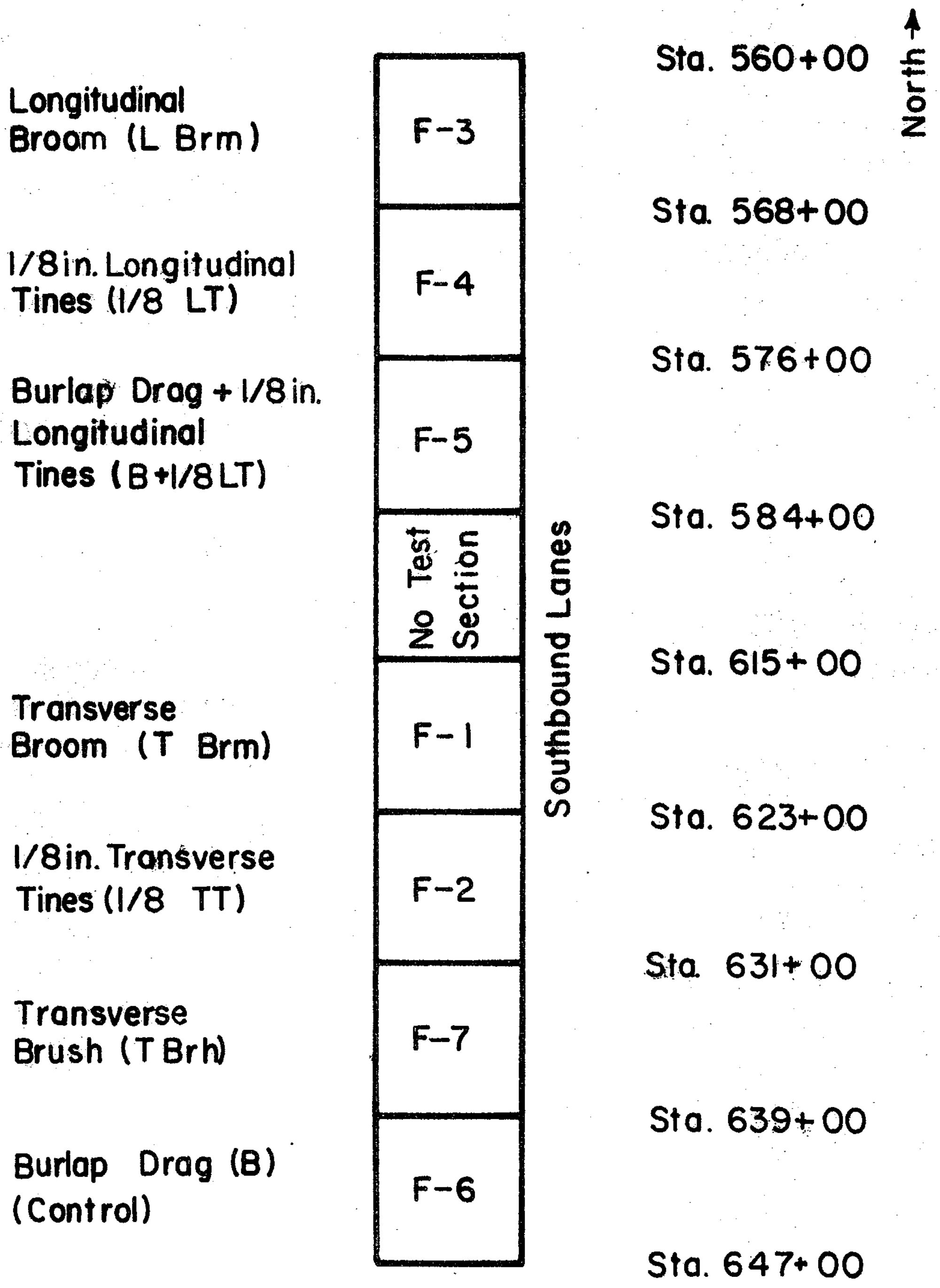

Fig. 2-1 Location of Test Sections on SH 6 in College Station, Texas

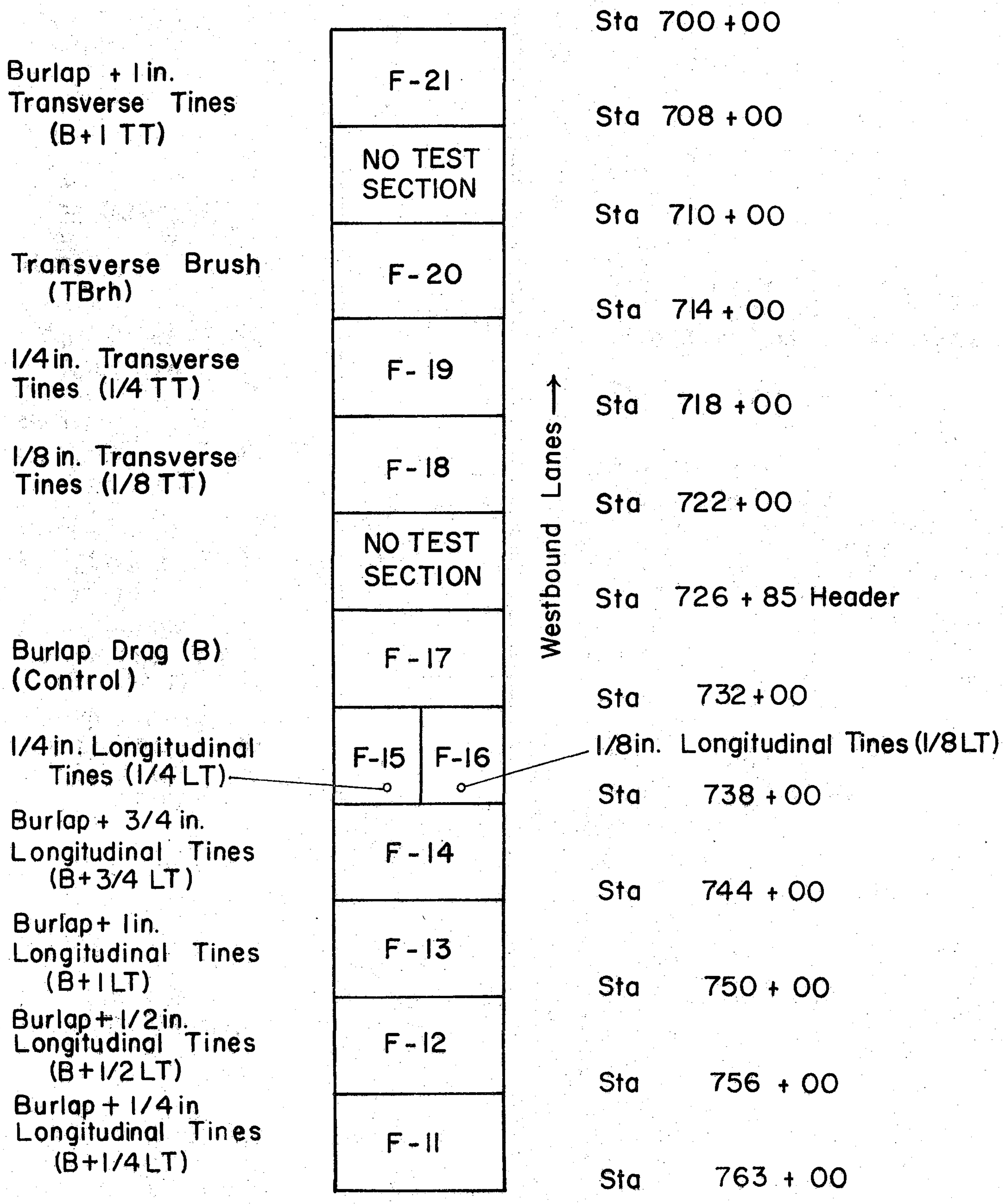

Fig. 2-2 Location of Test Sections IH 10
Near Van Horn, Texas

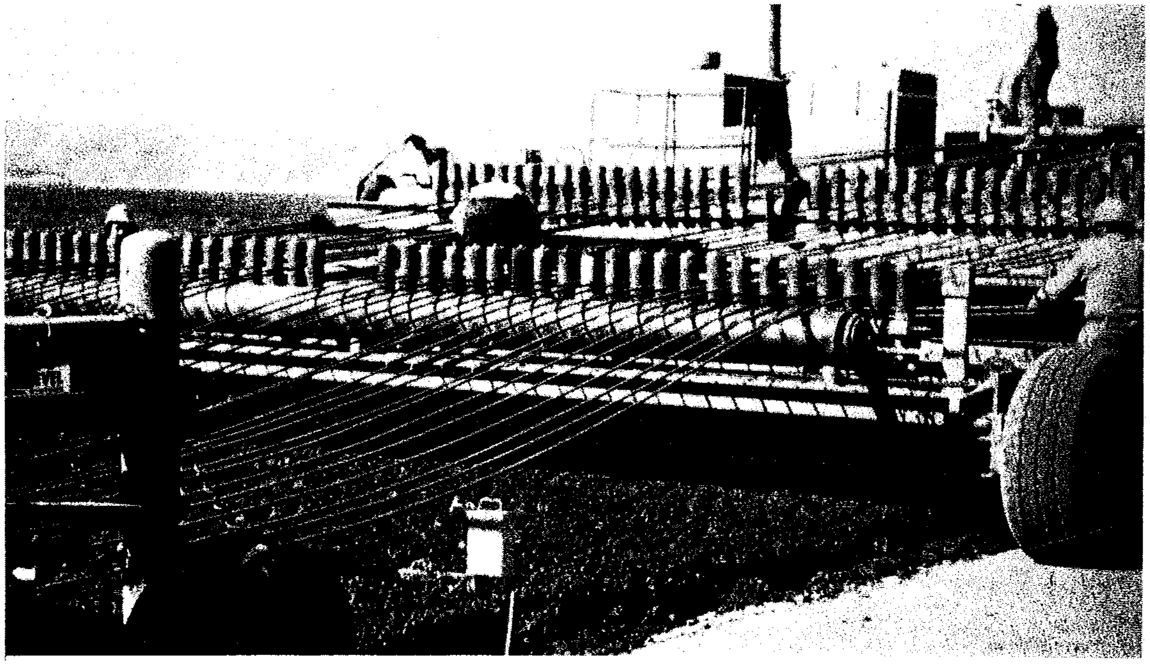

Fig. 2-3 Paving Operation Showing Steel Spacer

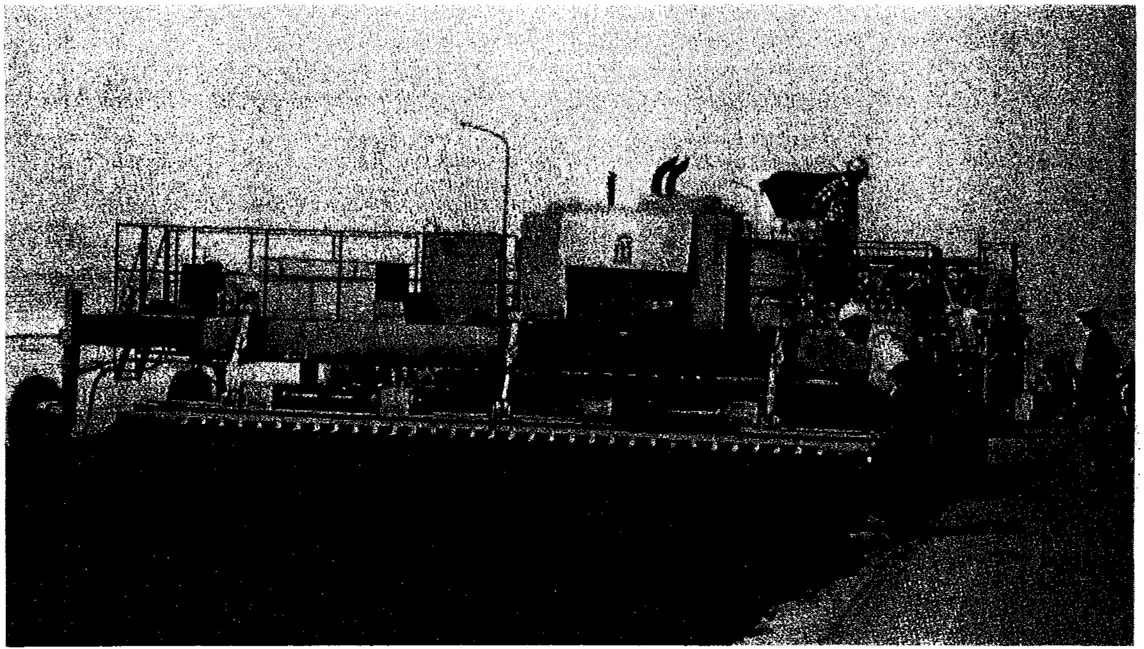

Fig. 2-4 Interior View of Paving Operation
Showing Steel Depressor

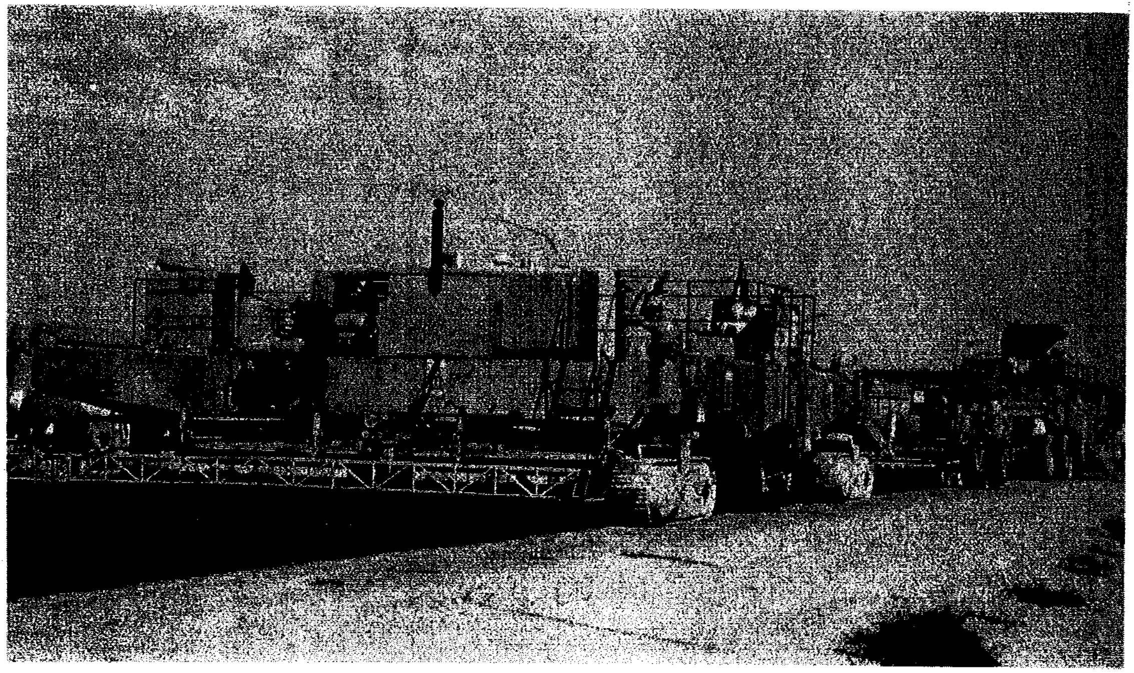

Fig. 2-5 Rear View of Paving Operation Showing Paver

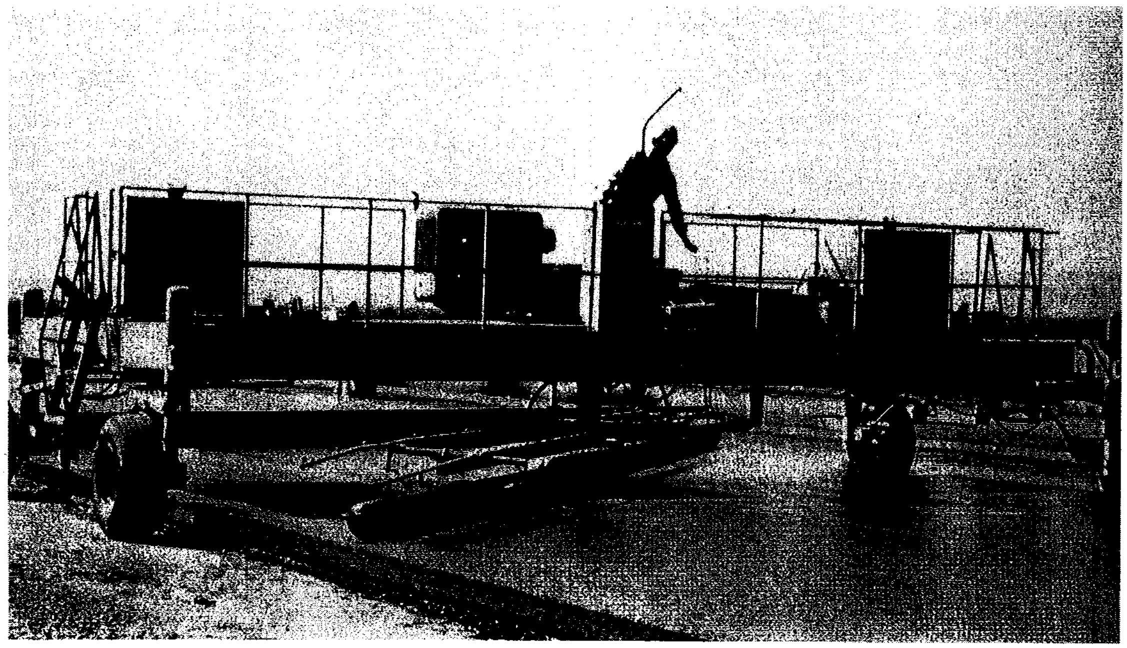

Fig. 2-6 Tube Float

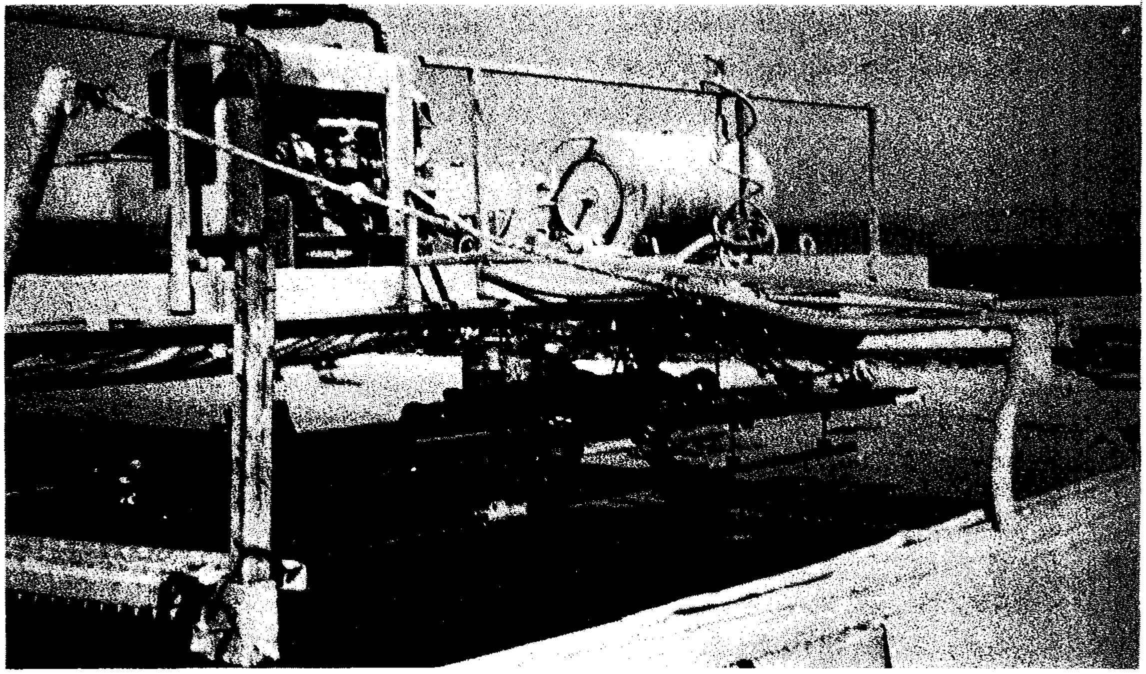

Fig. 2-7 Finishing Machine Applying Longitudinal Tine Finish

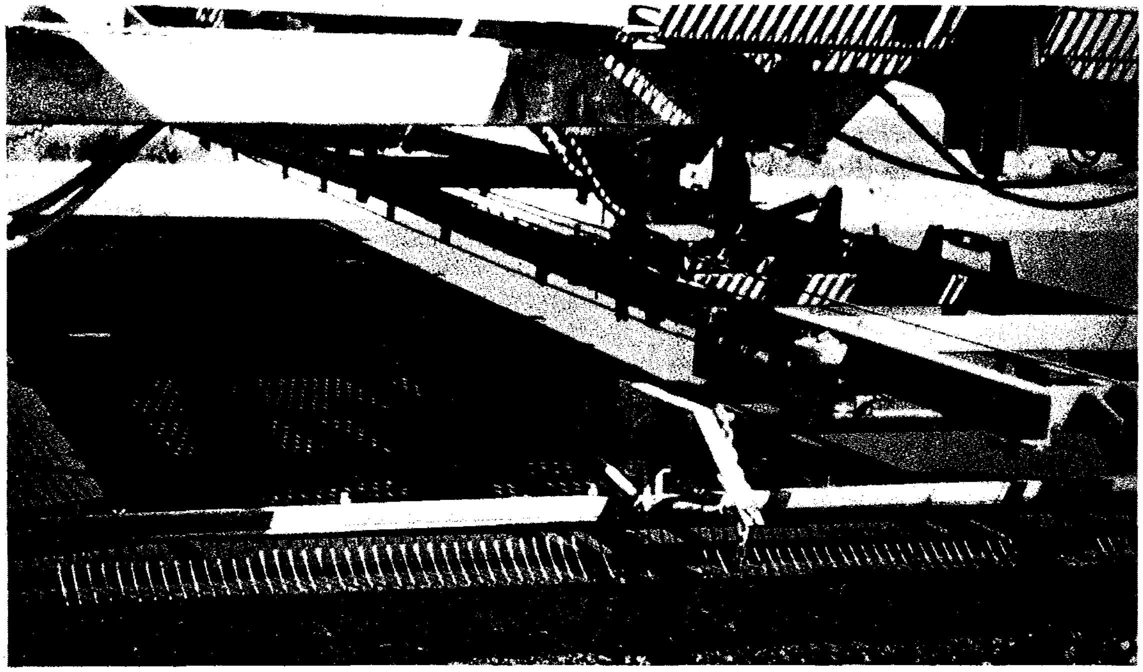

Fig. 2-8 Finishing Machine Applying Transverse Tine Finish

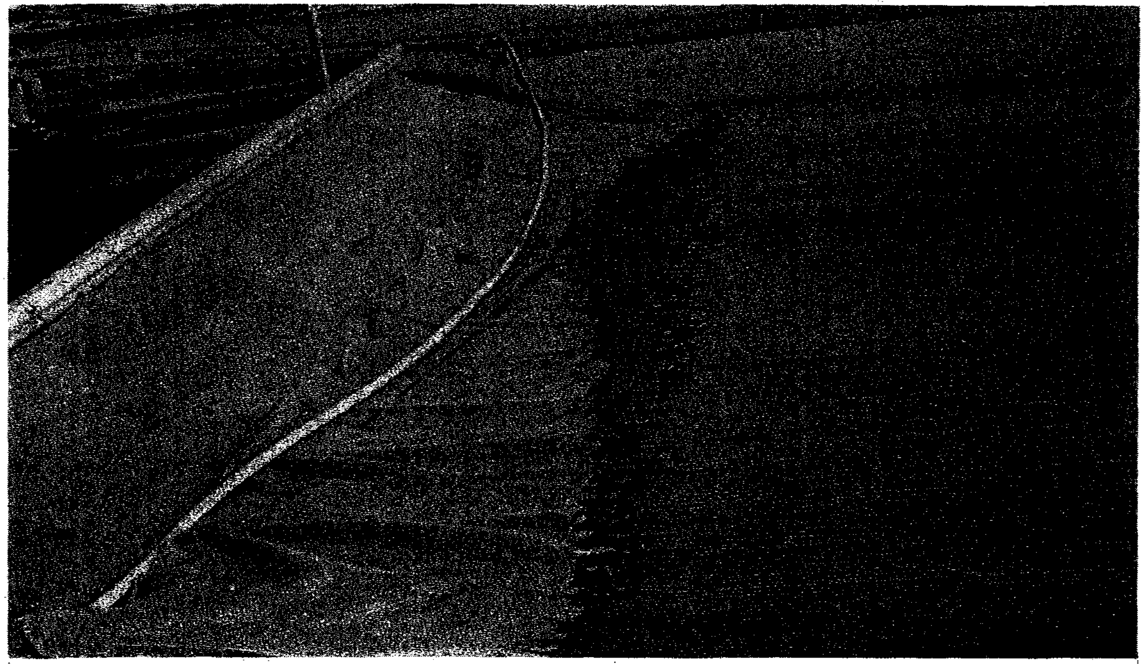

Fig. 2-9 Finishing Machine Applying Burlap Drag Finish

2.2.2 Variables

Type of Finish. The various types of finish employed on the various test sections are described in Table 2-1. Both longitudinal and transverse experimental textures as well as a longitudinal burlap drag (control) were constructed. Photographs of each surface are shown in Figs. 2-10 through 2-20.

Construction Sequence and Traffic. The test sections were constructed in September 1973 and the entire main lane pavement was constructed between August 1973 and December 1973. Following the construction of the main lanes, light construction traffic used the main lanes until the roadway was officially opened to traffic in March 1974.

The actual time for the construction of the test sections was two days. Weather during the construction period was clear, windy, and warm, ranging between 70 (night) and 100°F (day).

The traffic over the test sections averaged 6500 vehicle passes per day (VPD) in June 1974.

2.2.3 Constants

The mixes were designed under the supervision of the Texas Highway Department personnel using the absolute volume method of design with a specified cement factor and air entraining admixture. The batches were designed to produce similar strengths based on a minimum cement factor of 5 sks per cu yd, a coarse aggregate factor (CAF) of 0.78, a water cement ratio of 0.59, an air content of 4 percent, and a slump of 1 in. ± 1/2 in.

TABLE 2-1 Surface Finish Types on IH 10 Near Van Horn, Texas

Finish Type	Description	Test Section No.
Burlap Drag	A burlap drag finish is accomplished by passing a wet burlap cloth, with approximately two ft of burlap in contact with the surface until the desired texture is obtained.	F-17
Brush	Accomplished by passing a natural-bristle brush (strawlike) over the slab surface, slightly grooving the concrete. The broom is inclined at an angle of approximately 30 degrees to the surface.	F-20
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 varied from 1/8 in. to 1/4 in. (clear distance between tines).	F-15, F-16, F-18, F-19
Burlap Drag Plus Tines	Accomplished by first passing burlap drag over the section surface, followed by one pass of the 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 varied from 1/4 in. to 1.0 in. (clear distance between tines).	F-11, F-12, F-13 F-14, F-21

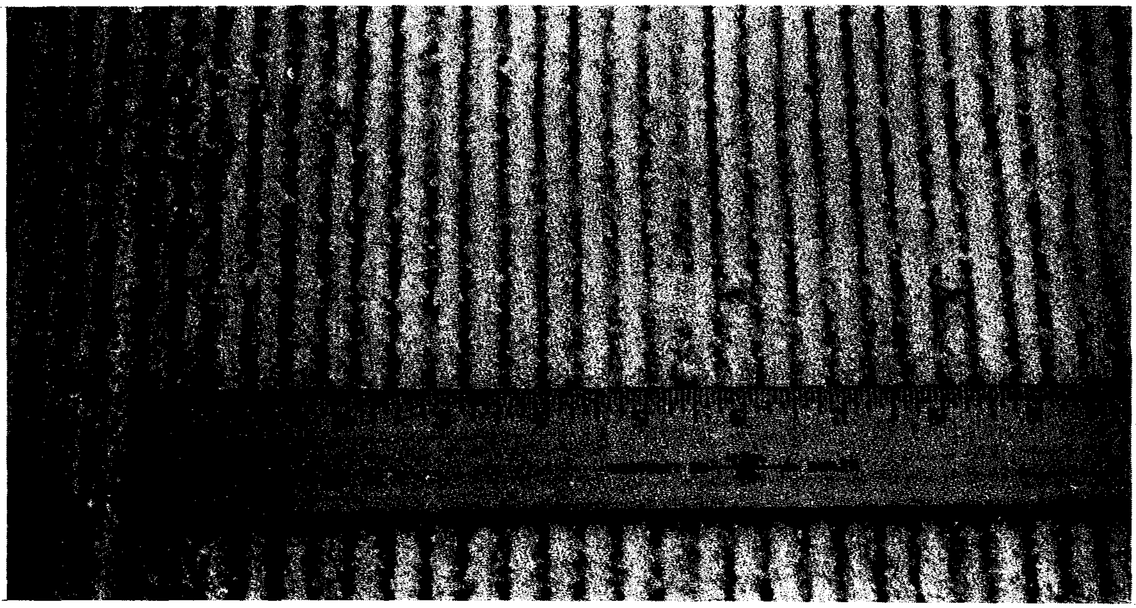

Fig. 2-10 Test Section F-11: Burlap + 1/4 in. Longitudinal Tine Finish (As Constructed)

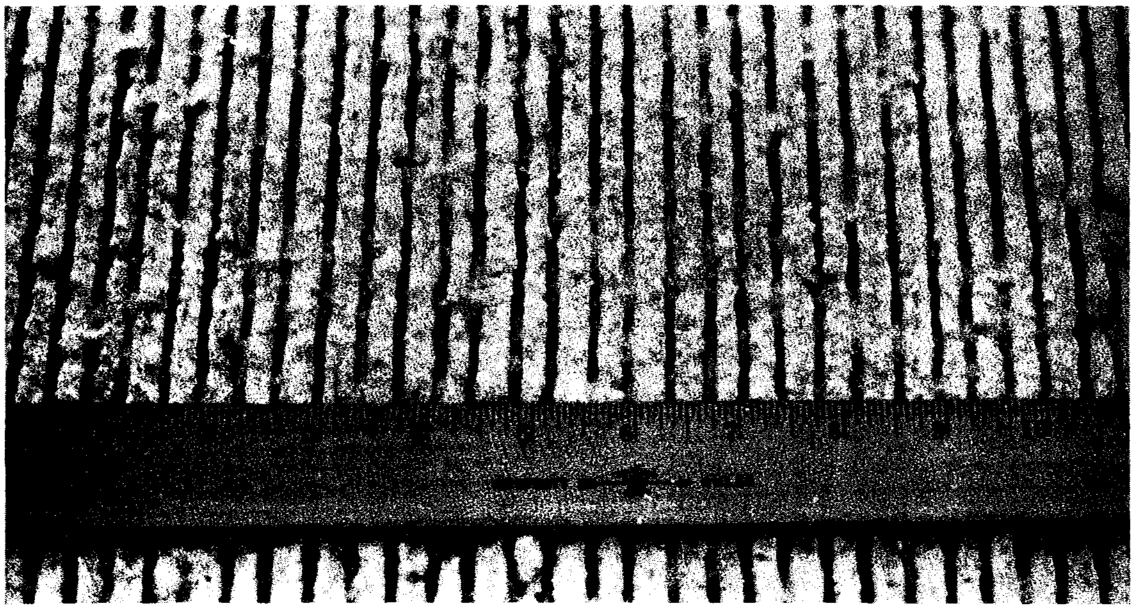

Fig. 2-11 Test Section F-12: Burlap + 1/2 in. Longitudinal Tine Finish (As Constructed)

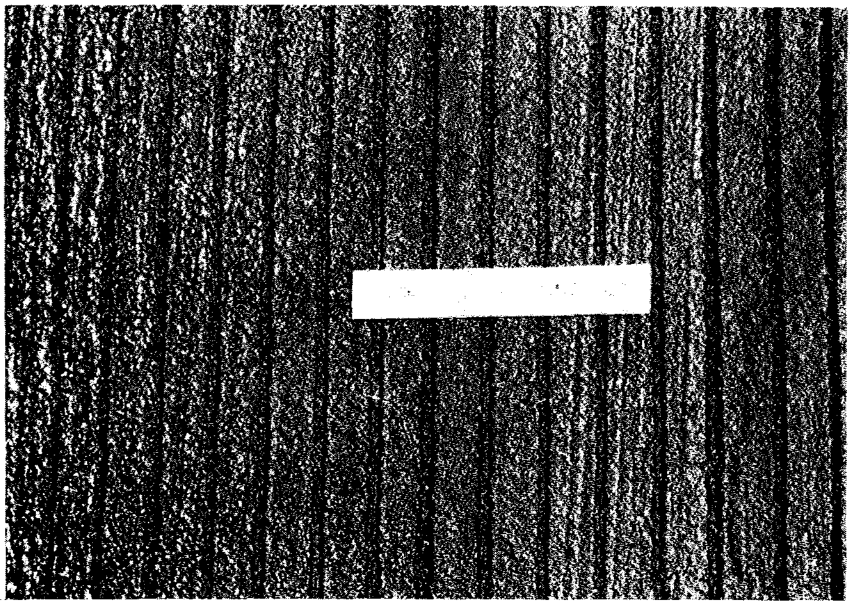

Fig. 2-12 Test Section F-13: Burlap + 1 in.
Longitudinal Tine Finish (As Constructed)

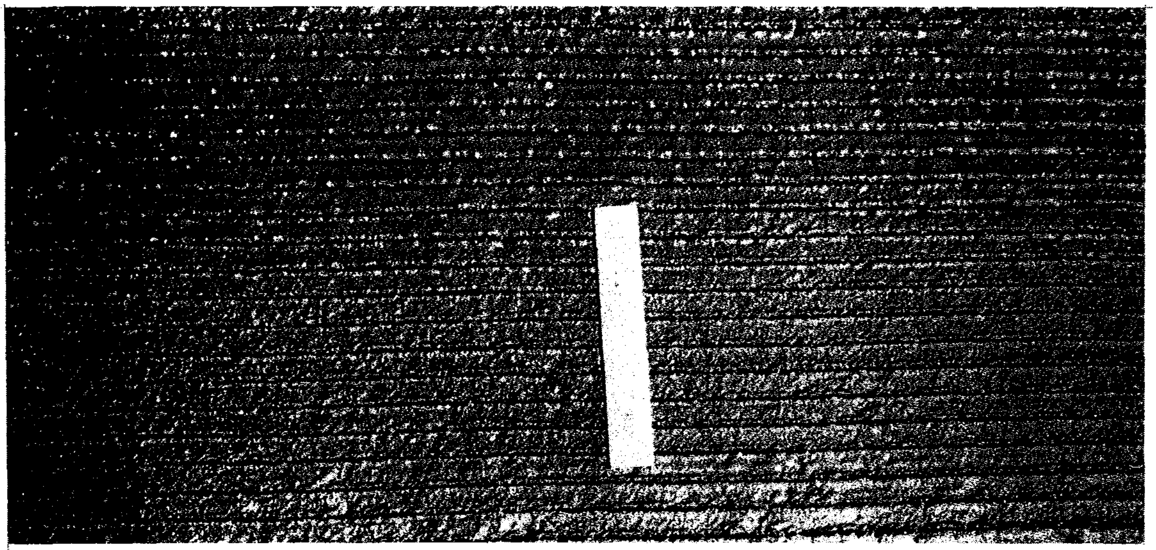

Fig. 2-13 Test Section F-14: Burlap + 3/4 in.
Longitudinal Tine Finish (As Constructed)

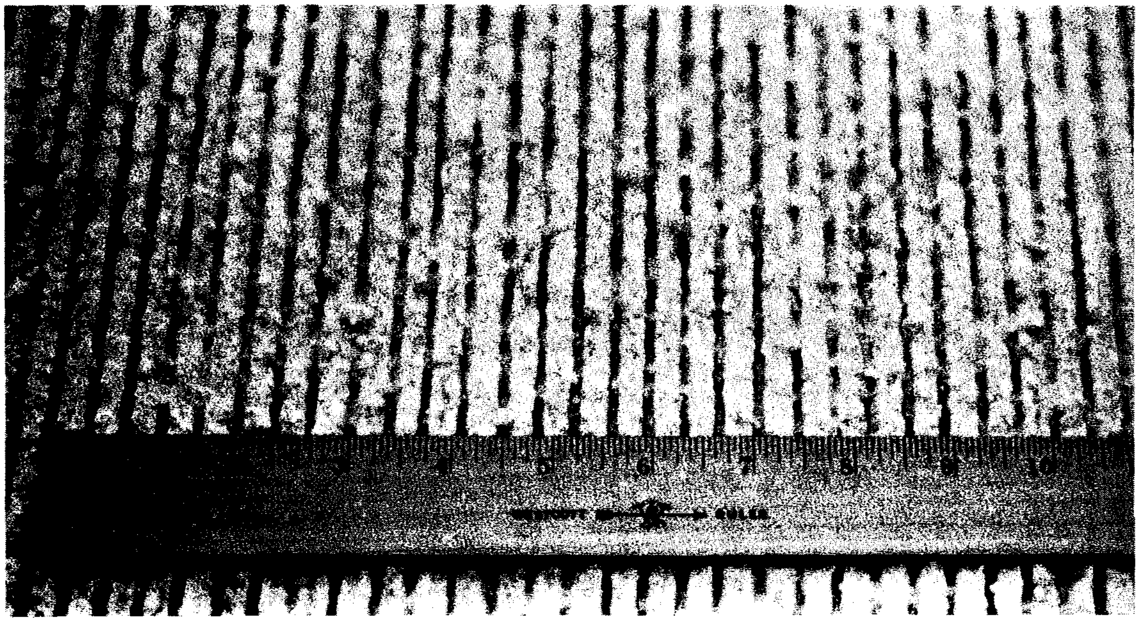

Fig. 2-14 Test Section F-15: 1/4 in. Longitudinal
Tine Finish (As Constructed)

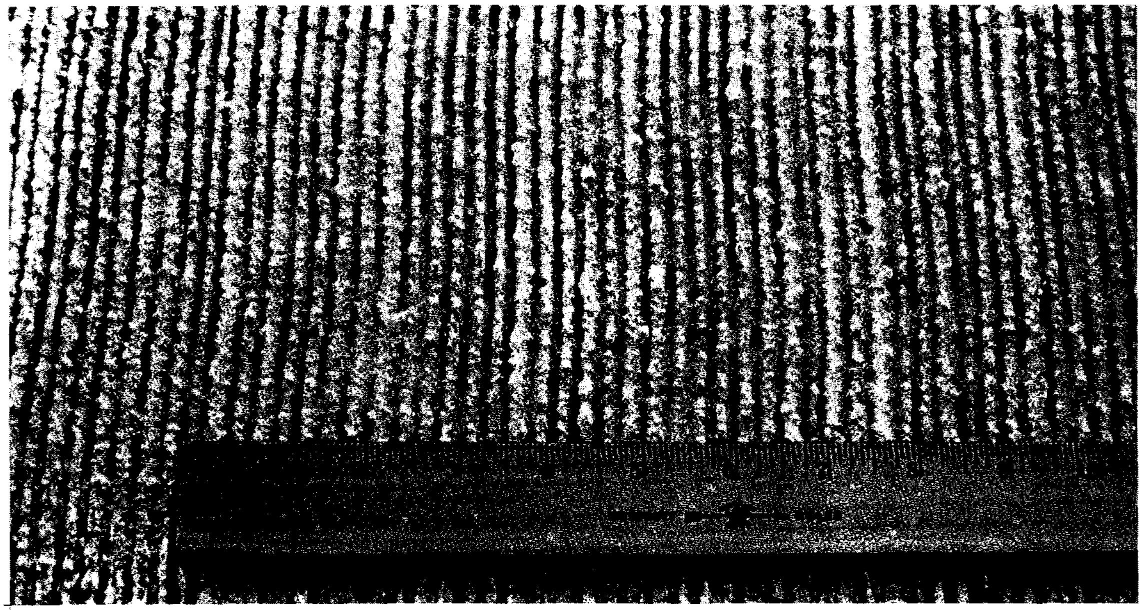

Fig. 2-15 Test Section F-16: 1/8 in. Longitudinal
Tine Finish (As Constructed)

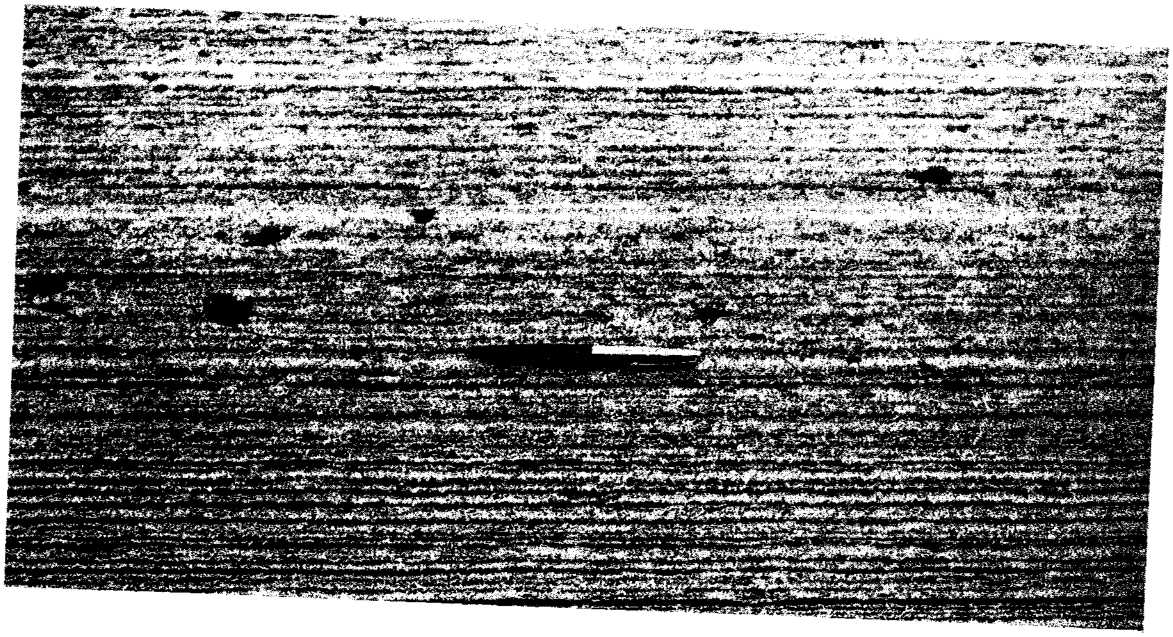

Fig. 2-16 Test Section F-17: Burlap Control Finish (As Constructed)

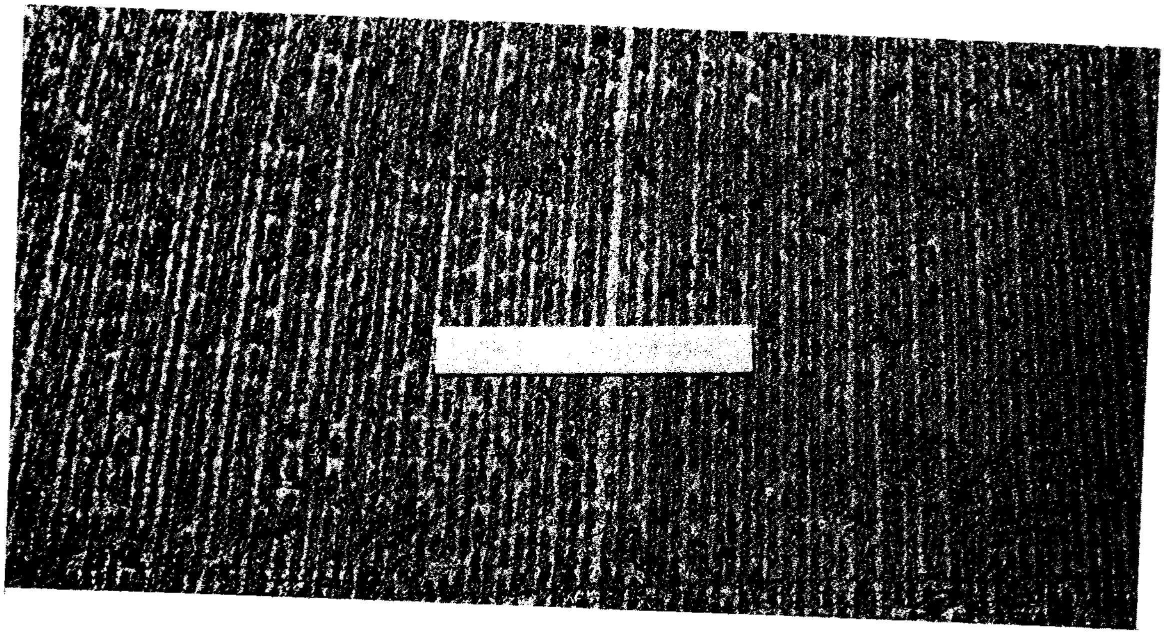

Fig. 2-17 Test Section F-18: 1/8 in. Transverse Tine Finish (As Constructed)

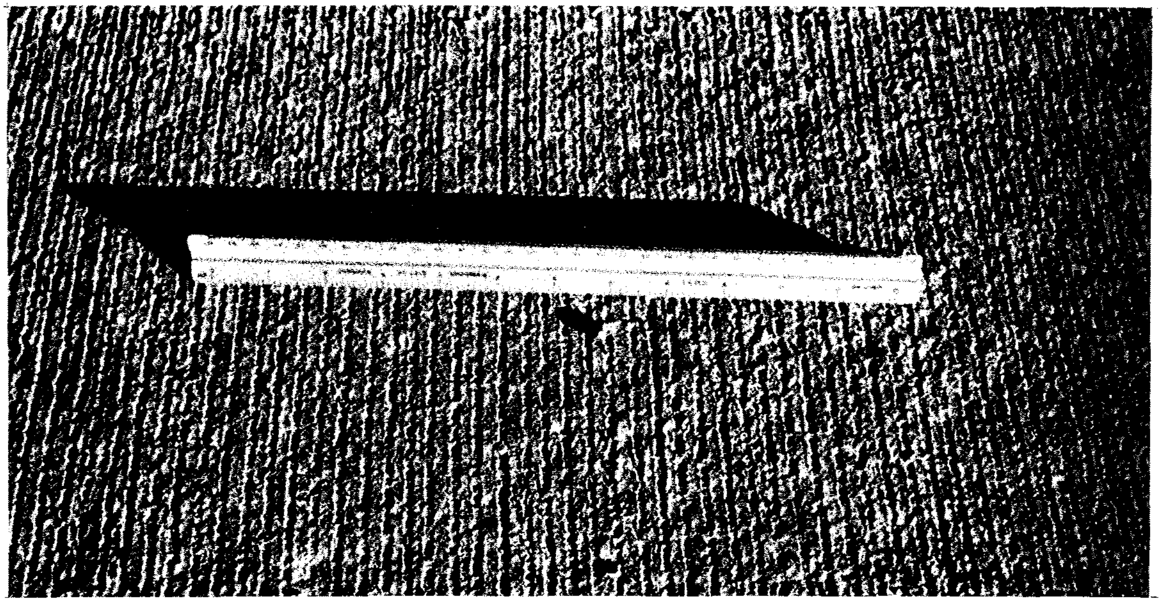

Fig. 2-18 Test Section F-19: 1/4 in. Transverse Tine Finish (As Constructed)

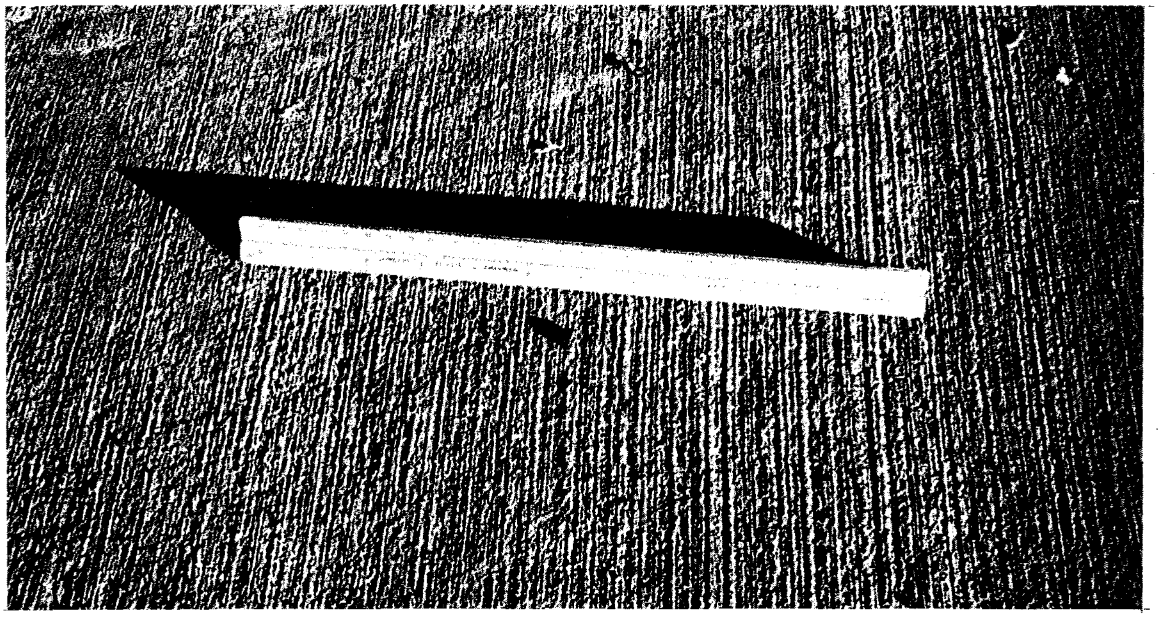

Fig. 2-19 Test Section F-20: Transverse Brush Finish (As Constructed)

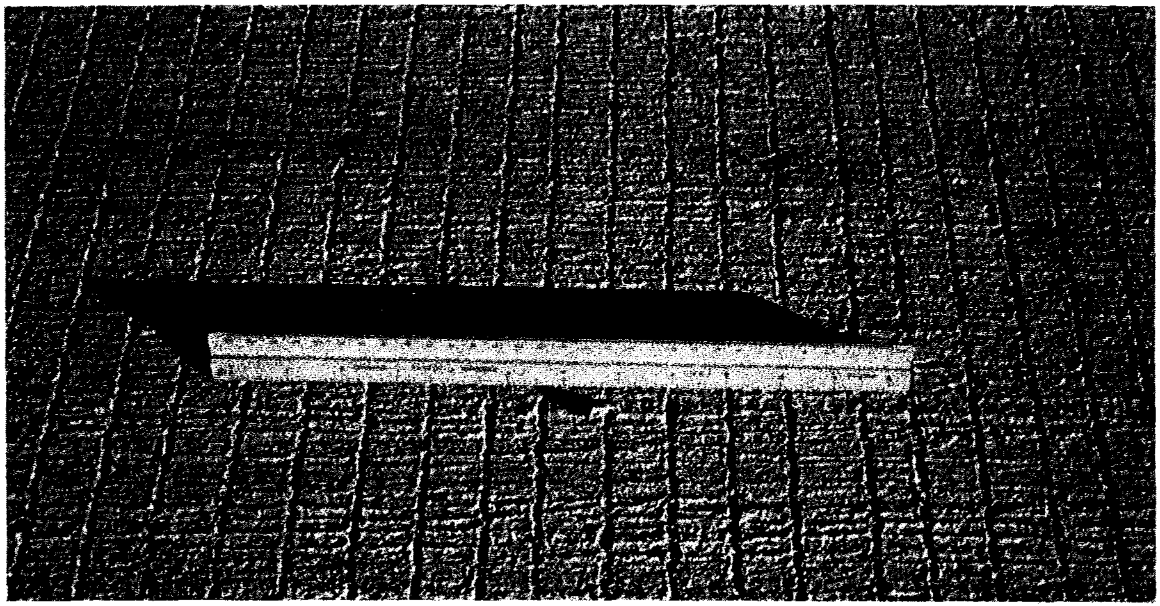

Fig. 2-20 Test Section F-21: Burlap + 1 in. Transverse Tine Finish (As Constructed)

The concrete test sections used in performing these tests were made utilizing a granitic fine and coarse aggregate produced by the Dahlstrom Corporation. Aggregate data are given in Table 4-1.

2.2.4 Control Tests

For control purposes flexural strength tests were performed on two 6 x 6 x 20 in. beams and compressive strengths were determined from three 6 x 12 in. cylinders. All specimens were made from selected batches of concrete at each test section and were tested for 7-day strength. After a minimum of 28 days, 3 cores (4 in. in dia.) were taken from each test section and subjected to the splitting tensile strength test (ASTM C496). Two tests were made on each core, one on the top 3 in. of the core, the other on the bottom 3 in.

The data are given in Section 4.2 (Table 4-2). These data were analyzed statistically and the results are given in Table 2-2. As expected the strengths of the bottom of the concrete were higher than the top (as seen by their splitting tensile strengths). All strengths were satisfactory, and quality control was "good" as defined by ACI 214-65 (7).

2.2.5 Texture Depth Measurements

Surface texture depths were determined in December 1973 after completion of the test sections, and again in July 1974. Both the Putty Impression (8) and the Sand Patch methods (Tex 436-A) (9) were used to determine the texture depths of each section. The Sand Patch test is a texture depth measurement developed by the Texas Highway Department (THD) and used as a standardized test. The Putty Impression

TABLE 2-2 Comparison of Control of Concrete Properties on IH 10 Near Van Horn, Texas

Property	Number Used in Calculation	Mean (psi)	Standard Deviation (psi)	Coefficient of Variation (%)	Control[a]
Compressive Strength (f'_c)[b], 7-day	33	2206	278	13	Good
Splitting Tensile Strength (Top)[c]	16	594	60	10	Good
Splitting Tensile Strength (Bottom)[c]	12	629	62	10	Good
Modulus of Rupture[d] (Center Pt.), 7-day	-	578	-	-	-

[a] Taken from Reference 6.

[b] ASTM C39.

[c] As determined from cored specimen, ASTM C496.

[d] ASTM C293.

test determines texture depth with a known volume of silicone putty 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.

A relationship between the Sand Patch and the Putty Impression test is described in Section 3.2. This relationship was used to compare putty impression values to sand patch values where sand patch values were not available.

2.2.6 Skid Measurements Using Standard Trailer Water

Skid measurements were made on each test section using a standard skid trailer (ASTM E274). The trailer uses a water system which sprays a thin film of water directly in front of the tire to prewet the pavement surface. Tests were made using the ASTM standard tread tires (ASTM E501) inflated to 24 psi. Further details of this test are given in references 10 and 11. Skid measurements were made at 40 mph (see Tables 4-3 and 4-4) at selected times during the period of this study. Additionally some measurements were made at 20 and 60 mph.

2.2.7 Skid Measurements Under Simulated Rainfall

Skid measurements were also made utilizing the standard skid trailer under simulated rainfall conditions. The rain simulator is shown in Fig. 2-21 (12).

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 the manifold with 2 in. diameter pipes used as feeder lines for the nozzles.

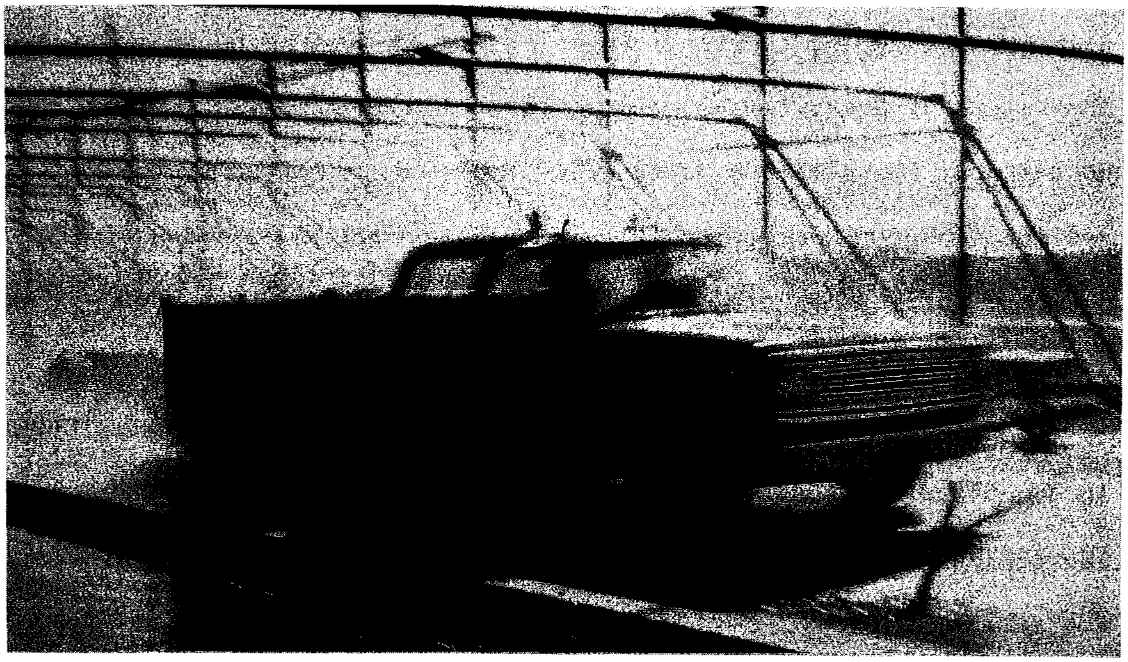

Fig. 2-21 Rain Simulator and Skid Trailer

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 well near the batch plant equipped with a high pressure pump was used for supplying water through irrigation pipe to the system. Water depths were measured at various distances along the wheel paths.

Rainfall intensities were measured and recorded at several locations along the center of the lane using a rain gauge.

Water depth measurements were taken with a Leopold 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.

Skid measurements were made at speeds of 20, 40, and 60 mph using both the standard ASTM treaded tire (ASTM E501), and the same type tire ground smooth to remove all tread (termed "bald" in this report). The data are given in Tables 4-5 and 4-6.

3. DISCUSSION OF RESULTS TO DATE

3.1 General

The results of the research on concrete textures for highway surfaces were obtained from six sections of SH 6 in College Station, Texas and eleven sections of IH 10 near Van Horn, Texas. Although the coarse aggregate type, mix design, and curing environment were different for the two locations, these differences are not believed to influence the results discussed in this chapter.

3.2 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 used.

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

$$TXD_{sp} = 0.8185\ TXD_{pi} \quad . . . . \quad (3\text{-}1)$$

with a correlation coefficient squared = .96

where: TXD_{sp} = Sand Patch value
TXD_{pi} = Putty Impression value

This equation is graphically portrayed in Fig. 3-1.

For SH 6, texture depth measurements were taken at various intervals between December 1971 and July 1974. Complete data are given in Table 4-3. 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. Table 3-1 shows the effect of the texture method on both initial texture and worn texture. The table was constructed of the mean values from each test section on SH 6. The texture depth changes with time are shown in Fig. 3-2. Note the texture depths decrease rapidly at first and then appear to level off.

Evaluation of each surface finish on IH 10 was conducted essentially the same. The initial textures were measured in December 1973, prior to any traffic movement. The second measurements were made in July 1974 after the eleven different textures had been subjected to approximately 3 months of construction traffic and 5 months of public traffic. Texture data are given in Table 3-2 and graphically portrayed in Fig. 3-3.

The average wear down for the SH 6 textures was 32 percent (Table 3-1) which is in substantial agreement with data taken from

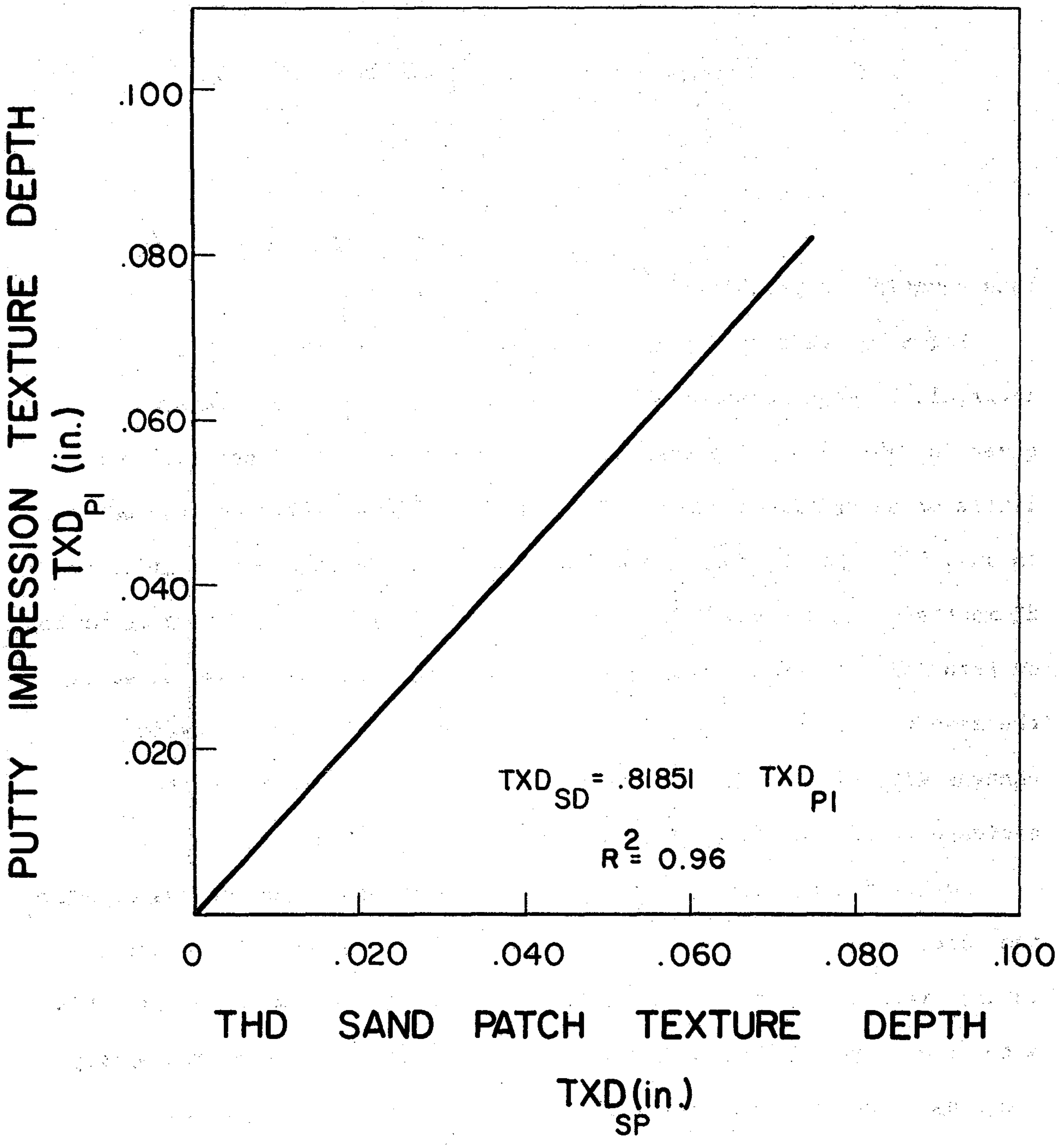

Fig. 3-1 Relationship Between
Putty Impression Test and THD
Sand Patch Test

TABLE 3-1 Texture Depths on SH 6 Sections

Test Section	Texture Depth (in.)[a] Dec. 71[b]	Texture Depth (in.)[a] June 74	Percent Loss Over 30-Month Period
F-1 Transverse Broom	.057	.030	47
F-2 1/8 in. Transverse Tines	.064	.050	22
F-3 Longitudinal Broom	.036	.018	50
F-4 1/8 in. Longitudinal Tines	.093	.051	45
F-5 Burlap + 1/8 in. Longitudinal Tines	.083	.062	25
F-6 Burlap Drag (Control)	.028	.023	18
F-7 Transverse Brush	.031	.026	16

[a] Sand patch values (Tex 436-A).

[b] Calculated from putty impression measurements (see Section 3.2).

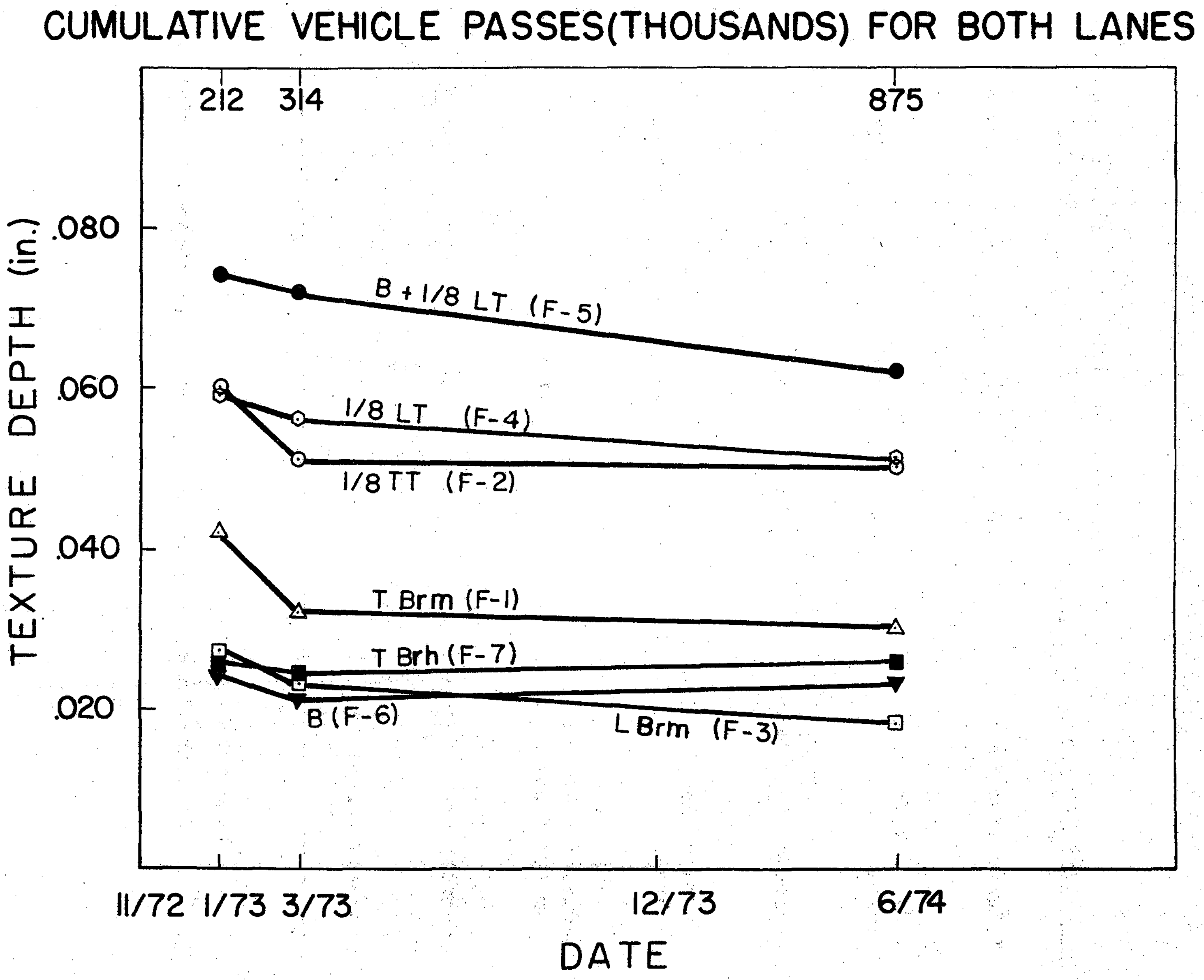

Fig. 3-2 Average Texture Depths at Various Times on SH 6 in College Station

TABLE 3-2 Texture Depths on IH 10 Sections

Test Section	Texture Depth (in.)[a] Dec. 73	Texture Depth (in.)[a] July 74	Percent Loss Over 7 Month Period
F-11 Burlap + 1/4 in. Longitudinal Tines	.070	.053	24
F-12 Burlap + 1/2 in. Longitudinal Tines	.061	.045	26
F-13 Burlap + 1 in. Longitudinal Tines	.045	.029	36
F-14 Burlap + 3/4 in. Longitudinal Tines	.052	.033	36
F-15 1/4 in. Longitudinal Tines	.049	.031	37
F-16 1/8 in. Longitudinal Tines	.065	.029	55
F-17 Burlap Drag (Control)	.027	.025	7
F-18 1/8 in. Transverse Tines	.052	.028	46
F-19 1/4 in. Transverse Tines	.031	.020	35
F-20 Transverse Brush	.022	.014	36
F-21 Burlap + 1 in. Transverse Tines	.031	.019	39

[a] Sand patch values (Tex 436-a).

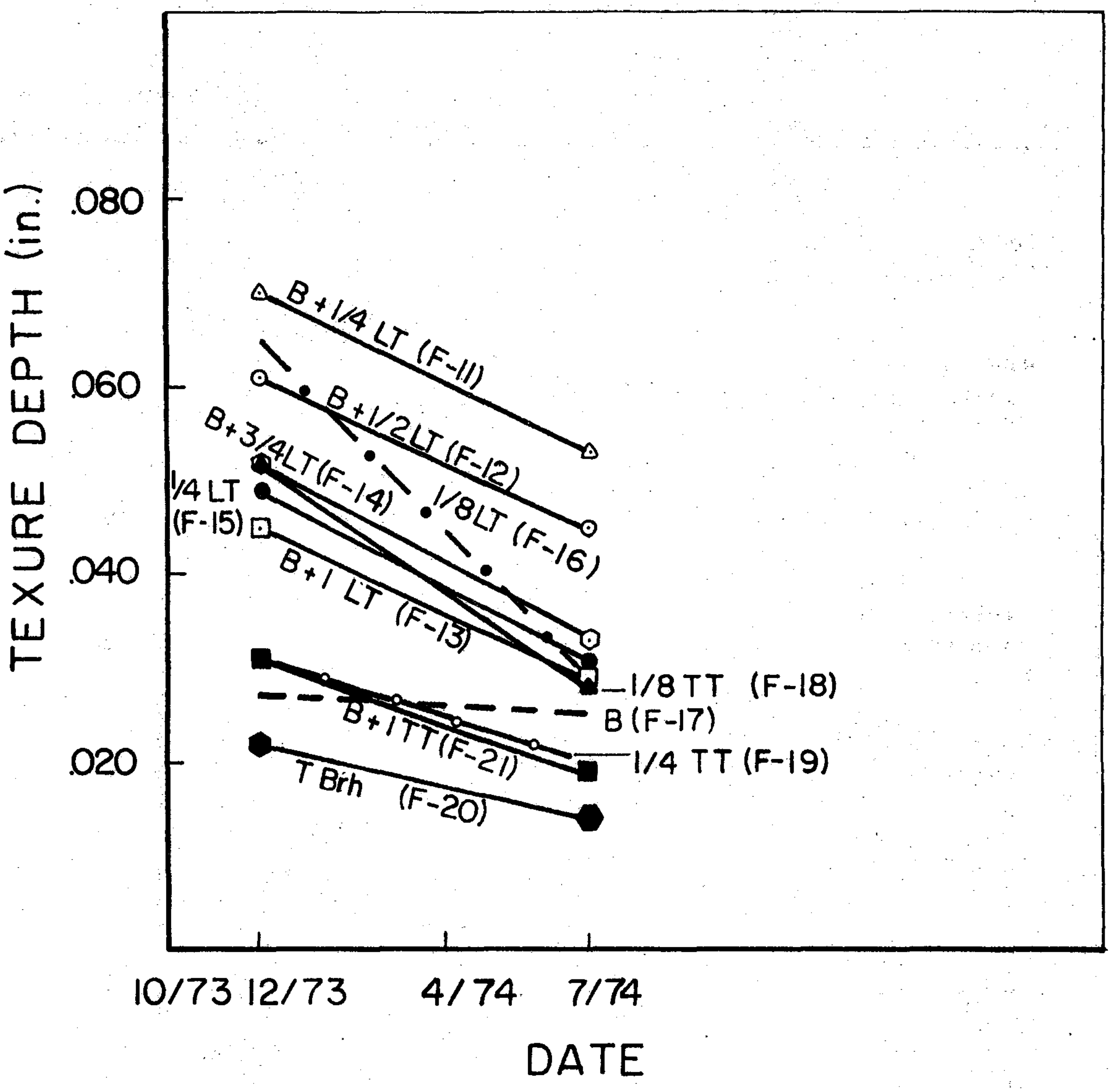

Fig. 3-3 Average Texture Depths at Various Times on IH 10 Near Van Horn

accelerated wear testing of 98 laboratory constructed concrete finishes on the Texas Highway Department circular test track. The average wear-down of these 98 surfaces was 24 percent with a standard deviation of 13 percent.* The average wear-down for the IH 10 textures was 34 percent (Table 3-2). Therefore it can be concluded that concrete pavement textures, regardless of the type, may be expected to wear-down a minimum of 25 to 35 percent under normal traffic conditions, based on initial texture depth.

Examination of the texture depths at both test section sites reveals that the SH 6 textures (Fig. 3-1) were initially deeper than corresponding textures on IH 10 (Fig. 3-2) and, initially, longitudinal tine textures were deeper than transverse tine textures. These differences are believed to be due to environment and to construction techniques. SH 6 was constructed in the fall of the year under almost ideal conditions (70°F) and the concrete remained plastic for a relatively long time. IH 10 was constructed under hot (100°F), windy, conditions and the concrete achieved its initial set fairly rapidly. Hence the IH 10 textures are all somewhat lower than the SH 6 textures. Concerning construction techniques, longitudinal texturing could proceed at the same pace as the paver without difficulty, whereas transverse texturing often was delayed. The primary reason for the delay was the fact that the finishing machine was also the curing machine and finishing had to be suspended while curing compound was being applied. Several times on IH 10 excessive delays were encountered. These conditions existed

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*Unpublished data from Study 1-8-68-126 by the Texas Highway Department.

solely because all textures were experimental. If any of the textures were selected as a standard, and the contractor required to have separate machines for finishing and curing, then no significant differences in texture depths should result between longitudinal and transverse texturing.

3.3 Skid Measurements Under Standard Conditions

For the SH 6 test sections, the variations in skid resistance at 40 mph with time are shown in Figs. 3-4 and 3-5. The data are given in Table 4-3. 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 the burlap control. Since the outside lane has experienced the greatest traffic volumes, the associated texture behavior is believed to be the more significant (Fig. 3-4), and on the outside lanes all texture wear appears to be leveling off with values higher than the burlap finish.

On IH 10, only two skid resistance measurements have been made (Table 4-4), and the results are portrayed in Figs. 3-6 and 3-7. As these sections are still relatively new, the longer term behavior of the IH 10 test sections is unknown at this time.

3.4 Skid Measurements Under Simulated Rainfall

Skid measurements under simulated rainfall conditions on the SH 6 test sections are summarized in Fig. 3-8 and 3-9. The data are given in Table 4-5. Under rainfall of approximately 1.5 in. per hr (Fig. 3-8), all of the experimental textures exhibited higher skid resistances (10 to 20 skid numbers) than the burlap control, although skid gradients were

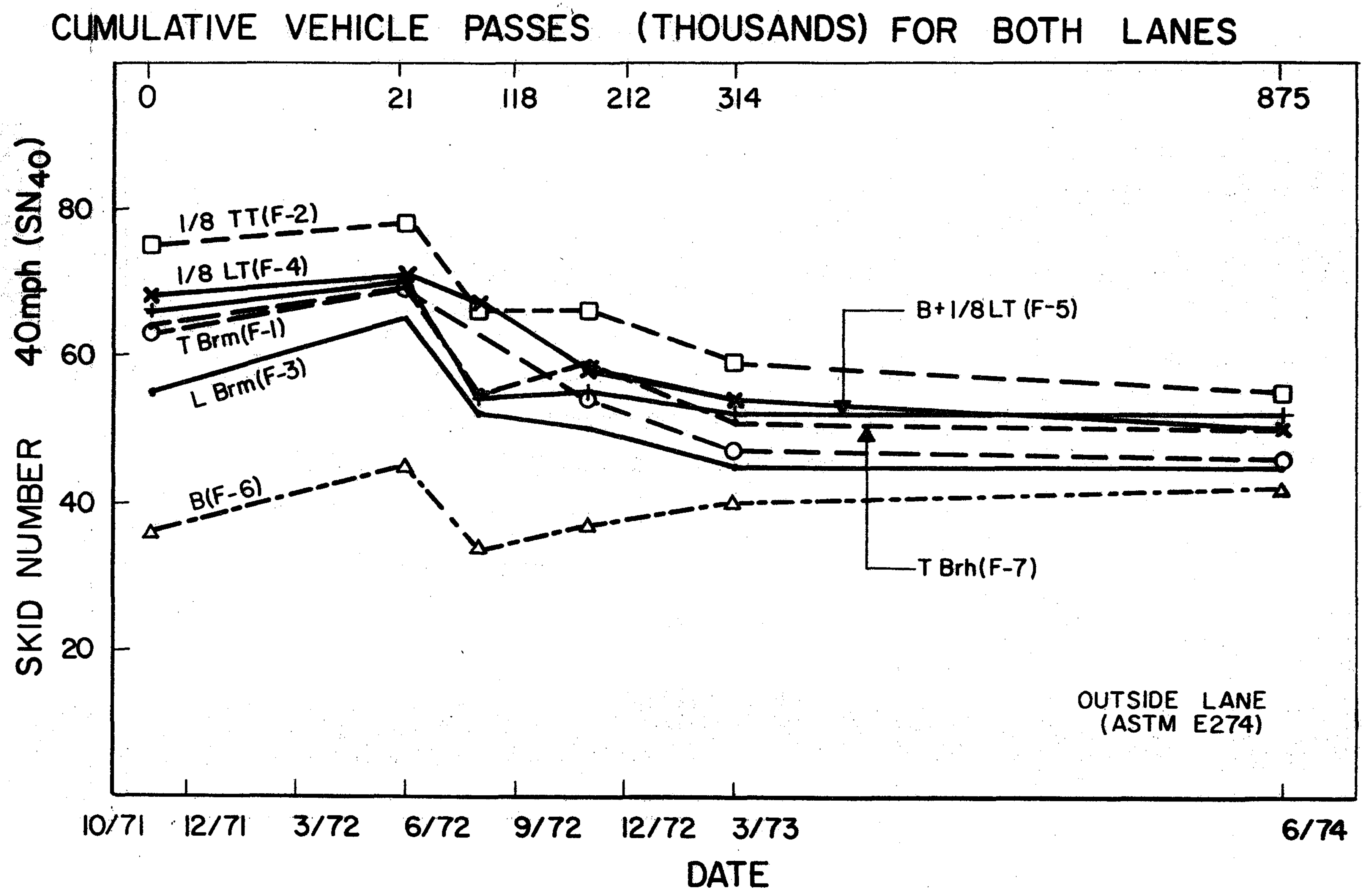

Fig. 3-4. Skid Measure Results at 40 MPH on the Outside Lane of SH 6 in College Station

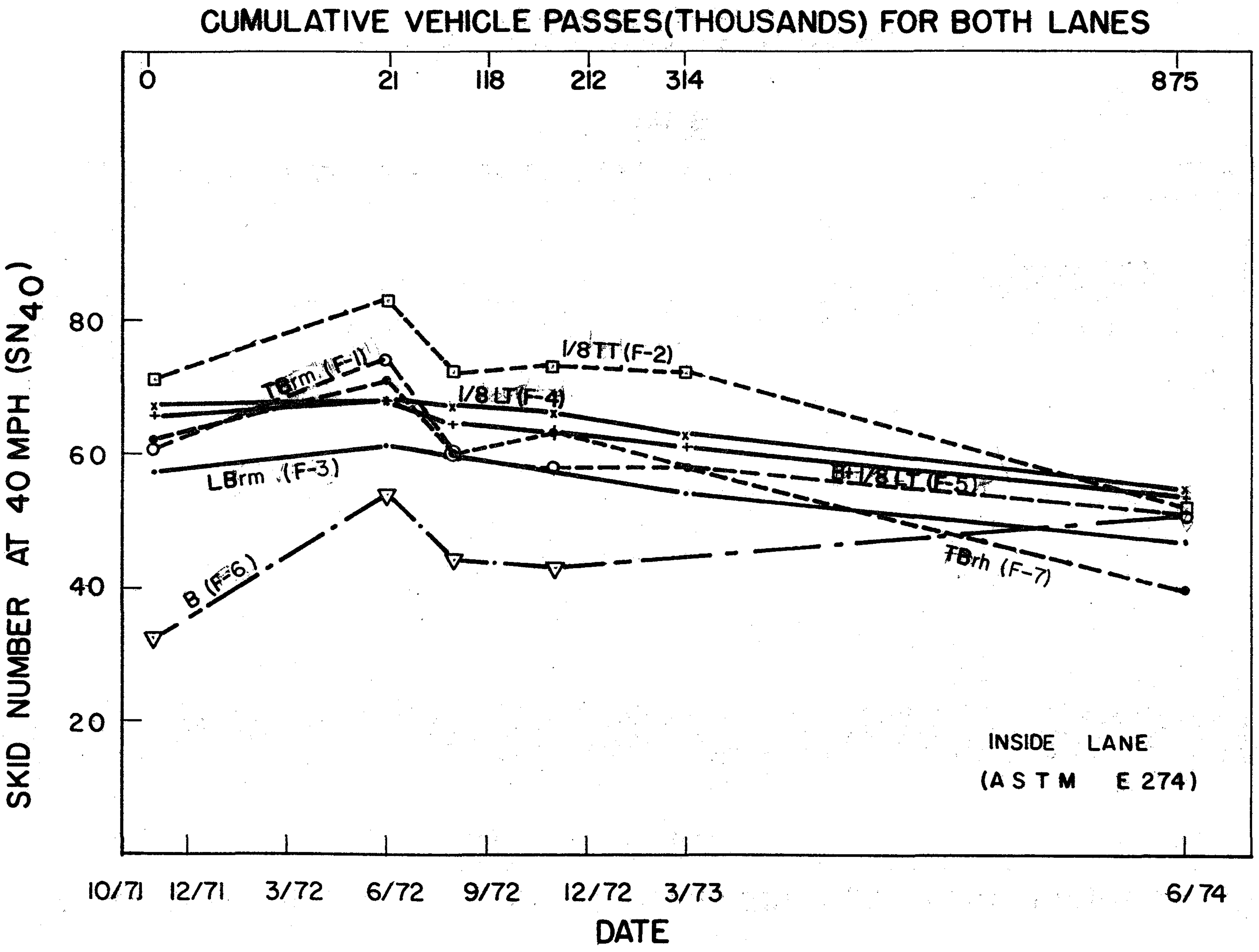

Fig. 3-5 Skid Measurements at 40 MPH on the Inside Lane of SH 6 in College Station

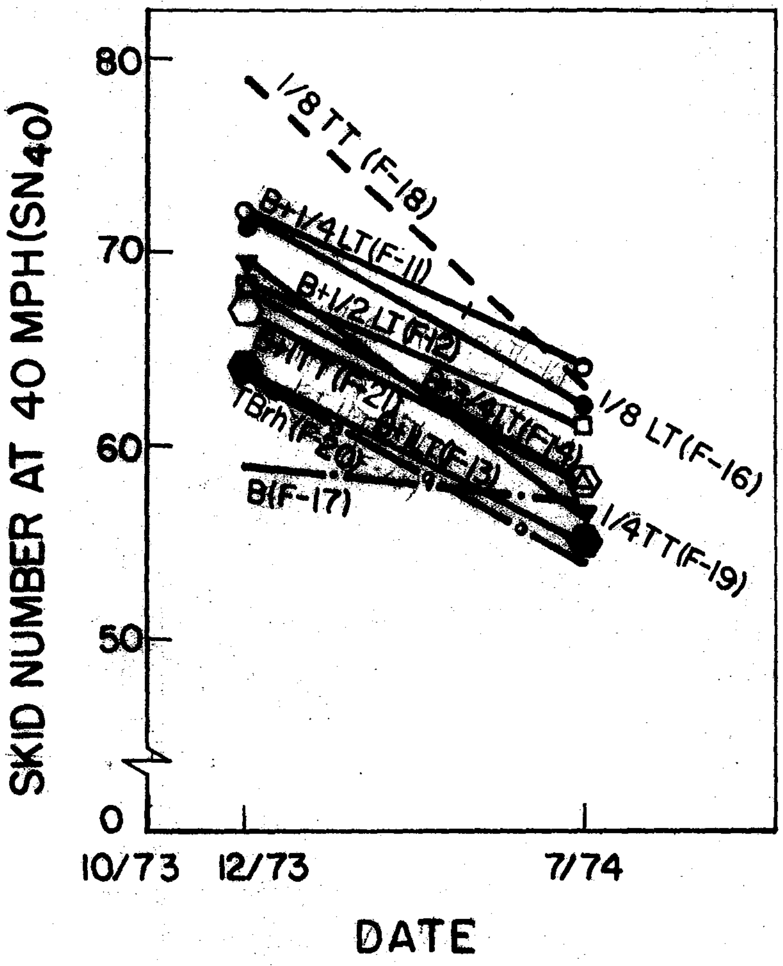

Fig. 3-6 Skid Measurements at 40 MPH on the Outside Lane of IH 10 near Van Horn

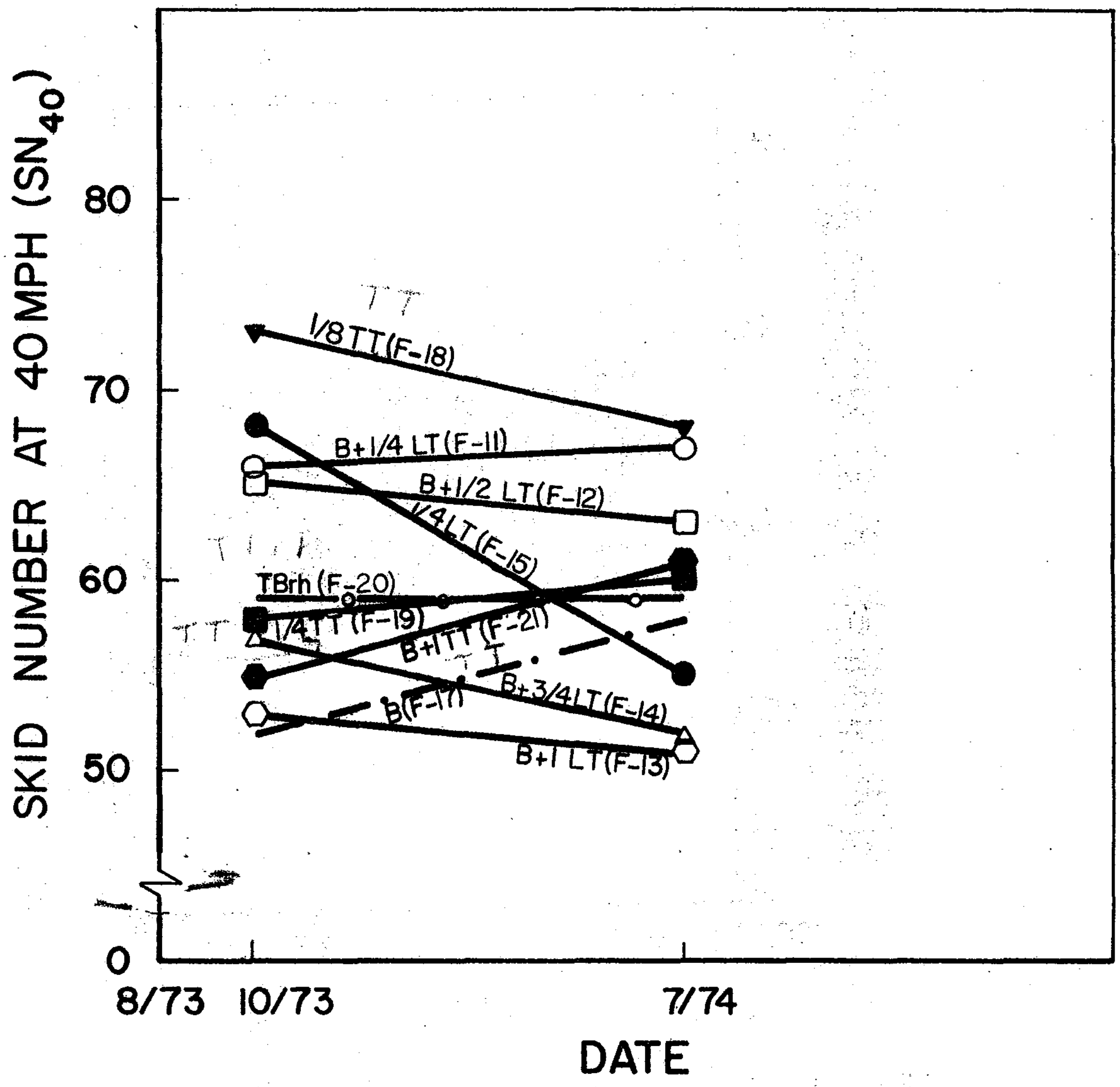

Fig. 3-7 Skid Measurements at 40 MPH on the Inside Lane of IH 10 near Van Horn

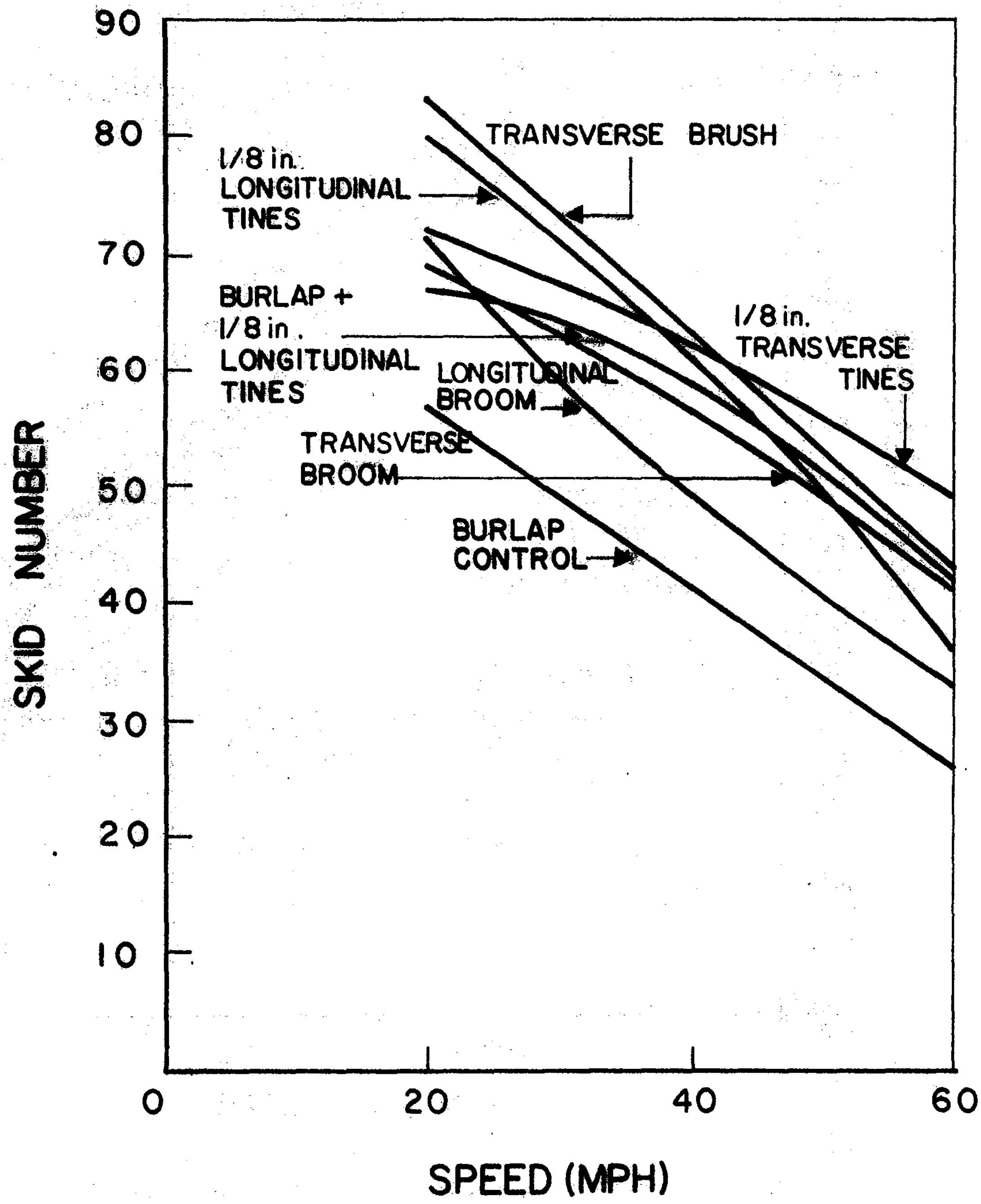

Fig. 3-8 Effect of Vehicle Speed on Skid Values of SH 6 Test Sections under Simulated Light Rainfall

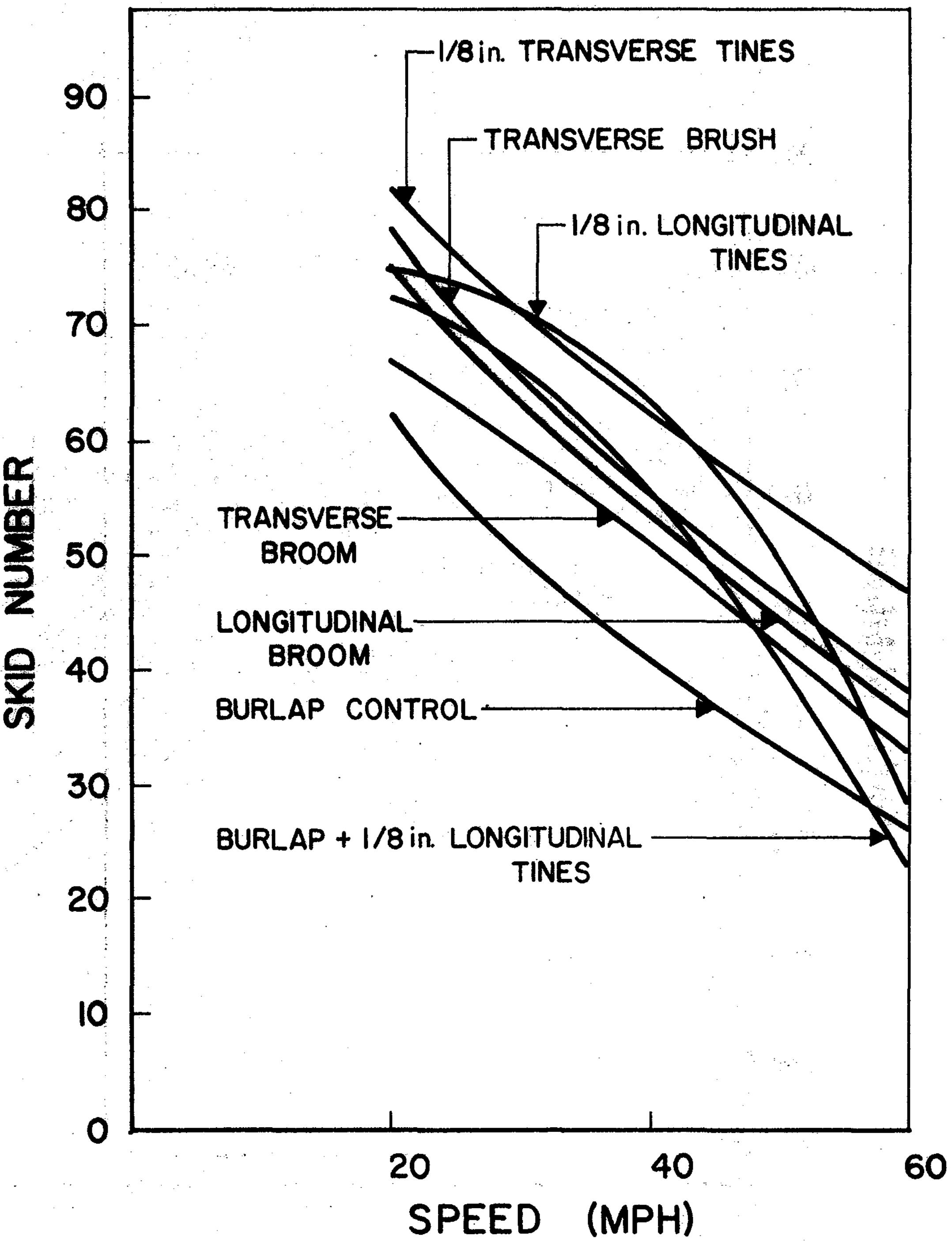

Fig. 3-9 Effect of Vehicle Speed on Skid Values of SH 6 Test Sections under Simulated Heavy Rainfall

similar (around 0.6 SN drop per mph). Under rainfall of approximately 6 in. per hr, the beneficial skid effects of the deeper textures were somewhat masked, especially at higher speeds (Fig. 3-9). A more complete discussion of these figures can be found in Research Report 141-2 (6).

For the IH 10 test sections, skid measurements under simulated rainfall are given in Fig. 3-10 through Fig. 3-19 for each test section on IH 10.* The data are given in Table 4-6. For comparison purposes, skid values using standard trailer water are also shown. These data and figures show that at elevated speeds (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 which had neither been worn nor contaminated by road films, etc. If worn pavements had been used, lower skid values would be expected.

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 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 (13).

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*Test Section F-15 is omitted because it is only on the inside lane and the rain simulator could be used on only the outside lanes.

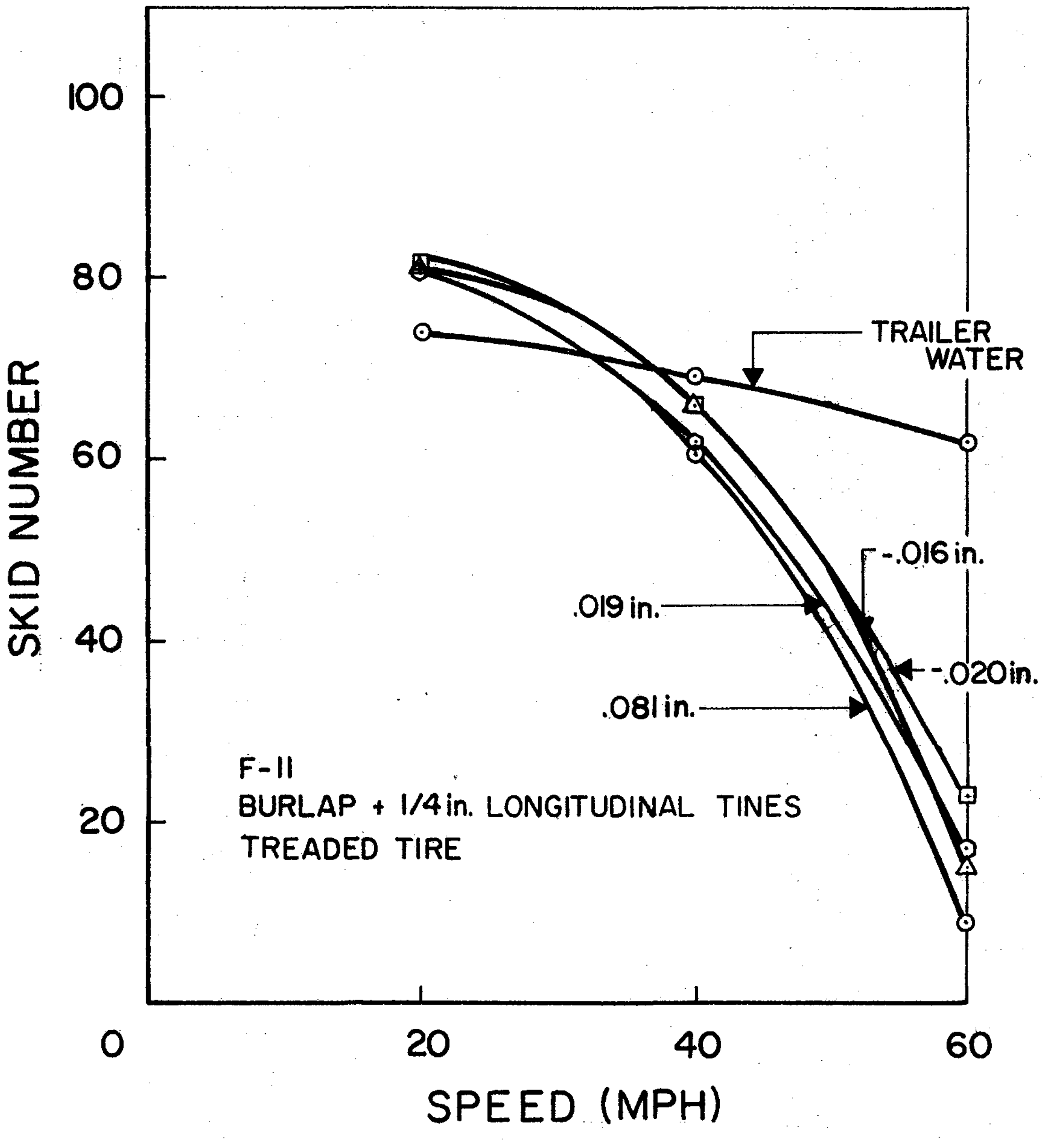

Fig. 3-10 Effect of Vehicle Speed on Skid Values of Section F-11 on IH 10 Under Simulative Rainfall

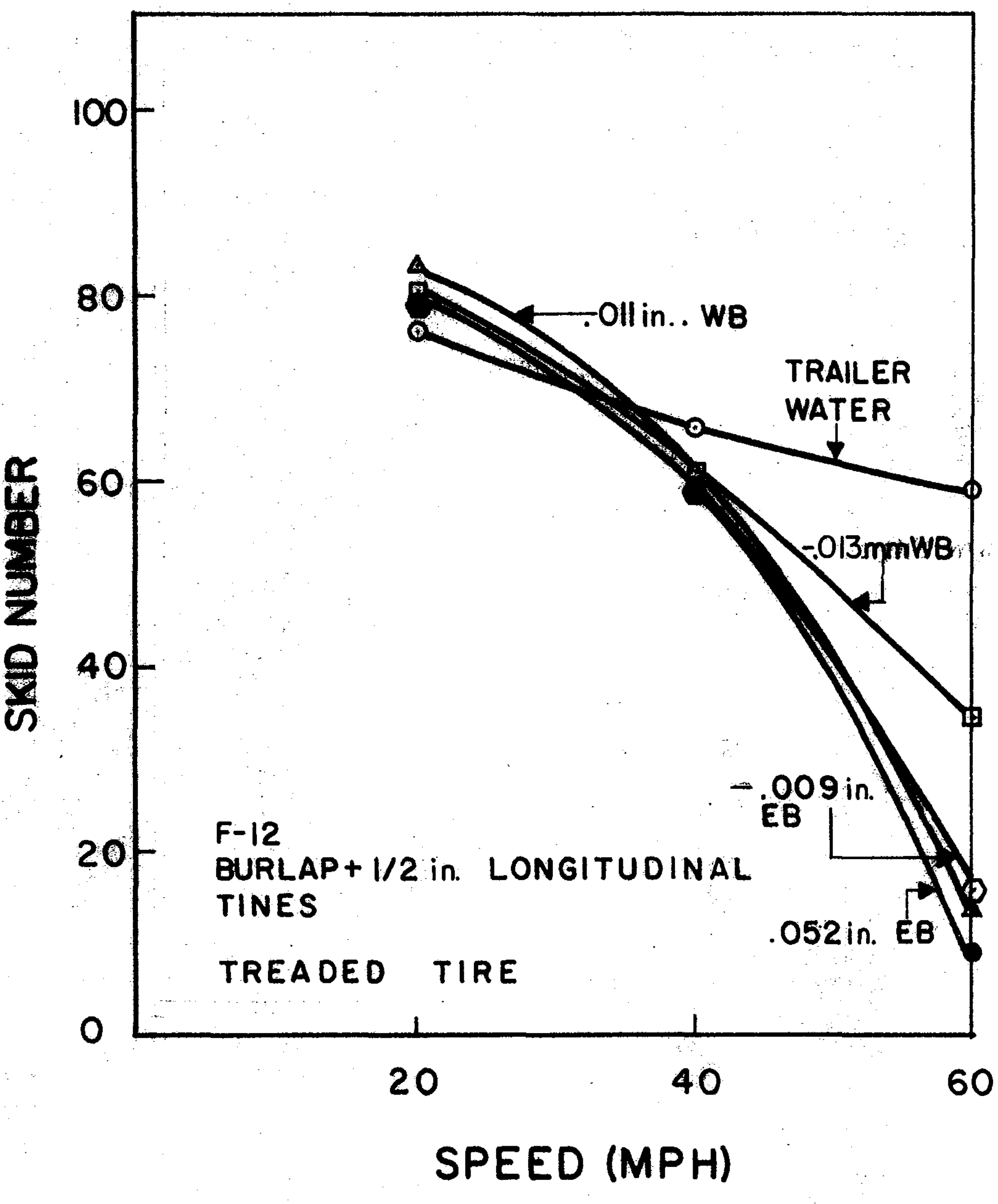

Fig. 3-11 Effect of Vehicle Speed on Skid Values of Section F-12 on IH 10 Under Simulated Rainfall

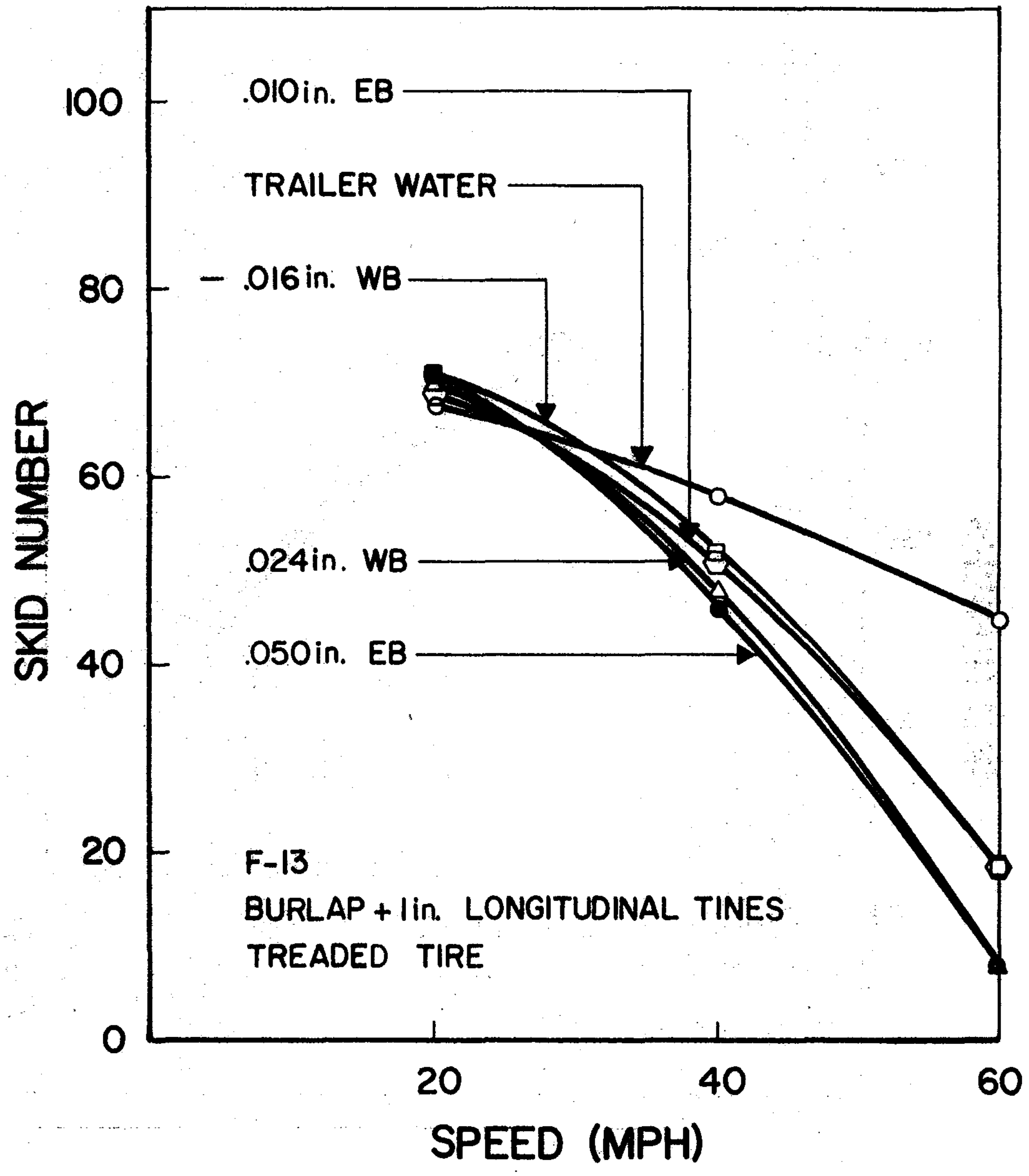

Fig. 3-12 Effect of Vehicle Speed on Skid Values of Section F-13 on IH 10 Under Simulated Rainfall

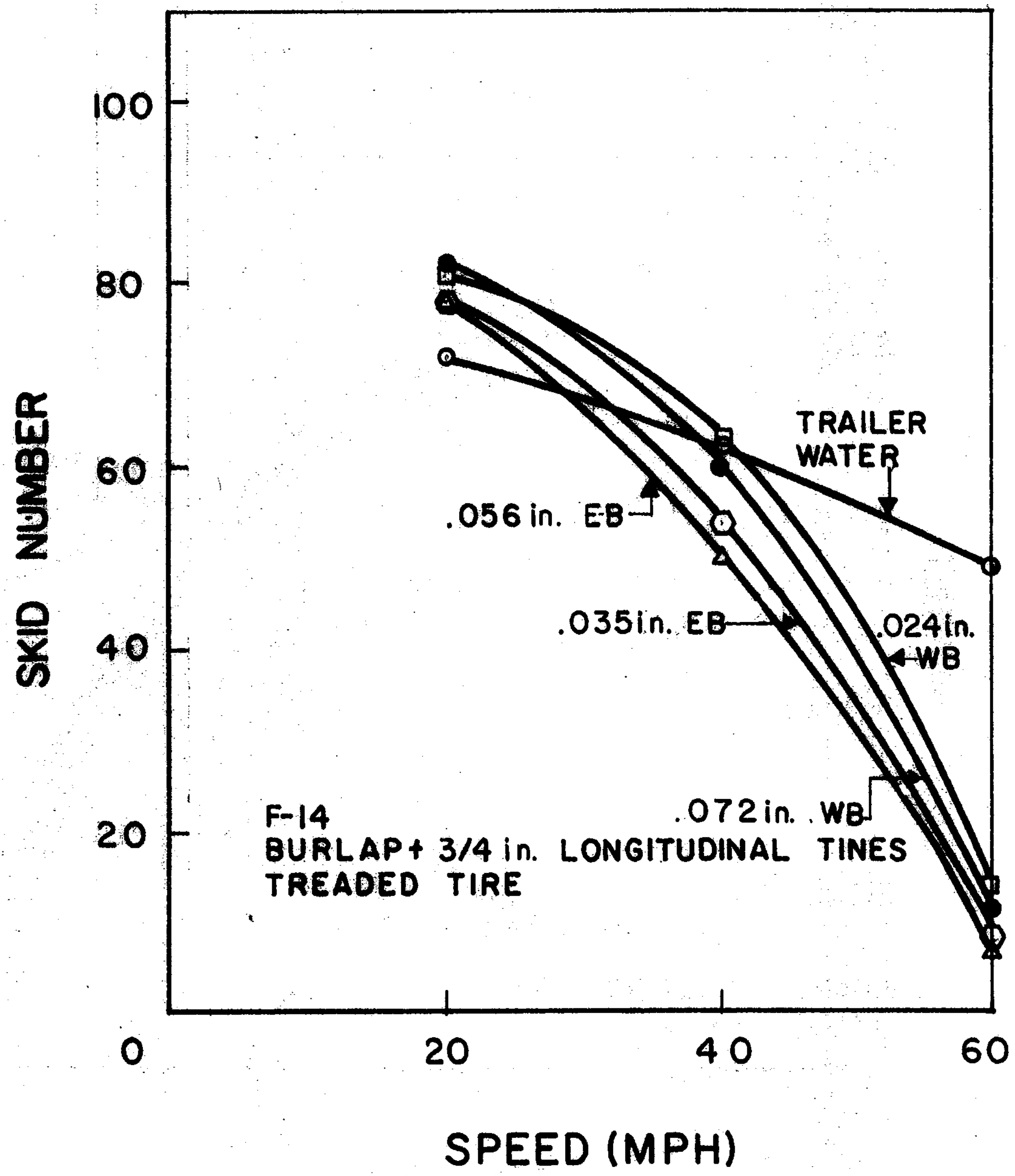

Fig. 3-13 Effect of Vehicle Speed on Skid Values of Section F-14 on IH 10 Under Simulated Rainfall

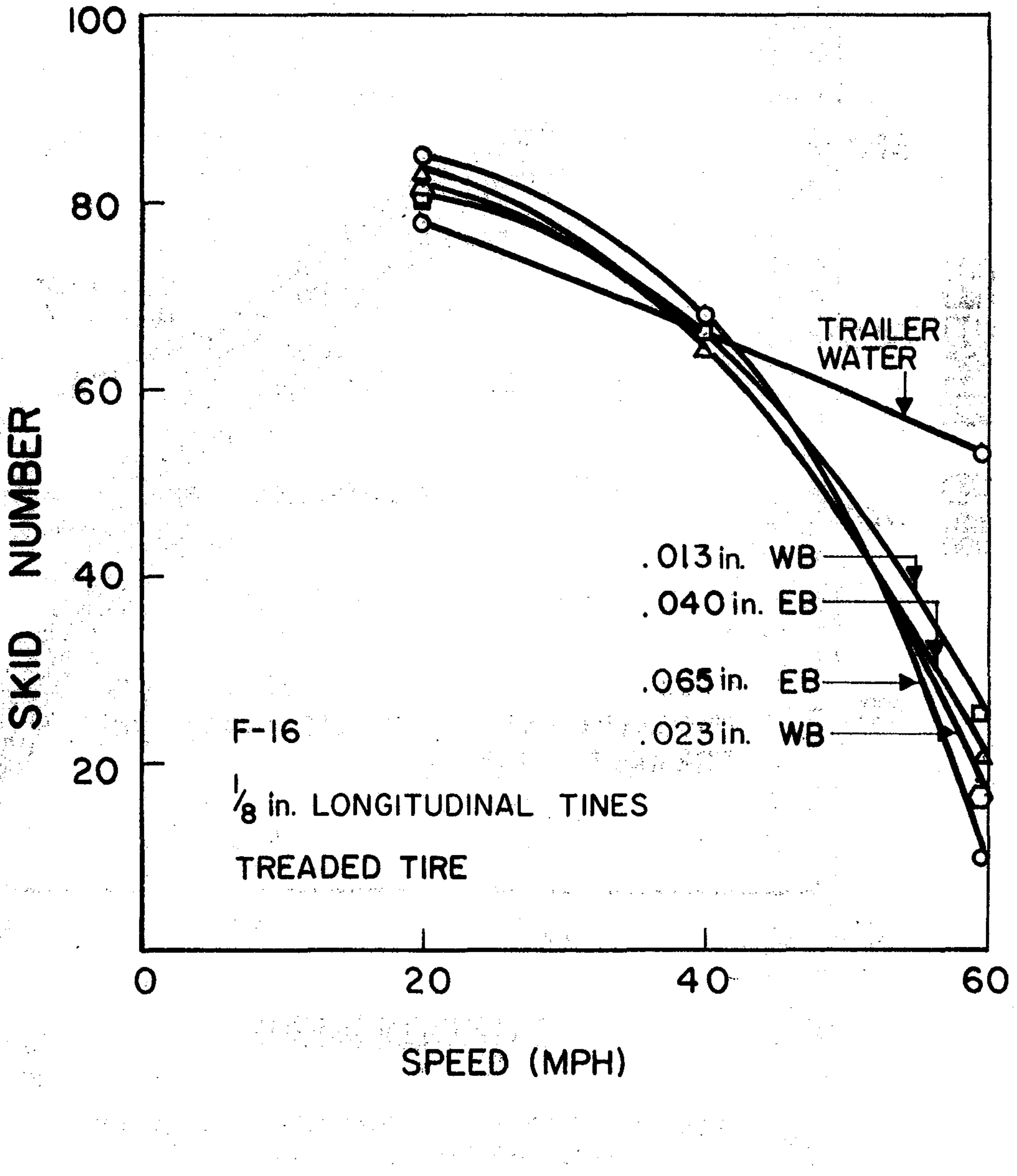

Fig. 3-14 Effect of Vehicle Speed on Skid Values of Section F-16 on IH 10 Under Simulated Rainfall

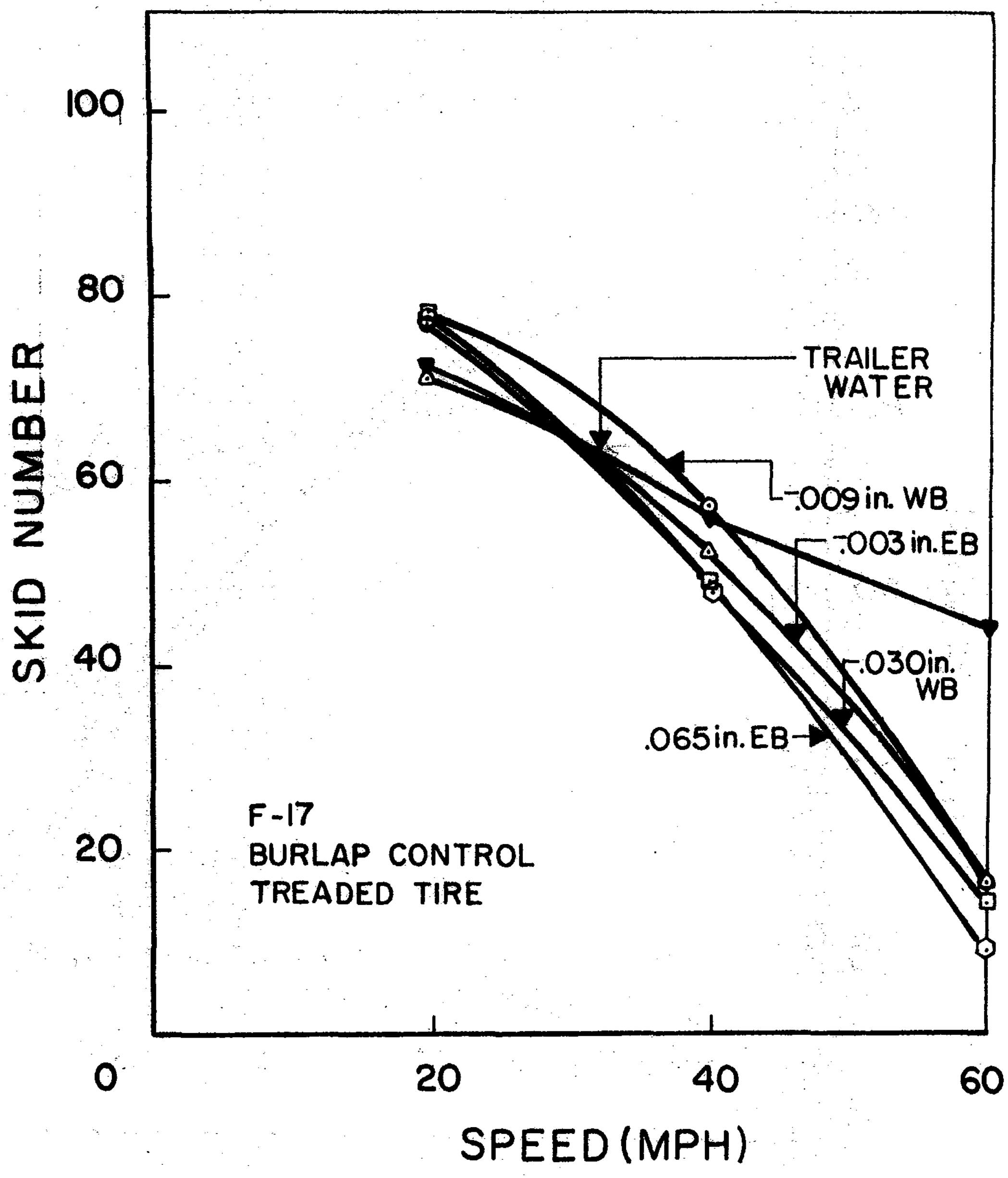

Fig. 3-15 Effect of Vehicle Speed on Skid Values Section F-17 on IH 10 Under Simulated Rainfall

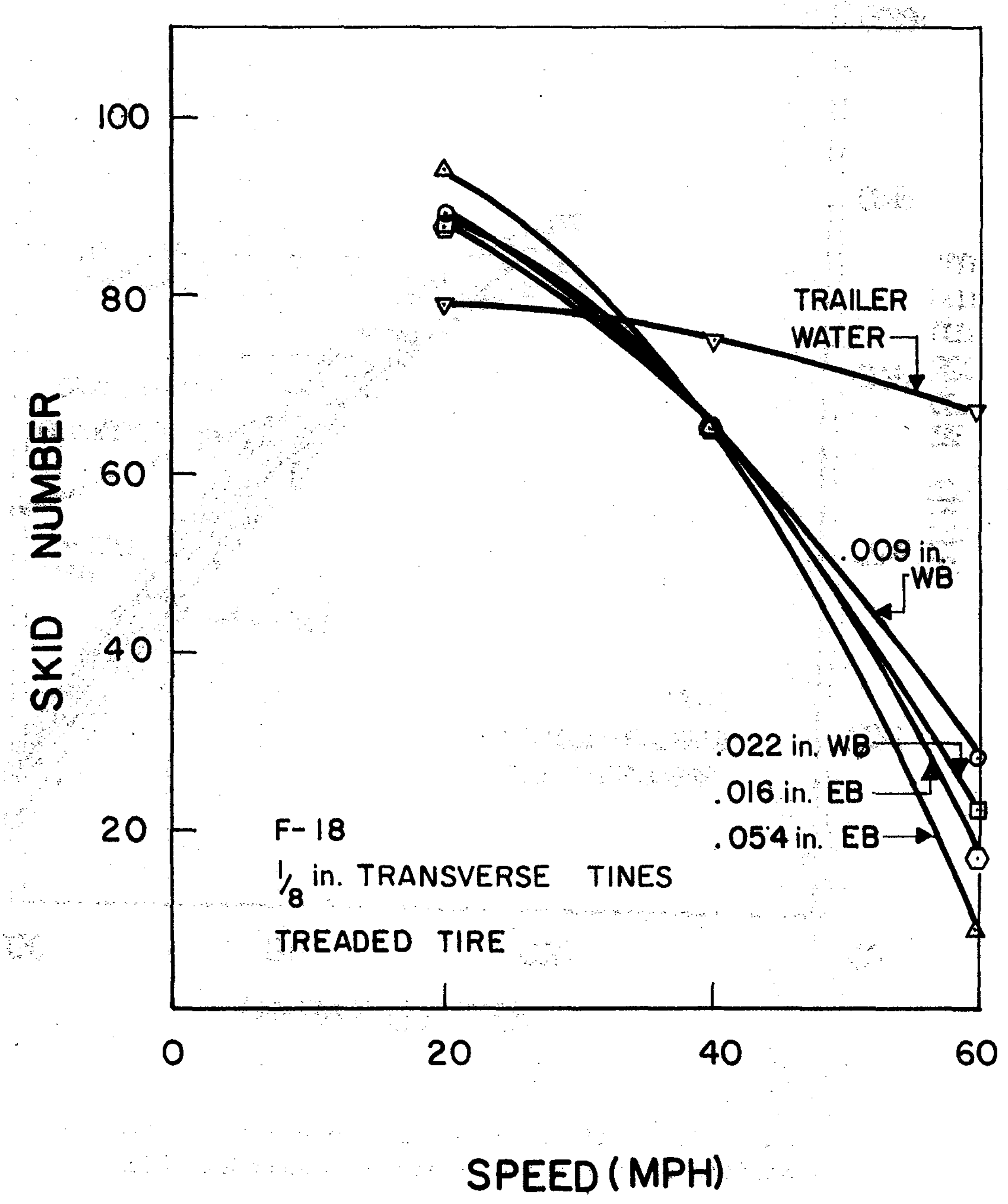

Fig. 3-16 Effect of Vehicle Speed on Skid Values of Section F-18 on IH 10 Under Simulated Rainfall

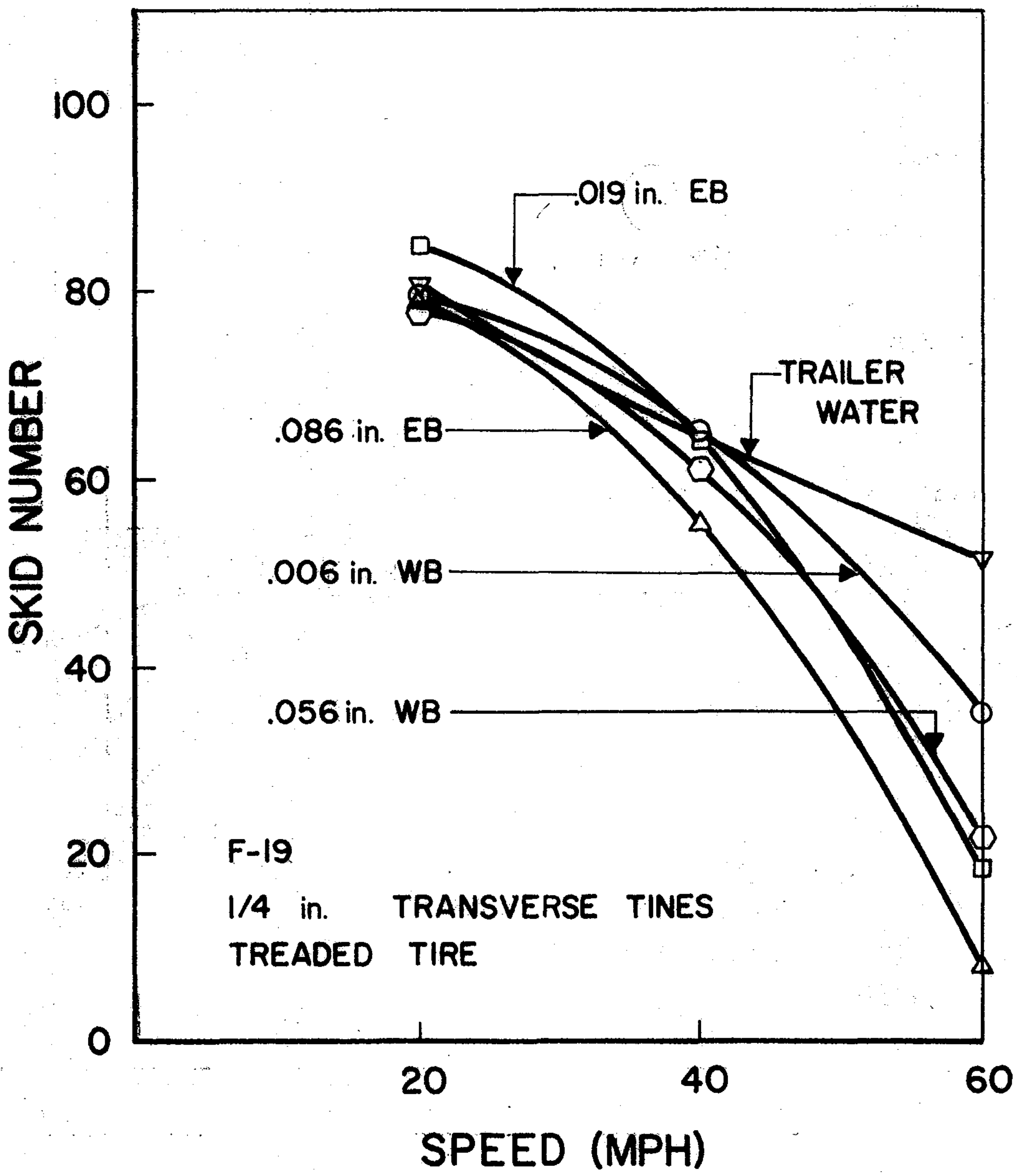

Fig. 3-17 Effect of Vehicle Speed on Skid Values of Section F-19 on IH 10 Under Simulated Rainfall

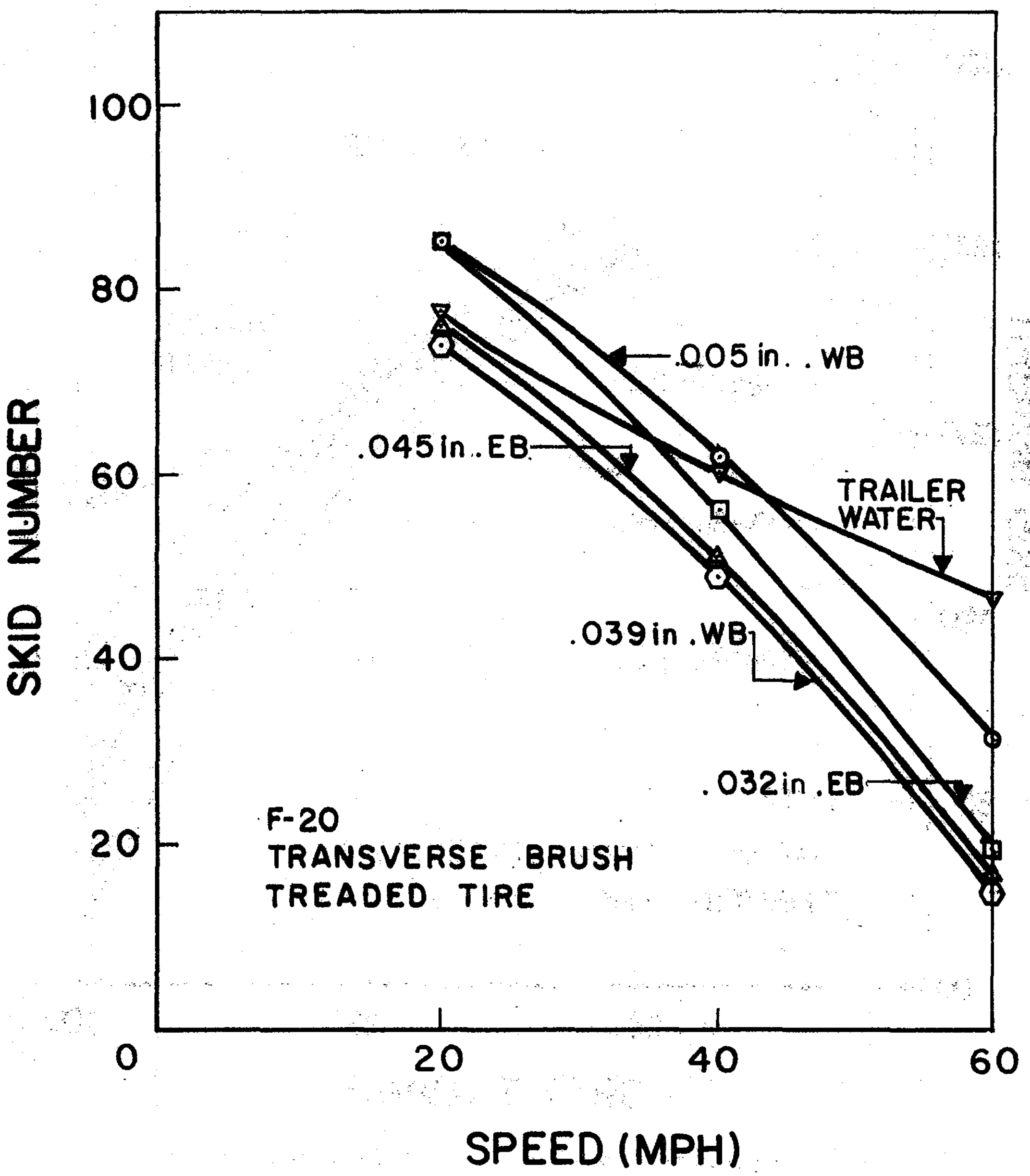

Fig. 3-18 Effect of Vehicle Speed on Skid Values of Section F-20 on IH 10 Under Simulated Rainfall

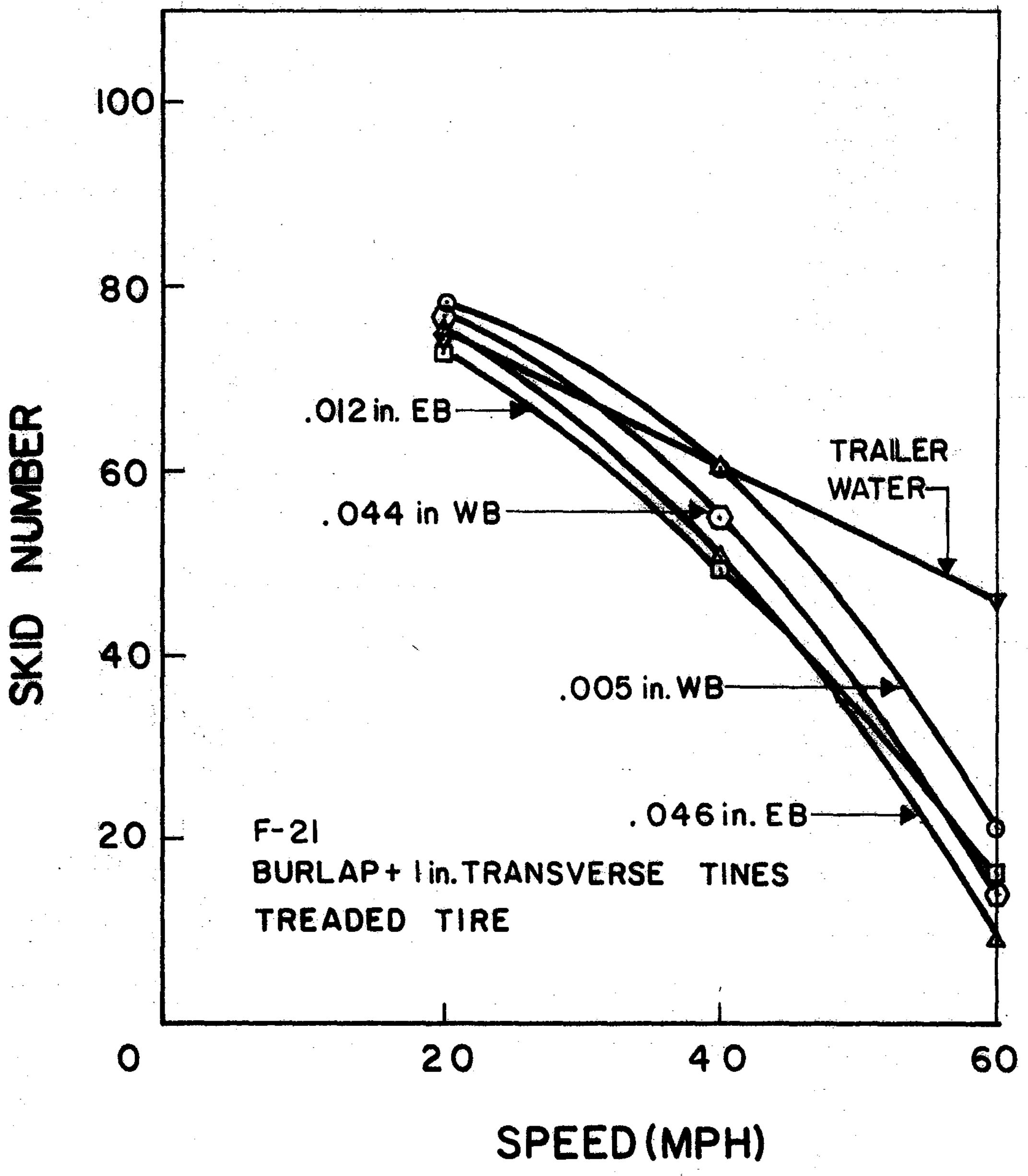

Fig. 3-19 Effect of Vehicle Speed on Skid Values of Section F-21 on IH 10 Under Simulated Rainfall

At the different test speeds, the tire-pavement interface becomes wetted 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 using 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. Assuming the simulated rainfall conditions represent real-life conditions, then the lack of skid resistance under these rainfall conditions is alarming at speeds in excess of about 40 to 50 mph - regardless of texture.

The next question is - what does all this mean in the light of the probabilities of obtaining wet surfaces on highways? This question is discussed in the next section.

3.5 Statistical Analysis of Skid Measurements Under Simulated Rain Conditions

All the data (see Tables 4-5 and 4-6) from the test sections on SH 6 and IH 10, including the "bald tire" data, were statistically analyzed using a two-step select regression analysis technique where best fit models of the following form were developed:

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

where:

SN = skid value

MPH = vehicle speed in mph

TD = skid tire tread depth in 32nd of an in. measurements

TXD = pavement texture depth in in.

WD = water depth on the pavement surface in in., measured from the top of the pavement asperities

C_1, C_2, C_3, C_4, C_5, C_6 = constants

A complete description of this technique is given in references 14 and 15.

The regression analyses yielded two equations, one for transverse textures and one for longitudinal textures, which are summarized in Table 3-3. The correlation coefficients obtained through the use of this statistical technique are satisfactory. However, the standard errors in terms of skid number 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. A plot of predicted skid value using the appropriate equation versus the measured skid value is given in Fig. 3-20 and Fig. 3-21. A line of equality is shown to indicate the degree of correlation for each equation. So at best these models for the prediction of skid number must be used with engineering judgment as considerable variability between predicted values and actual values may exist.

In order to better visualize the meaning of these equations, they were solved for certain conditions representative of what might be expected on Texas highways. The results have been plotted in the next several figures.

Fig. 3-22 shows the effect of increasing speed on skid value, of both transverse and longitudinal texturing, assuming a tread depth of

TABLE 3-3 Regression Models

Texture Direction	Equation No.	Regression Model	No. of Data Points	R^2[a]	SE[b]
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

[a] Correlation coefficient squared.

[b] Standard error in terms of skid number.

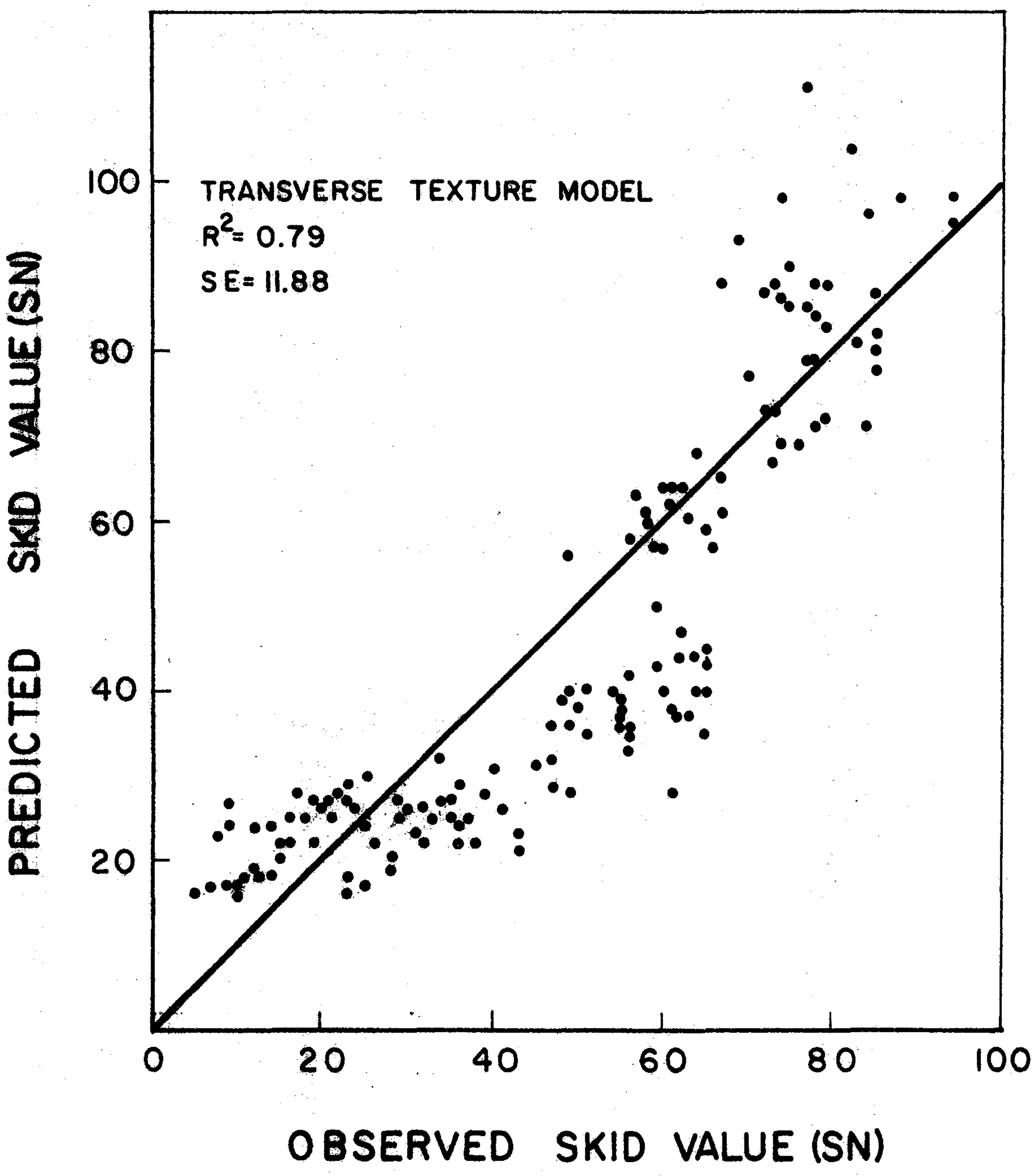

Fig. 3-20 Predicted Versus Observed Skid Values for Transverse Textures Using Model No. 24

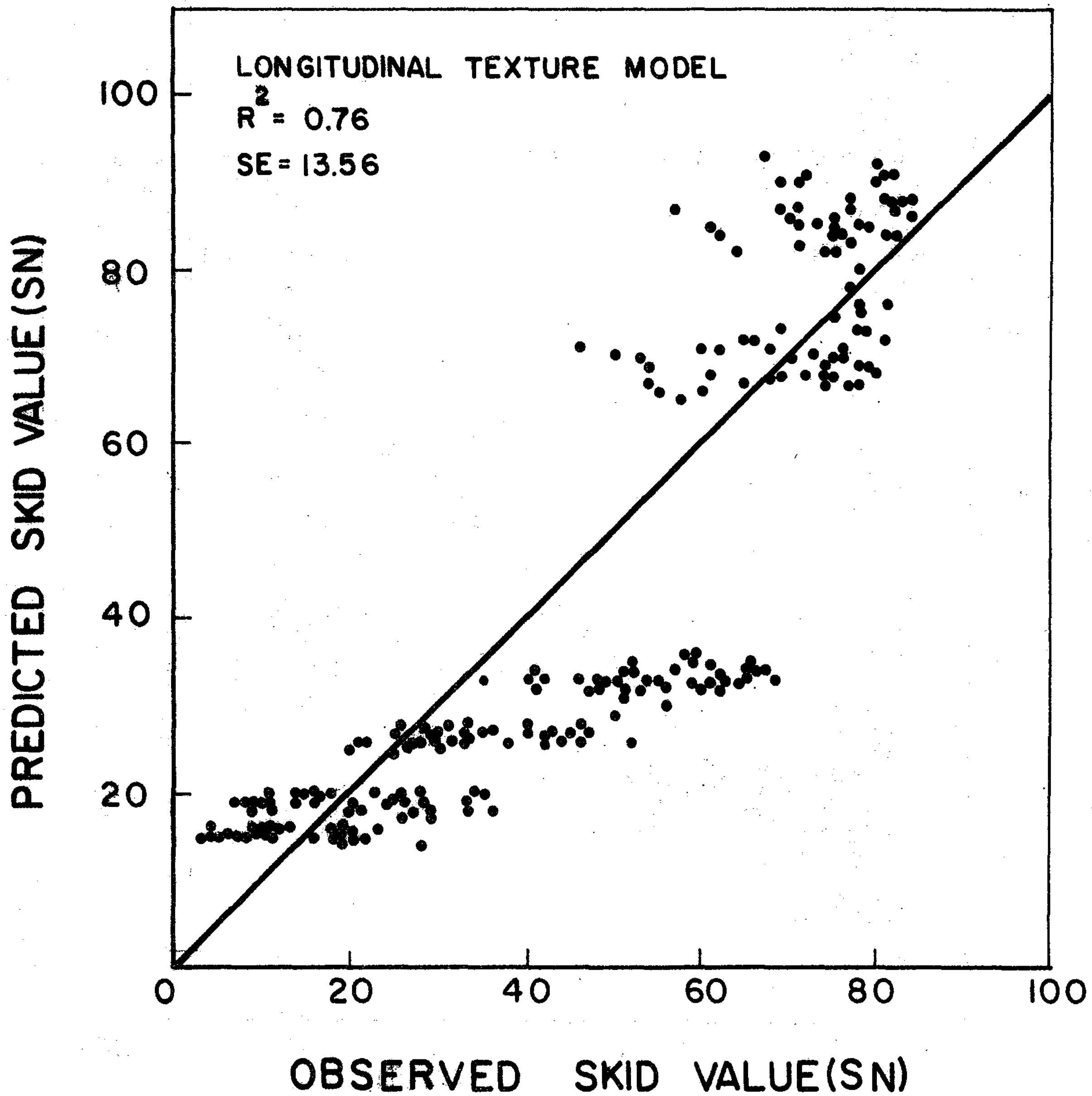

Fig. 3-21 Predicted Versus Observed Skid Values for Longitudinal Textures Using Model No. 25

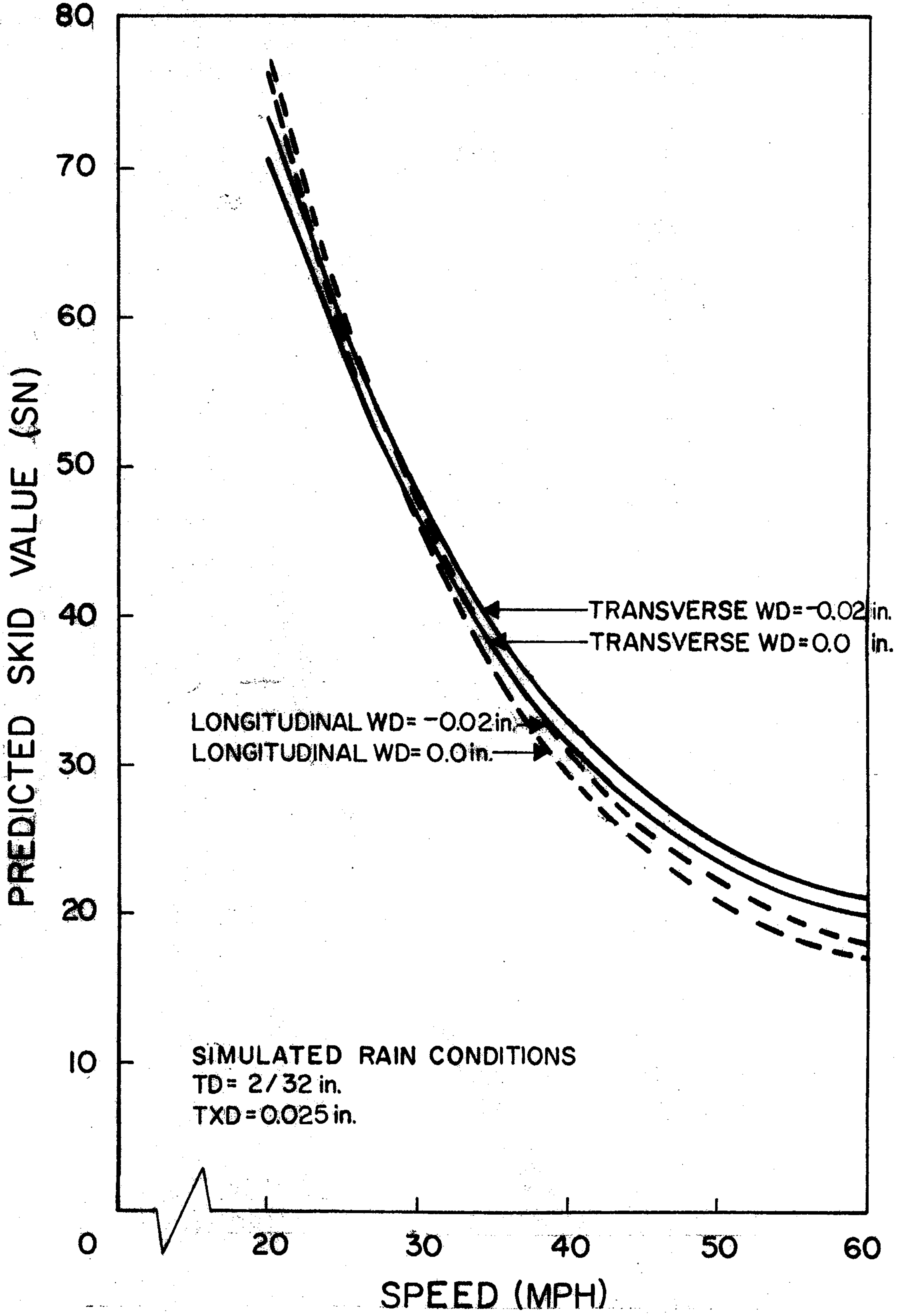

Fig. 3-22 Effect of Vehicle Speed on Skid Value for Tread Depth of 2/32 in. and Texture Depth of 0.025 in.

2/32 in. (the legal minimum in Texas) and a texture depth of 0.025 in. (the specified as-constructed minimum in Texas (1) for two water depths (-0.02 in. and 0.00 in.).* The significant influence of vehicle speed on available friction (SN) can be immediately seen, as the SN value drops very rapidly as speed is increased. At low speeds very high SN values are obtained, but at high speeds (above around 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 60 mph as the skid values are very low (around 20) and even small increases in skid values become significant on a relative basis.

Fig. 3-23 is the same type of plot, but for a tire tread depth of 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. And here again at speeds in excess of 30 mph the transverse textures exhibit higher skid values than longitudinal ones. For example, at 60 mph and -0.02 in. water depth, there is a 25 percent greater skid value for transverse texturing over longitudinal texturing (25 vs. 20 SN). Another interesting finding depicted in Fig. 3-23 is the relatively small influence of water depth on measured skid value (only 1 SN difference for a change in water depth from -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. Carrying this finding further, <u>it would seem to indicate that low skid values could be obtained in almost any rainfall in which the pavement were completely wetted</u>.

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*Water depths are measured from the top of the asperities.

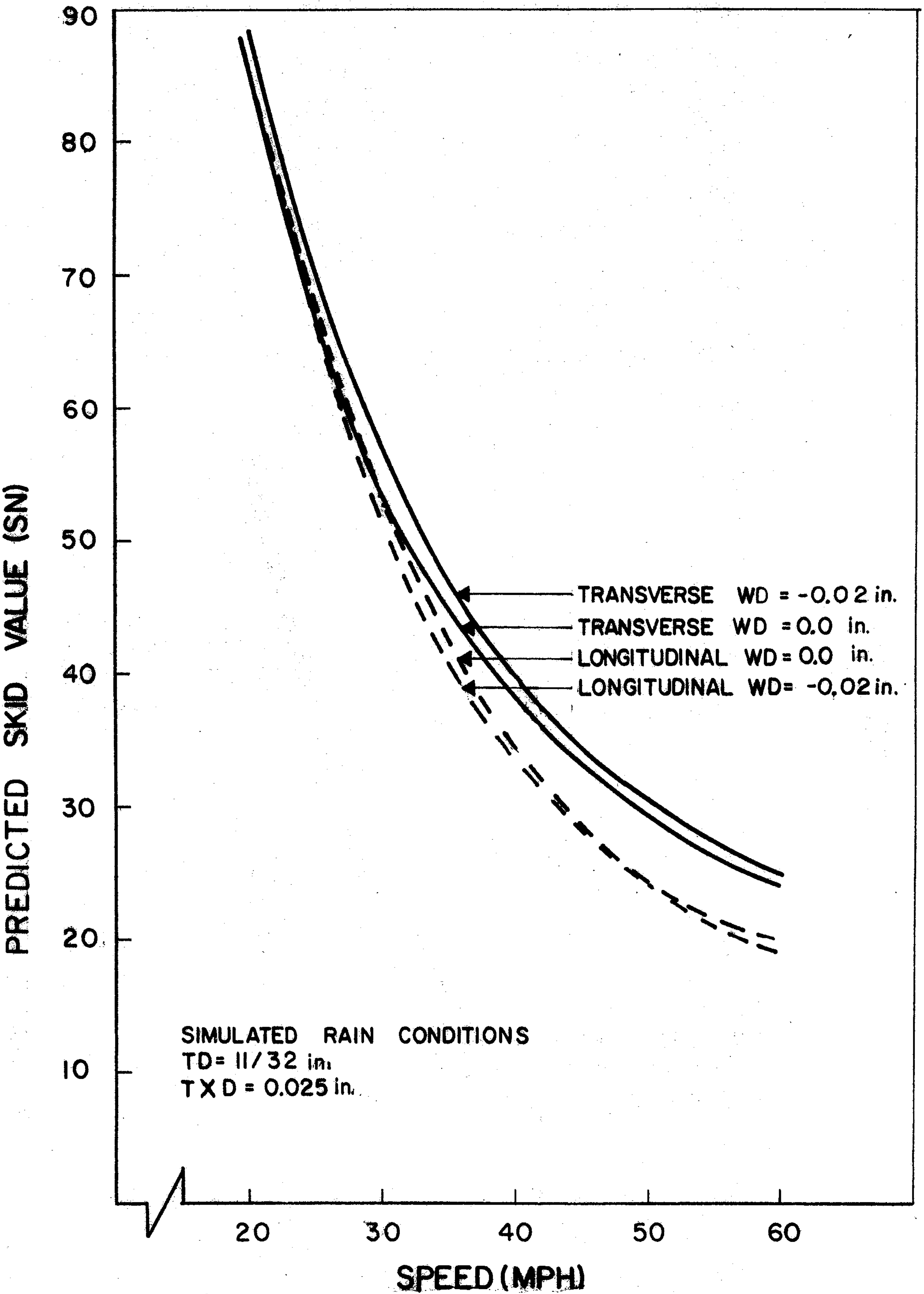


Fig. 3-23 Effect of Vehicle Speed on Skid Value for Tread Depth of 11/32 in. and Texture Depth of 0.025 in

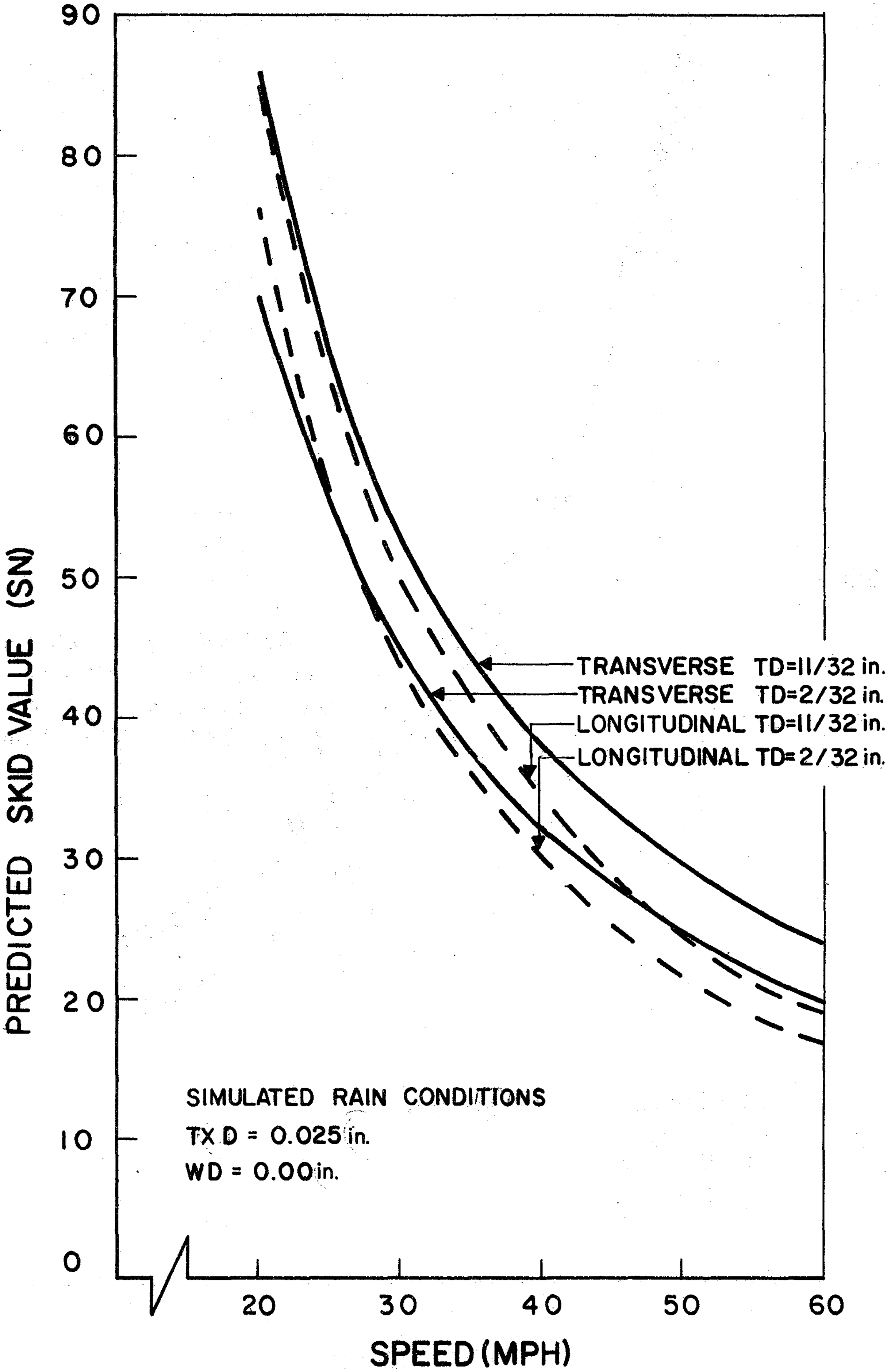


Fig. 3-24 Effect of Vehicle Speed on Skid Value for Water Depth of 0.00 in. and Texture Depth of 0.025 in

The effect of tread depth on skid values for a water depth of 0.00 in. and a texture depth of 0.025 in. are shown in Fig. 3-24. At speeds approaching 60 mph the relative differences in SN values between full tread (11/32 in.) and minimum tread (2/32 in.) become very significant. Full tread results in 20 percent more available skid resistance than minimum tread (SN values of 24 vs. 20).

The effects of texture depth and texture direction are portrayed in Fig. 3-25 for a tread depth of 2/32 in. and a water depth of 0.00 in. For this water depth, at 60 mph transverse texturing is again significantly better than longitudinal texturing, and a 0.060 in. texture depth is significantly better than 0.025 in. texture depth (20 percent for transverse texturing - 24 vs. 20). Fig. 3-25 summarizes the effects of vehicle speed on skid value for conditions which may reasonably be expected to exist on Texas highways in almost any rainfall in which the pavement is completely wetted. The reasons for this statement are given in the following paragraphs.

First, the change in skid value with changes in water depth from -0.02 in. to 0.00 in. are almost insignificant (Fig. 3-23). This could account for the fact that up to 10 times as many accidents occur in wet weather (presumably regardless of the intensity of the rainfall) as in dry weather (16). Further, in study of wet weather accidents in Arizona it was observed that days with more than 0.1 in. rainfall accounted for 75 percent of the wet weather accidents even though less than 5 percent of the days annually had these rainfalls (17). In central Texas there are 10 to 20 percent of the days annually that have an hourly rainfall total greater than .1 in. (18).

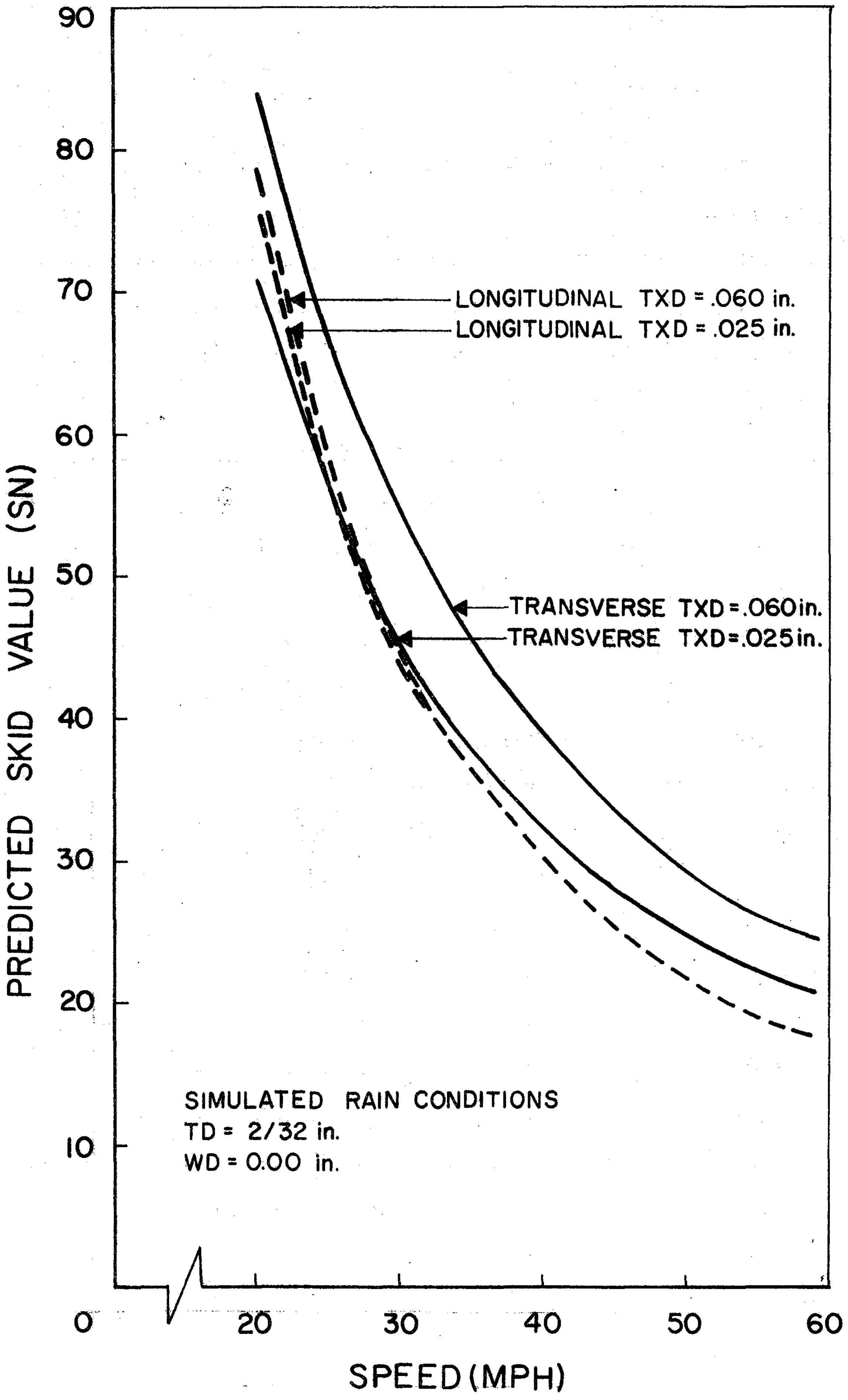


Fig. 3-25 Effect of Vehicle Speed on Skid Value for Tread Depth of 2/32 in. and Water Depth of 0.00 in

Second, the water depth assumption of 0.00 in. measured from the top of the asperities can occur in almost any rainfall. Weaver, et al., report the average 85th percentile rainfall in Texas for the year 1969 was 0.14 in. per hr, for annual rainfalls from 4.34 to 48.44 in (16). Examination of 1971 rainfall data in Texas as published by the U. S. Department of Commerce, National Oceanic and Atmospheric Administration, revealed that rainfall is normally recorded in hourly increments, rather than in intensities. Therefore, the average hourly 85th percentile rainfall was 0.14 in., while the intensity varied. Data are available on excessive short-duration rainfall from 20 Texas cities. This is defined as rainfall in which the rainfall equaled or exceeded 0.25 in. in any 5 min. period, or 0.30 in. in any 10 min. period, or 0.35 in. in any 15 min. period, etc. A plot of the 1971 maximum rainfall in any five min. period (in. per hr) vs. the accumulated total rainfall in one hour is given in Fig. 3-26. Note that the maximum intensity exceeds the accumulated total rainfall by 2.1 times at the 95 percentile. This 3.8 factor is in substantial agreement with the 3.48 factor reported by Ivey, et al. (18). If similar intensity distributions are assumed for all rains, the average 85th percentile rainfall would have an average maximum intensity of 3.8 times 0.14, or 0.53 in. per hr sometime during the rain.

Third, looking at the assumed texture depth value of 0.025 in., this was selected as it is the specified minimum as-constructed value on concrete pavements today.

Fourth, the 2/32 in. tread depth, being the legal minimum in Texas, was selected as a reasonable lower bound for analysis purposes. Even though there may be some vehicles with tread depths less than the minimum,

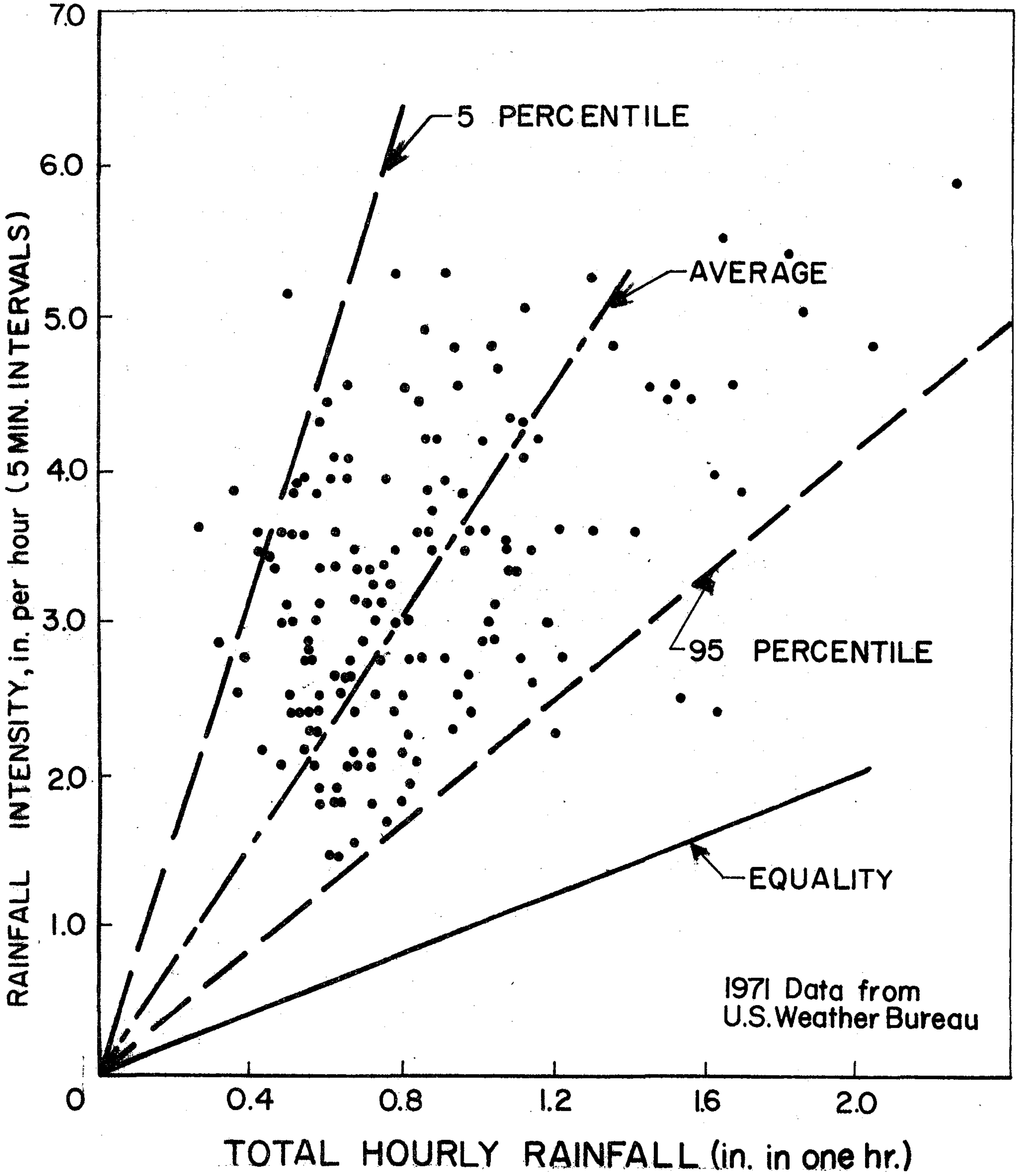


Fig. 3-26 Rainfall Intensity for Twenty
Texas Cities (5 minute intervals)

the authors considered the use of even lower tread depths to be unduly conservative.

Fifth, using this intensity (0.53) in Gallaway's equation for determination of water depth (12) for a cross slope of 1/4 in. per ft, a drainage length of 9.5 ft, and a texture depth of 0.025 in. indicates there would be a water depth of almost 0.0 in. on the pavement. Thus, for the average 85th percentile rainfall, water depths will probably reach around 0.0 in. (all asperities filled) on a 0.025 in. texture during the peak intensity in that rain.

Last, the foregoing discussion does not consider the situations where cross slope approaches zero, a situation that occurs in a number of places where soil shifts, pavement curl, and other factors, reduce the cross slope. Gallaway's equation (12) indicates water depths can increase without bound whenever cross slope is reduced to zero.

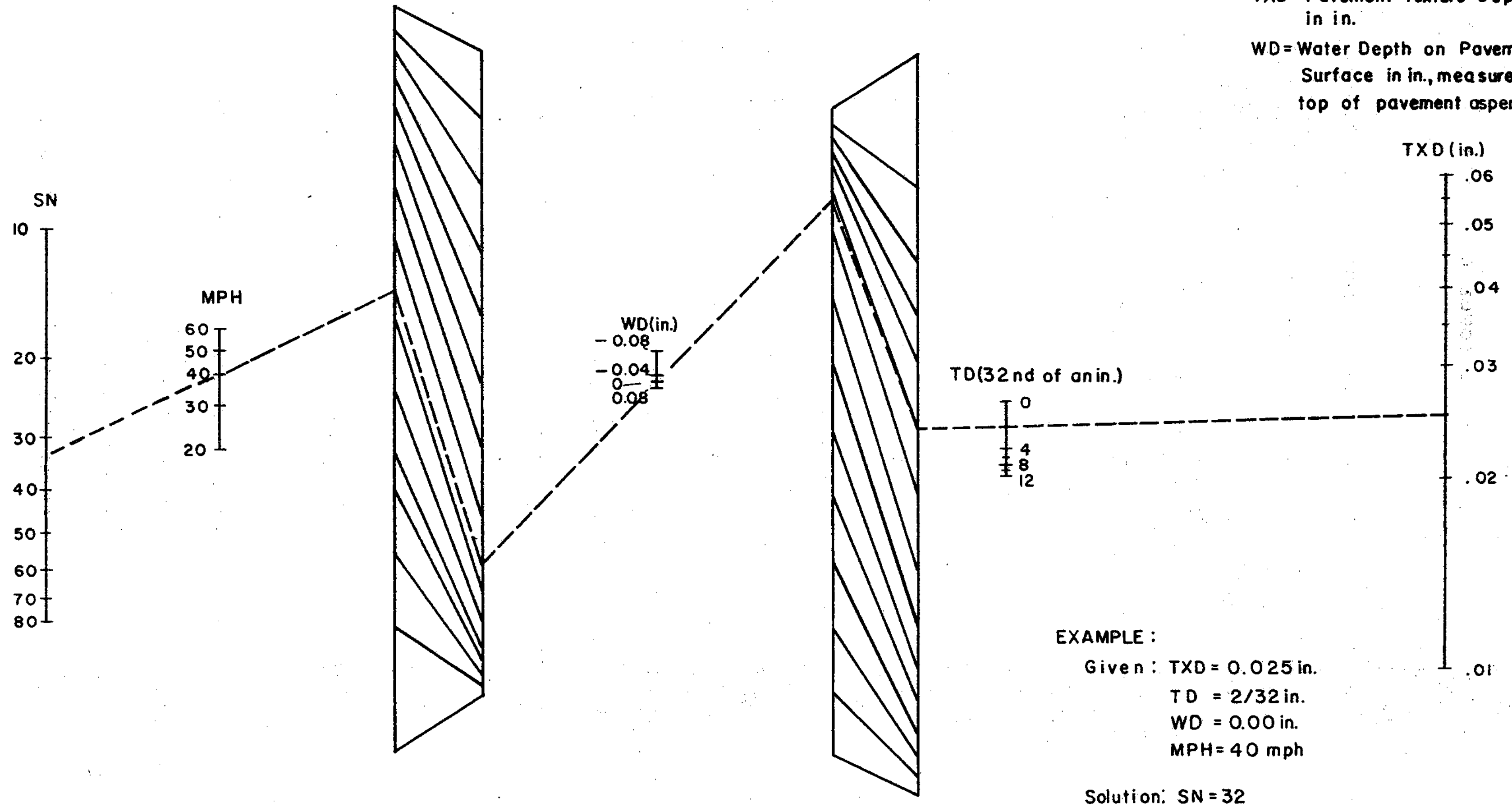
In summary, low skid values could be obtained in almost any rainfall in which the pavement is completely wetted. In Central Texas such a condition occurs in from 10 to 20 percent of the days annually. And the skid resistance can best be improved by constructing deeper textures in the transverse direction.

3.6 Design Implications of Skid Measurement Results Under Simulated Rain Conditions

In order to more completely assess the design implications of the two mathematical models developed (Model Numbers 24 and 25 in Table 3-3), they have been put into nomograph form in Fig. 3-27 and 3-28. In this form the equations can be easily solved for skid value, given

$$SN = \frac{205}{MPH^{1.15}}\left[17.92(TD+1)^{0.18}\,TXD^{0.29} + \frac{1}{(WD+0.1)^{0.53}}\right]$$

SN = Skid Value
MPH = Vehicle Speed, mph
TD = Tire Tread Depth, 32nd of an in.
TXD = Pavement Texture Depth in in.
WD = Water Depth on Pavement Surface in in., measured from top of pavement asperities.



EXAMPLE :

Given : TXD = 0.025 in.
TD = 2/32 in.
WD = 0.00 in.
MPH = 40 mph

Solution: SN = 32

Fig. 3-27 Nomograph of Model for Transverse Texture

$$SN = \frac{910}{MPH^{1.37}}\left[3.06(TD+1)^{0.14}\ TXD^{0.04} + \frac{1}{(WD+0.1)^{0.31}}\right]$$

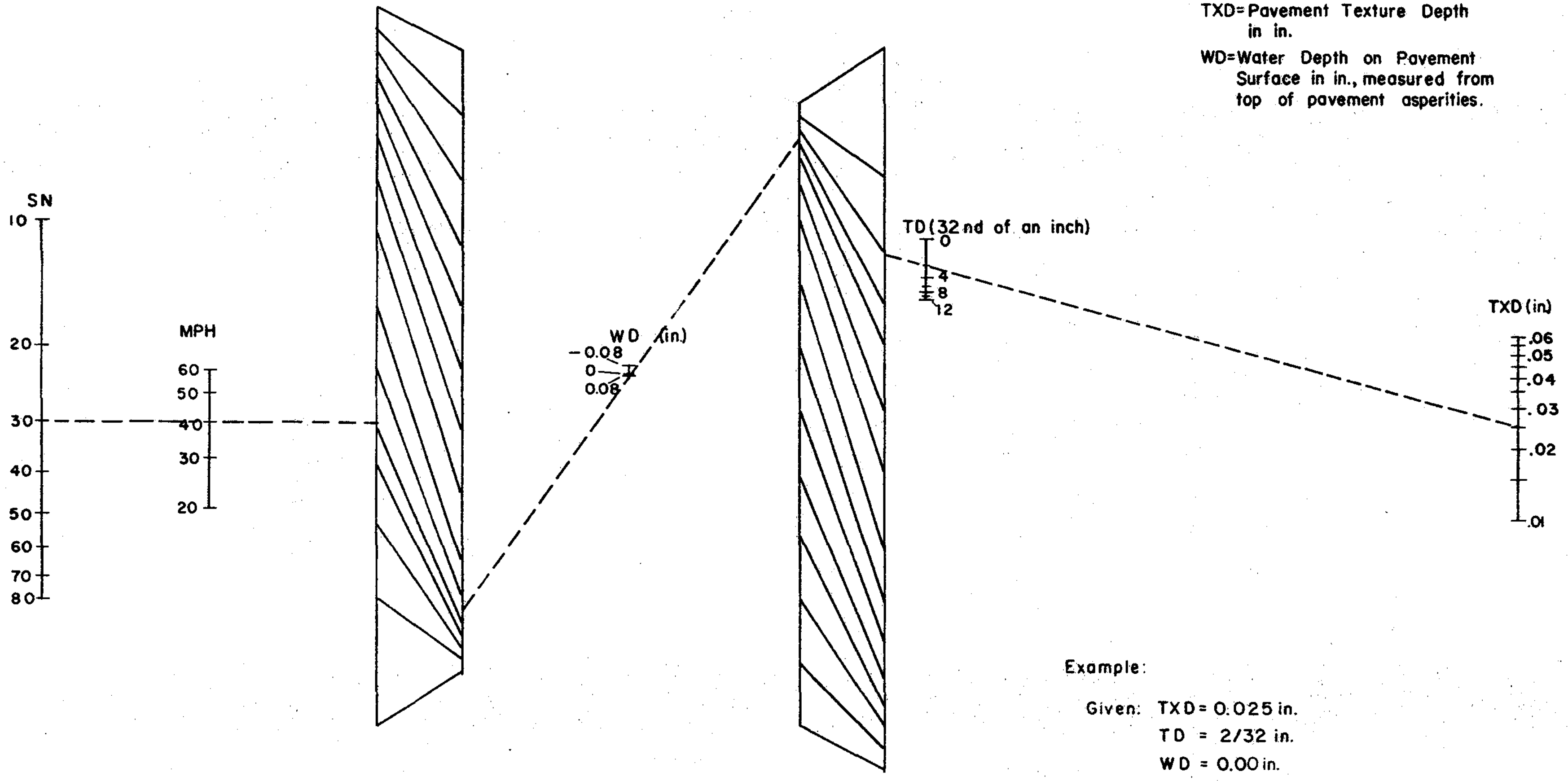
SN=Skid Value

MPH=Vehicle Speed, mph

TD=Tire Tread Depth, 32nd of an in.

TXD=Pavement Texture Depth in in.

WD=Water Depth on Pavement Surface in in., measured from top of pavement asperities.



Example:

Given: TXD = 0.025 in.
TD = 2/32 in.
WD = 0.00 in.
MPH = 40 mph

Solution: SN = 30

Fig. 3-28 Nomograph of Model for Longitudinal Texture the remaining variables. They can also be used to solve for a required texture depth, given the desired skid value and other variables. However, caution should be exercised in using the equations for this purpose because the data were developed for given textures and the low values of the exponents for texture depth make the equations very sensitive to small changes in skid value (the reciprocal of the texture depth exponent becomes the exponent of the skid value).

An additional point should be made here. As discussed in Sec. 3.2, all textures can be expected to wear-down a minimum of 25 to 35 percent, based on initial texture depths. Therefore, when using these nomographs an appropriate factor for expected wear-down should be used when establishing the required texture depths to be constructed for any given design condition.

4. APPENDIX

4.1 References

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16. Weaver, G. D., et al, "Factors Affecting Vehicle Skids: A Basis for Wet Weather Speed Zoning," Research Report No. 135-2F, Texas Transportation Institute, February 1973, 60 pp.

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4.2 Data

Data developed in this study are given in Tables 4-1 through 4-6.

TABLE 4-1 Aggregate Data on IH 10 Near Van Horn, Texas

Fine Aggregate		Coarse Aggregate	
Sieve Size	Cumulative Percent Retained	Sieve Size	Cumulative Percent Retained
4	.4	1 1/2	2.7
8	7.6	1	34.3
16	26.4	3/4	58.2
30	51.0	1/2	78.6
50	77.5	3/8	87.2
100	94.9	4	97.4

Fineness Modulus = 2.58
Specific Gravity = 2.64
Percent Solids = 58.9
Percent Voids = 41.1

Specific Gravity = 2.65
Percent Solids = 41.7
Percent Voids = 58.3

TABLE 4-2 Concrete Test Data on IH 10 Near Van Horn, Texas

	Splitting Tensile Strength - psi[a]		
Test Section	Top	Bottom	Compressive Strength - psi[b]
F-11 Burlap + 1/4 in. Longitudinal Tines	580	720	2000
F-12 Burlap + 1/2 in. Longitudinal Tines	520	732	2300
F-13 Burlap + 1 in. Longitudinal Tines	600	660	2140
F-14 Burlap + 3/4 in. Longitudinal Tines	570	-	2340
F-16 1/8 in. Longitudinal Tines	470	580	1720
F-17 Burlap Drag (Control)	580	640	1890
F-18 1/8 in. Transverse Tines	650	600	1900
F-19 1/4 in. Transverse Tines	680	610	2400

TABLE 4-2 (Cont'd.)

Test Section	Splitting Tensile Strength - psi[a]		Compressive Strength - psi[b]
	Top	Bottom	
F-20 Transverse Brush	590	640	2380
F-21 Burlap + 1 in. Transverse Tines	680	-	2480

[a] Core taken from test section cured in natural environment until tested at an age of 60 days in accordance with ASTM C496.

[b] 6 x 12 in. cylinder made from selected batches of concrete used in each test section, then cured for 7 days at 73° - 95% R.H. and tested in accordance with ASTM C39.

TABLE 4-3 Field Measurements on SH 6 Under Standard Conditions

Test Section	Date	Texture Depth (in.)		Skid Number 40 mph	
		Putty Impression[a]	Sand Patch[b]	IL[c]	OL[d]
F-1 Transverse Broom	Dec. 71	.064	-	61	63
	June 72	-	-	74	69
	Aug. 72	.043	-	60	53
	Nov. 72	-	-	58	54
	Jan. 73	.058	.042	-	-
	March 73	.044 (11/73)	.032	58	47
	June 74	.040	.030	51	46
F-2 Transverse Tines	Dec. 71	.070	-	71	75
	June 72	-	-	83	78
	Aug. 72	.064	-	72	66
	Nov. 72	-	-	73	66
	Jan. 73	.059	.060	-	-
	March 73	.050 (11/73)	.051	72	59
	June 74	.045	.050	52	55
F-3 Longitudinal Broom	Dec. 71	.046	-	57	55
	June 72	-	-	61	65
	Aug. 72	.028	-	59	52
	Nov. 72	-	-	57	50
	Jan. 73	.045	.027	-	-
	March 73	.027 (11/73)	.023	54	45
	June 74	.020	.018	47	45
F-4 Longitudinal Tines	Dec. 71	.094	-	67	68
	June 72	-	-	68	71
	Aug. 72	.062	-	67	55
	Nov. 72	-	-	66	58
	Jan. 73	.065	.059	-	-
	March 73	.063 (11/73)	.056	63	54
	June 74	.060	.051	55	50

TABLE 4-3 (Cont'd.)

Test Section	Date	Texture Depth (in.) Putty Impression[a]	Texture Depth (in.) Sand Patch[b]	Skid Number 40 mph IL[c]	Skid Number 40 mph OL[d]
F-5 Burlap + Longitudinal Tines	Dec. 71	.086	-	66	66
	June 72	-	-	68	70
	Aug. 72	.065	-	64	54
	Nov. 72	-	-	63	55
	Jan. 73	.083	.074	-	-
	March 73	.076 (11/73)	.072	61	52
	June 74	.075	.062	54	52
F-6 Burlap Drag (Control)	Dec. 71	.039	-	33	36
	June 72	-	-	54	45
	Aug. 72	.032	-	44	34
	Nov. 72	-	-	43	37
	Jan. 73	.040	.024	-	-
	March 73	.031 (11/73)	.021	45	40
	June 74	.034	.023	51	42
F-7 Transverse Natural Brush	Dec. 71	.042	-	62	64
	June 72	-	-	71	69
	Aug. 72	.033	-	60	55
	Nov. 72	-	-	63	59
	Jan. 73	.044	.026	-	-
	March 73	.036 (11/73)	.024	58	51
	June 74	.032	.026	40	50

[a] As measured by Silicone Putty Impression Test.

[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).

TABLE 4-4 Field Test Measurements on IH 10 Under Standard Conditions

Test Section	Date	Texture Depth (in.) Putty Impression[a]	Sand Patch[b]	Skid Number 40 mph IL[c]	OL[d]
F-11					
Burlap + 1/4 in.	Dec. 73	.081	.070	66	72
Longitudinal Tines	July 74	-	.053	67	64
F-12					
Burlap + 1/2 in.	Dec. 73	.075	.061	65	68
Longitudinal Tines	July 74	-	.045	63	61
F-13					
Burlap + 1 in.	Dec. 73	.062	.045	53	64
Longitudinal Tines	July 74	-	.029	51	55
F-14					
Burlap + 3/4 in.	Dec. 73	.065	.052	57	68
Longitudinal Tines	July 74	-	.033	52	58
F-15					
1/4 in. Longitudinal	Oct. 73	.058	.049	68	-
Tines	July 74	-	.031	55	-
F-16					
1/8 in. Longitudinal	Dec. 73	.068	.065	59	72
Tines	July 74	-	.029	-	62
F-17					
Burlap Drag	Dec. 73	.034	.027	52	59
(Control)	July 74	-	.025	58	57

TABLE 4-4 (Cont'd.)

Test Section	Date	Texture Depth (in.)		Skid Number 40 mph	
		Putty Impression[a]	Sand Patch[b]	IL[c]	OL[d]
F-18					
1/8 in. Transverse	Dec. 73	.050	.052	73	79
Tines	July 74	-	.028	68	63
F-19					
1/4 in. Transverse	Dec. 73	.031	.031	58	69
Tines	July 74	-	.020	60	56
F-20	Dec. 73	.021	.022	59	64
Transverse Brush	July 74	-	.014	59	54
F-21					
Burlap + 1 in.	Dec. 73	.030	.031	55	67
Transverse Tines	July 74	-	.019	61	58

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

[b] As measured by Tex 436-8 (See Section 4.4).

[c] IL - Inside lane (south side of westbound direction).

[d] OL - Outside lane (north side of westbound direction).

TABLE 4-5 Skid Measurements Under Simulated Rainfall on SH 6 in College Station, Texas - August 1972 (ASTM E274 with 14 in. Tire)

		Bald Tire				Treaded Tire		
Test Section and Description	WD (in.)	20 MPH	40 MPH	60 MPH	WD (in.)	20 MPH	40 MPH	60 MPH
F-1	-.020	64	40	28	-.020	69	56	41
Transverse Broom	.004	67	36	23	.004	75	54	37
TXD_s = 0.033 in.	.024	57	39	24	.024	67	51	33
TXD_p = 0.043 in.	.050	58	28	16	.050	74	55	25
F-2	-.059	72	48	36	-.059	77	59	45
Transverse Tines	-.035	77	47	32	-.035	82	62	47
TXD_s = 0.057 in.	.000	72	56	43	.000	74	62	49
TXD_p = 0.064 in.	.024	84	47	28	.024	84	59	34
F-3	-.008	53	32	19	-.008	71	49	33
Longitudinal Broom	.020	61	29	22	.020	75	53	28
TXD_s = 0.015 in.	.031	54	29	19	.031	71	51	33
TXD_p = 0.028 in.	.042	55	26	19	.042	75	53	36
	.051	66	28	21	.051	74	51	27
	.061	58	25	19	.061	75	62	29
F-4	-.026	75	50	29	-.026	80	61	35
Longitudinal Tines	.008	76	47	23	.008	84	67	28
TXD_s = 0.055 in.	.028	69	35	20	.028	75	64	28
TXD_p = 0.062 in.	.059	74	30	18	.059	75	63	24
F-5	-.014	69	40	23	-.034	67	59	42
Burlap + Longitudinal Tines	.012	68	42	20	-.019	72	58	34
TXD_s = 0.059 in.	.051	72	46	20	.051	73	56	23
TXD_p = 0.065 in.	.071	74	46	18	.071	76	55	18

TABLE 4-5 (Cont'd.)

Test Section and Description	WD (in.)	Bald Tire 20 MPH	40 MPH	60 MPH	WD (in.)	Treaded Tire 20 MPH	40 MPH	60 MPH
F-6	-.010	46	26	16	-.010	57	41	26
Burlap Drag (Control)	.004	50	28	16	.004	61	45	21
TXD_s = 0.020 in.	.016	54	26	16	.016	62	41	26
TXD_p = 0.032 in.	.055	60	31	16	.055	64	47	20
F-7	.000	64	35	25	.000	83	63	43
Transverse Natural Brush	.020	56	30	25	.020	78	55	38
TXD_s = 0.021 in.	.031	66	32	23	.031	85	65	36
TXD_p = 0.033 in.	.050	49	29	23	.050	70	56	26

TABLE 4-6 Skid Measurements Under Simulated Rainfall on
IH 10 Near Van Horn, Texas - October 1973
(ASTM E274 with 14 in. Tire)

Test Section and Description	Bald Tire				Treaded Tire			
	WD (in.)	20 MPH	40 MPH	60 MPH	WD (in.)	20 MPH	40 MPH	60 MPH
F-11	-.053	78	51	16	-.020	82	66	23
Burlap + 1/4 in. Longitudinal Tines	-.046	77	56	26	-.016	81	66	15
TXD_s = 0.070 in.	-.007	78	46	12	.019	81	62	17
TXD_p = 0.081 in.	.065	80	52	9	.081	81	61	9
F-12	-.007	79	46	18	-.013	80	61	34
Burlap + 1/2 in. Longitudinal Tines	.002	81	45	14	-.009	79	59	16
TXD_s = 0.061 in.	.029	78	40	7	.011	83	61	14
TXD_p = 0.075 in.	.063	78	38	3	.052	79	59	9
F-13	-.012	66	33	13	-.016	71	52	18
Burlap + 1 in. Longitudinal Tines	.064	60	32	11	.010	69	51	18
TXD_s = 0.045 in.	.014	70	30	5	.024	70	48	8
TXD_p = 0.062 in.	.042	68	27	4	.050	71	46	8
F-14	.014	73	33	11	.024	81	63	14
Burlap + 3/4 in. Longitudinal Tines	.027	74	29	6	.035	78	54	8
TXD_s = 0.052 in.	.052	75	33	6	.056	78	50	7
TXD_p = 0.064 in.	.053	69	22	3	.072	82	60	11
F-16	.018	75	43	13	.013	81	66	25
1/8 in. Longitudinal Tines	.022	75	36	4	.023	82	65	17
TXD_s = 0.065 in.	.045	79	44	11	.040	84	65	20
TXD_p = 0.068 in.	.069	77	42	4	.065	85	68	10

TABLE 4-6 (Cont'd.)

	Bald Tire				Treaded Tire			
Test Section and Description	WD (in.)	20 MPH	40 MPH	60 MPH	WD (in.)	20 MPH	40 MPH	60 MPH
F-17	-.011	65	31	10	-.009	77	57	16
Burlap Drag (Control)	-.002	62	25	4	-.003	71	52	16
TXD_s = 0.027 in.	.032	67	28	8	.030	78	49	14
TXD_p = 0.034 in.	.053	65	21	4	.065	77	48	9
F-18	-.006	73	33	21	.022	88	64	22
1/8 in. Transverse Tines	.057	73	25	7	.054	94	65	9
TXD_s = 0.052 in.	.0002	79	32	20	.009	89	65	28
TXD_p = 0.050 in.	.005	78	34	15	.016	88	65	17
F-19	.074	65	23	9	.086	79	55	8
1/4 in. Transverse Tines	.054	63	21	9	.056	78	61	22
TXD_s = 0.031 in.	.019	61	24	13	.019	85	64	18
TXD_p = 0.031 in.	.006	60	25	14	.006	79	65	35
F-20	.045	59	20	5	.045	76	51	16
Transverse Brush	.039	60	20	5	.039	74	49	15
TXD_s = 0.022 in.	.032	56	24	10	.032	85	56	19
TXD_p = 0.021 in.	.005	58	29	16	.005	85	62	31
F-21	.044	67	22	10	.044	77	55	14
Burlap + 1 in. Transverse Tines	.046	67	19	7	.046	75	50	9
TXD_s = 0.031 in.	.013	61	28	13	.012	73	49	16
TXD_p = 0.030 in.	.006	62	23	11	.005	78	60	21