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Coefficient Of Friction Of Various Grooving Patterns On PCC Pavement

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16. ABSTRACT
Six different grooving patterns; 1/8 by 1/8 inch rectangular grooves spaced at 1/2, 3/4 and one inch centers and the number 6,7 and 15 patterns of the Christensen Diamond Services Company were cut in each of two PCC test slabs. One slab had a trowelled finish with an average initial coefficient of friction of 0.14 as determined by the California Skid Tester. The other slab had a burlap drag finish with an average initial coefficient of friction of 0.35.

Higher coefficients of friction were obtained with the Christensen grooving patterns than by the 1/8 by 1/8 inch rectangular grooves. The frictional properties of the burlap drag finish were unchanged by the 1/8 by 1/8 inch rectangular grooves. Longitudinal coefficient of friction measurements were quite erratic for the three 1/8 by 1/8 inch rectangular patterns which were cut in the trowelled PCC surface and very little improvement in frictional properties were obtained. Friction measurements measured at 15 to 45 degrees to the direction of the grooves were much more consistent, and are probably more representative of the actual improvement in the frictional properties of the surface. This is caused by the small contact area of the tire used on the California Skid Tester which may touch as few as 2 grooves during a longitudinal test with the grooves spaced at one inch. If 1/8 by 1/8 inch rectangular grooves are used, the most improvement in skid resistance is provided by the 1/2 inch center to center spacing.

17. KEYWORDS
Pavements, surfaces, pavement surface texture, skid resistance testing, pavement skidding characteristics, grooving Portland cement concrete pavements, coefficient of friction

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HIGHWAY RESEARCH REPORT

COEFFICIENT OF FRICTION OF VARIOUS GROOVING PATTERNS ON PCC PAVEMENT

INTERIM REPORT

DND
68-25

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 633126

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

July 1968
Interim Report
M&R No. 633126

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

COEFFICIENT OF FRICTION OF VARIOUS

GROOVING PATTERNS ON PCC PAVEMENT

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Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Zube, E., Skog, J. B., Munday, H. A. Jr., "Coefficient of Friction of Various Grooving Patterns on PCC Pavement", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633126 - 4, July 1968.

ABSTRACT: Six different grooving patterns; 1/8 by 1/8 inch rectangular grooves spaced at 1/2, 3/4 and one inch centers and the number 6, 7 and 15 patterns of the Christensen Diamond Services Company were cut in each of two PCC test slabs. One slab had a trowelled finish with an average initial coefficient of friction of 0.14 as determined by the California Skid Tester. The other slab had a burlap drag finish with an average initial coefficient of friction of 0.35.

Higher coefficients of friction were obtained with the Christensen grooving patterns than by the 1/8 by 1/8 inch rectangular grooves. The frictional properties of the burlap drag finish were unchanged by the 1/8 by 1/8 inch rectangular grooves. Longitudinal coefficient of friction measurements were quite erratic for the three 1/8 by 1/8 inch rectangular patterns which were cut in the trowelled PCC surface and very little improvement in frictional properties were obtained. Friction measurements measured at 15 to 45 degrees to the direction of the grooves were much more consistent, and are probably more representative of the actual improvement in the frictional properties of the surface. This is caused by the small contact area of the tire used on the California Skid Tester which may touch as few as 2 grooves during a longitudinal test with the grooves spaced at one inch. If 1/8 by 1/8 inch rectangular grooves are used, the most improvement in skid resistence is provided by the 1/2 inch center to center spacing.

Assuming the Christensen patterns do not wear excessively, all three of the patterns tested appear to be superior to the 1/8 by 1/8 inch grooving patterns in terms of the measured coefficient of friction. However, the use of rectangular longitudinal grooves at a number of field locations has resulted in a marked reduction in wet weather accidents. Further studies are required prior to recommending any specific pattern.

KEY WORDS: Pavements, surfaces, pavement surface texture, skid resistance testing, pavement skidding characteristics, grooving portland cement concrete pavements, coefficient of friction.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Christensen Diamond Services Company for their cooperation in preparing the various grooving patterns used in this project.

This is the fourth in a series of interim reports on a research project to determine the skid resistence of pavement surfaces. This work was done in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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INTRODUCTION

Various grooving patterns have been used to improve the skid resistance of a number of California highway surfaces. Although grooving was first used to improve skid resistance in California about ten years ago, grooving was not used extensively in this state until about three years ago. A number of different grooving patterns have been used such as 1/8 inch wide by 1/8 inch deep rectangular grooves spaced at 1/2 inch, 3/4 inch or 1 inch centers or the style 15 pattern produced by the Christensen concrete planer (see figure 1). All but one of the field projects were cut in PCC surfacing. In one special case, a dry and brittle asphalt concrete pavement was grooved. Due to the fear that this pavement might be subject to ravelling, it was decided that 1/4" by 1/4" rectangular grooves on one inch centers might prove more practical than 1/8" by 1/8" grooves. Shortly after this grooving pattern was completed, complaints were received from operators of motorcycles and light cars. They complained that the vehicle tended to "track" and appeared to be caught in a manner resembling being caught in street car tracks.

Since a number of different grooving patterns have been used, there has been considerable conjecture as to the type of pattern which is best for improving skid resistance and maintaining the improved skid properties for an extended period of time. There is, however, very little data available to indicate which type of grooving pattern is most efficient.

This project was initiated to evaluate the effect of six different grooving patterns on the surface friction properties of a portland cement concrete slab.

CONCLUSIONS

1. Higher coefficients of friction were obtained on the number 6, 7 and 15 grooving patterns of the Christensen Diamond Services Company than were obtained on 1/8" by 1/8" rectangular grooves spaced at 1/2", 3/4" or one inch centers.

2. When the initial coefficient of friction was 0.35, it was not changed by 1/8" by 1/8" rectangular grooves cut at any of the 3 spacings used in this test.

3. Longitudinal coefficient of friction measurements were quite erratic for the three 1/8" by 1/8" rectangular grooving patterns which were cut in the trowelled PCC finish and very little improvement from the original low values was noted. The erratic friction values and part of the reason for the small improvement in the skid resistance of this surface is explained by the small contact area of the tire on the California Skid Tester. With such a small contact area, only a few grooves are contacted, and slight variations in the lateral placement of the skid tester may cause sizeable changes in the measured coefficient of friction. This was confirmed by the finding that friction measurements made at an angle to the grooves were much higher. Resolution of this problem may be expected when grooved test sections are measured with the ASTM Towed Trailer unit.

CONSTRUCTION DETAILS

Two five feet by fifty feet PCC test slabs 0.3 feet thick were poured on the grounds of the Materials and Research Laboratory of the California Division of Highways on November 9th and 10th, 1967.

A six sack mix using one inch maximum size aggregate from Teicherts' Ready Mix Plant was used. The concrete was mixed to produce a two inch slump and was placed by hand. The slab placed on November 9, 1967 was given a smooth trowelled finish and the slab placed the following day was given a burlap drag finish. A pigmented curing seal, such as is generally used on PCC pavements placed in California, was used to cure the slabs.

INITIAL SKID RESISTANCE MEASUREMENTS

Preliminary coefficient of friction measurements were made on February 26, 1968 with the California Skid Tester (1). Measurements were made in the longitudinal and transverse direction and also at a 45° angle. The results of this testing were quite uniform as can be seen by referring to Table 1. The test values were measured in the central portion of ten test areas located in the middle forty feet of each test slab.

GROOVING

Six different grooving patterns were cut in each test slab on March 5, 1968, with a Christensen concrete planer. Rectangular grooves 1/8 inch wide by 1/8 inch deep at 1/2 inch, 3/4 inch and one inch center to center spacings and the number 6, 7 and 15 grooving patterns of the Christensen Diamond Services Company were used (Figures 1 and 2). The location of each of the grooving patterns on the slabs is shown in Figure 3. Due to the fact that the center of the south end of the trowelled slab was low, two passes with the number 15 pattern were necessary before the center of the slab could be grooved. For the same reason, an extra deep cut was used with the number six pattern on the trowelled slab. All the remaining grooves were cut at normal depth. The number 7 pattern was not cut for as long a distance as the other patterns because the machine started slipping sideways due to the smoothness of the trowelled surface and the fact that the slab had about a four percent cross slope. Figure 4 shows a close-up photograph of Christensen's number 6 pattern. The number 7 pattern is quite similar since it has the same dimensions for the grooves but has 57 grooves per foot while the number 6 pattern has 47 grooves per foot. Figure 5 shows the concrete planer operating in the background while in the foreground the 1/8 inch by 1/8 inch rectangular grooves at one inch centers are shown.

FRICTION MEASUREMENTS OF GROOVING PATTERNS

Coefficient of friction measurements of the grooving patterns were made on April 9, 1968. Longitudinal, transverse and tests at an angle of 45 degrees were measured as in the original series of tests. The results of these measurements are shown in Table 2 along with some check tests which were measured on May 1, 1968 and May 3, 1968.

Coefficient of friction measurements were measured on six different rectangular grooving patterns on the north bound center lane of the El Cerrito Overpass on October 8, 1962. Testing was done parallel to the grooves and at 90°, 45°, 30° and 15° to the grooves. Since the method of measurement was similar to that used during this investigation, the data from the El Cerrito Overpass is being included in this report as Table number 3. The grooves measured on this project were all cut 1/8 inch wide but two depths; 1/16 inch and 1/8 inch and three blade spacings; 1 inch, 1/2 inch and 1/4 inch were used. Due to the high traffic volume on this route, we have not been able to check the coefficient of friction on these test sections since 1962.

ANALYSIS OF RESULTS

The initial coefficient of friction values shown in Table 1 indicate quite uniform surface textures were attained on both test slabs. We had hoped to produce a lower coefficient of friction on the burlap drag surface because there would normally be no need to groove a surface with a coefficient of friction as high as that recorded.

The data in Table 2 for the 1/8 inch by 1/8 inch grooves on the burlap drag surface show no change from the original friction measurements. Also, these friction values remained quite consistent with respect to the direction in which the measurement was made. It appears, therefore, that the 1/8 inch by 1/8 inch rectangular grooves at 1/2 inch, 3/4 inch and one inch center to center spacing have no effect on the coefficient of friction as measured with the California Skid Tester when the initial coefficient is as high as 0.35.

Since the numbers 6, 7 and 15 grooving patterns of the Christensen Diamond Services Company are designed to completely remove the upper surface of the pavement, the measurements of each of these grooving patterns on both the trowelled and the burlap drag finishes are comparable. On the whole, these patterns produced a higher coefficient of friction than did the 1/8 inch by 1/8 inch grooves. With the exception of the number 7 pattern on the burlap drag finish, all of the Christensen patterns tended to produce higher coefficients in the longitudinal direction, lesser values at a 45 degree angle and the lowest values transversely. The reverse was found for the number 7 pattern on the burlap drag finish. This is possibly explained by the fact that the central area of this portion of the slab was not completely removed and the frictional properties of the original surface may have influenced the longitudinal measurements more than those which were measured at 45 degrees or transversely. The sloping surfaces of the sides of the lands between the grooves of the Christensen patterns tend to be lightly polished due to the high speed cutting action of the diamond cutting head. This polished surface is apparently the cause of the reduced coefficient of friction in the transverse direction. The deeper the cut the greater the effect of the polishing action, because the deeper cuts get further into the coarse aggregate of the concrete which polishes more readily than does the morter.

The coefficient of friction values measured in the longitudinal direction on the trowelled surface showed very little improvement due to the 1/8 inch by 1/8 inch rectangular grooving patterns. This was particularly true for the 3/4 inch and one inch spacings of the grooves. When these surfaces were tested at a 45 degree angle the coefficients improved markedly to a level nearly equivalent to that measured on the original burlap drag surface. The transverse values on these surfaces were intermediate between the longitudinal and the 45 degree angle coefficients. This effect is probably due to the action of two forces which tend to cancel each other. When the coefficient of friction is measured longitudinally, the tangential velocity of the wheel forces the film of glycerine, which is used as a lubricant during this test, straight down the channels provided by the grooves. When the test is run transversely, the film of glycerine is forced down at the side of the channels provided by the grooves and must then flow at right angles to its original direction. This must create great turbulence and decrease the rate of drainage of the film of glycerine which is originally between the tire and pavement at the start of the test. It is apparent that the drainage of the film of glycerine would then be faster when the test is performed longitudinally and would gradually decrease to its lowest level as the angle at which the test is performed is increased to 90 degrees. The effect of the angle at which the coefficient of friction is measured is only significant when the grooved surface was initially very smooth. Otherwise, the roughness of the ungrooved surface would provide adequate drainage in any direction at which the test is performed. The other force which is dependent upon the angle at which the coefficient of friction is measured is the frictional force which is directly produced by the grooves. When the measurement is made longitudinally, only portions of the tire print which are about the same width as the grooves, contact the rough sides of the grooves. As the angle at which the test is performed is increased more and more of the tire contact area encounters the grooves. Since the tire print is about four inches long, all of the contact area encounters grooves, which are spaced at one inch centers, at an angle of about 12 degrees or more. The test angle at which all of the tire print contacts the grooves decreases proportionally as the spacing between the grooves is decreased. The highest value of the coefficient of friction for grooved surfaces as measured with the California Skid Tester appears to be obtained when the test is performed at the smallest angle which insures complete contact of the tire print with the grooves since the smaller the angle the better the drainage for the test. This explains the reason for the higher values measured at 45 degrees shown in Table 2 for the trowelled PCC finish and the generally higher values for the tests measured at 15 degrees which are shown in Table 3.

On May 17, 1968, as a check on this conclusion, a series of measurements were made at angles of 5, 10 and 20 degrees on the 1/8 by 1/8 inch rectangular grooves in the trowelled surface. This data was combined with the measurements which were previously obtained and this information is presented as Figure 6. This figure shows the coefficients are nearly at their maximum values at an angle of 15 degrees and remain essentially at that level to an angle of 45 degrees and then gradually decrease to a lesser value at 90 degrees. This experiment tends to confirm our previous conclusion. Further evidence was visually noted during this testing. At the conclusion of a test at an angle which was too slight for the grooves to completely cover the contact area of the test tire, the portions of the tire that were in the grooves were relatively dry and the portions which were between the grooves were still quite wet.

The longitudinal coefficient of friction measurements which were made on the 1/8" by 1/8" grooving patterns on the trowelled PCC surface produced a wide range of values for each of the three groove spacings and very little improvement from the original low values were obtained. (See Table 2) The variation in these values and some of the reason for the small improvement in the friction measurements is explained by the small contact area of the tire on the California Skid Tester. When tested in the longitudinal direction the tire of the skid tester can touch from 2 to 3, 3 to 4 or 5 to 6 grooves respectively on the one, 3/4 or 1/2 inch spacings for the 1/8 by 1/8 inch rectangular grooves depending on the position of the grooves with respect to the centerline of the tire of the skid tester. For this test surface this effect could cause a spread of 0.04 to 0.06 in the measured coefficients of friction. When the normal error due to the repeatability of the tester and nonuniformity of the pavement surface is added to this error, the variation in these values is adequately explained.

Since a normal automobile tire has about twice the contact width of the tire used on our skid tester, the longitudinal test values undoubtedly underestimate the improvement in skid resistance for the 1/8" by 1/8" grooved surfaces. The tests which were measured at a 15 to 45 degree angle probably are a more accurate indication of the actual improvement in skid resistance which a typical automobile tire would experience due to the 1/8 inch by 1/8 inch rectangular grooving patterns. This would be particularly true when a vehicle is rounding a curve since the wheels would be contacting the grooves at an angle during such a maneuver. This assumption will be checked after we obtain a towed trailer type skid tester.

At this point only the first phase of this study is complete. We now plan to build a mechanized wheel polishing machine which will make a multitude of passages over these surfaces to see how well they maintain their skid resistant properties under an action similar to that produced by normal highway traffic.

REFERENCES

1. Hveem, F. N., Zube, E. and Skog, J., " California Type Skid Resistance Tester for Field and Laboratory Use", Proceedings First International Skid Prevention Conference, Part II, 1959.

2. Zube, E., Skog, J. B. and Kemp, G. R., "Field and Laboratory Studies on Skid Resistance of Pavement Surfaces", State of California, Department of Public Works, Division of Highways, Materials and Research Department, Research Report 633126-2, February 1968.

TABLE 1

COEFFICIENT OF FRICTION MEASUREMENTS
ON UNGROOVED SURFACES

Test Area	Type of PCC Finish					
	Trowelled			Burlap Drag		
	Longi-tudinal	Diagonal	Transverse	Longi-tudinal	Diagonal	Transverse
1	.14	.13	.14	.32	.35	.35
2	.13	.14	.14	.35	.36	.36
3	.14	.14	.14	.35	.35	.36
4	.12	.12	.12	.33	.35	.35
5	.12	.12	.12	.34	.34	.35
6	.13	.12	.12	.35	.37	.38
7	.14	.14	.14	.34	.36	.37
8	.13	.12	.14	.36	.38	.37
9	.16	.15	.16	.35	.34	.35
10	.15	.14	.13	.36	.36	.36
Average	.14	.13	.14	.35	.36	.36

See figure 3 for location of test areas.

Note: The coefficient of friction readings have been corrected for grade, and represent those obtained when a vehicle with smooth tires locks its brakes on a wet pavement traveling at 50 m.p.h.

TABLE 2

COEFFICIENT OF FRICTION MEASUREMENTS
ON THE VARIOUS GROOVING PATTERNS

Grooving Pattern	Trowelled PCC Finish									Burlap Drag PCC Finish								
	Longitudinal			45° Angle			Transverse			Longitudinal			45° Angle			Transverse		
	1*	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
No. 7	.42		.41	.34		.40	.32			.36	.31		.37	.37		.42		
	.40		.39	.34		.37	.32			.34	.37		.36	.42		.40		
	Ave.	.41		Ave.	.36		Ave.	.32		Ave.	35		Ave.	.38		Ave.	.41	
1/8" x 1/8" @ 3/4" centers	.20	.15	.15	.32		.33	.28			.33	.32		.35	.33		.34		
	.19		.16	.32		.34	.28			.33	.35		.32	.33		.36		
			.14															
	Ave.	.17		Ave.	.33		Ave.	.28		Ave.	.34		Ave.	.34		Ave.	.36	
1/8" x 1/8" @ 1/2" centers	.29	.23	.24	.34		.33	.26			.33	.34		.32	.35		.36		
	.27	.25	.27	.34		.34	.27			.36	.36		.35	.33		.35		
			.22															
			.20															
	Ave.	.25		Ave.	.34		Ave.	.27		Ave.	.35		Ave.	.34		Ave.	.36	
1/8" x 1/8" @ 1" centers	.23	.16	.19	.29		.30	.25			.35			.33	.33		.32		
	.25	.20	.18	.28		.31	.25			.33			.32	.31		.32		
			.17															
			.15															
	Ave.	.19		Ave.	.30		Ave.	.25		Ave.	.34		Ave.	.32		Ave.	.32	
No. 6	.37		.35	.32		.37	.32			.42			.39	.41		.34		
	.39		.38	.32		.37	.31			.38			.38	.38		.31		
			.38															
	Ave.	.37		Ave.	.35		Ave.	.32		Ave.	.40		Ave.	.39		Ave.	.33	
No. 15	.40		.37	.35		.35	.31			.38			.40	.41		.35		
	.40		.35	.34		.37	.32			.40			.37	.39		.35		
	Ave.	.38		Ave.	.35		Ave.	.32		Ave.	.39		Ave.	.39		Ave.	.35	

*Date measured: 4-9-68 in column 1, 5-1-68 in column 2 and 5-3-68 in column 3
Note: The coefficient of friction readings have been corrected for grade, and represent those obtained when a vehicle with smooth tires locks its brakes on a wet pavement traveling at 50 mph.

TABLE 3

COEFFICIENT OF FRICTION MEASUREMENTS

El Cerrito Overpass
(IV-Ala-7-Alb)

Section Designation & Depth of Cut & Width of Lands	Distance from N.end of bridge	Readings parallel with cut	Readings at 90° angle of saw cut	Readings at 45° angle of saw cut	Readings at 30° angle of saw cut	Readings at 15° angle of saw cut
Section #1	400'	.31	.29			
1/8"deep 1/4"wide	375'	.31	.28			
Entire structure	350'	.29	.29	.31	.34	.37
except last 100'	325'	.34	.27			
of N.B. lane 1	300'	.30	.28			
ground with this	275'	.31	.27	.31	.33	.35
cut. Outer Wheel						
Track	Ave.	.31	.28	.31	.34	.36
Section #2	75'	.35	.28			
1/16"deep 1/4"wide	50'	.34	.28			
2' strip next to	25'	.35	.31	.32	.33	.34
curb. N.B. Lane 1						
	Ave.	.35	.29	.32	.33	.34
Section #3	75'	.32	.28			
1/8"deep 1"wide	50'	.34	.33			
2' strip 100' long	25'	.36	.32			
next to Section						
#2	Ave.	.34	.31			
Section #4	75'	.27	.26			
1/6"deep 1"wide	50'	.26				
2' strip 100' long	25'	.26	.30	.27	.34	.30
next to Section						
#3	Ave.	.26	.28	.27	.34	.30
Section #5	75'	.31				
1/16"deep 1/2"wide	50'	.33				
2' strip 100' long	25'	.28	.28			
next to Section						
#4	Ave.	.31	.28			
Section #6	75'	.32	.29			
1/8"deep 1/2"wide	50'	.31				
2' strip 100' long	25'	.32	.29	.32	.32	.31
next to Section						
#5	Ave.	.32	.29	.32	.32	.31

Note: The coefficient of friction readings have been corrected for grade and represent those obtained when a vehicle with smooth tires locks its brakes on a wet pavement traveling at 50 m.p.h.

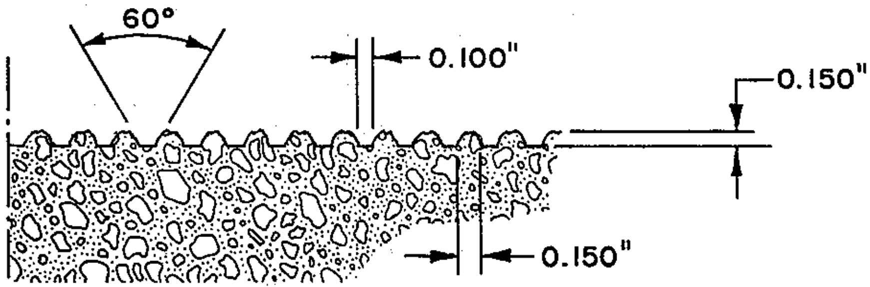
All grooves 1/8 inch wide.

Figure 1

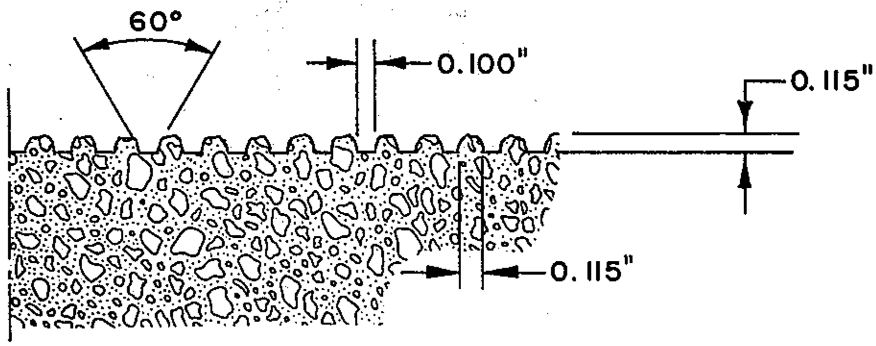
CHRISTENSEN STYLE 15 GROOVES

Figure 2

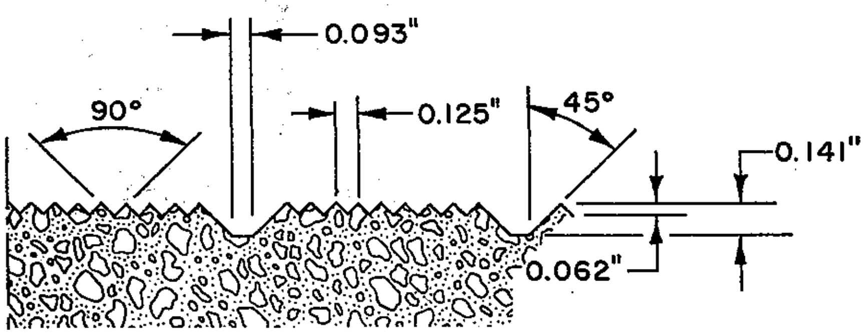
CHRISTENSEN GROOVING PATTERNS



STYLE 6 - 47 GROOVES PER FT.



STYLE 7 - 57 GROOVES PER FT



STYLE 15

Figure 3

LAYOUT OF GROOVING PATTERNS

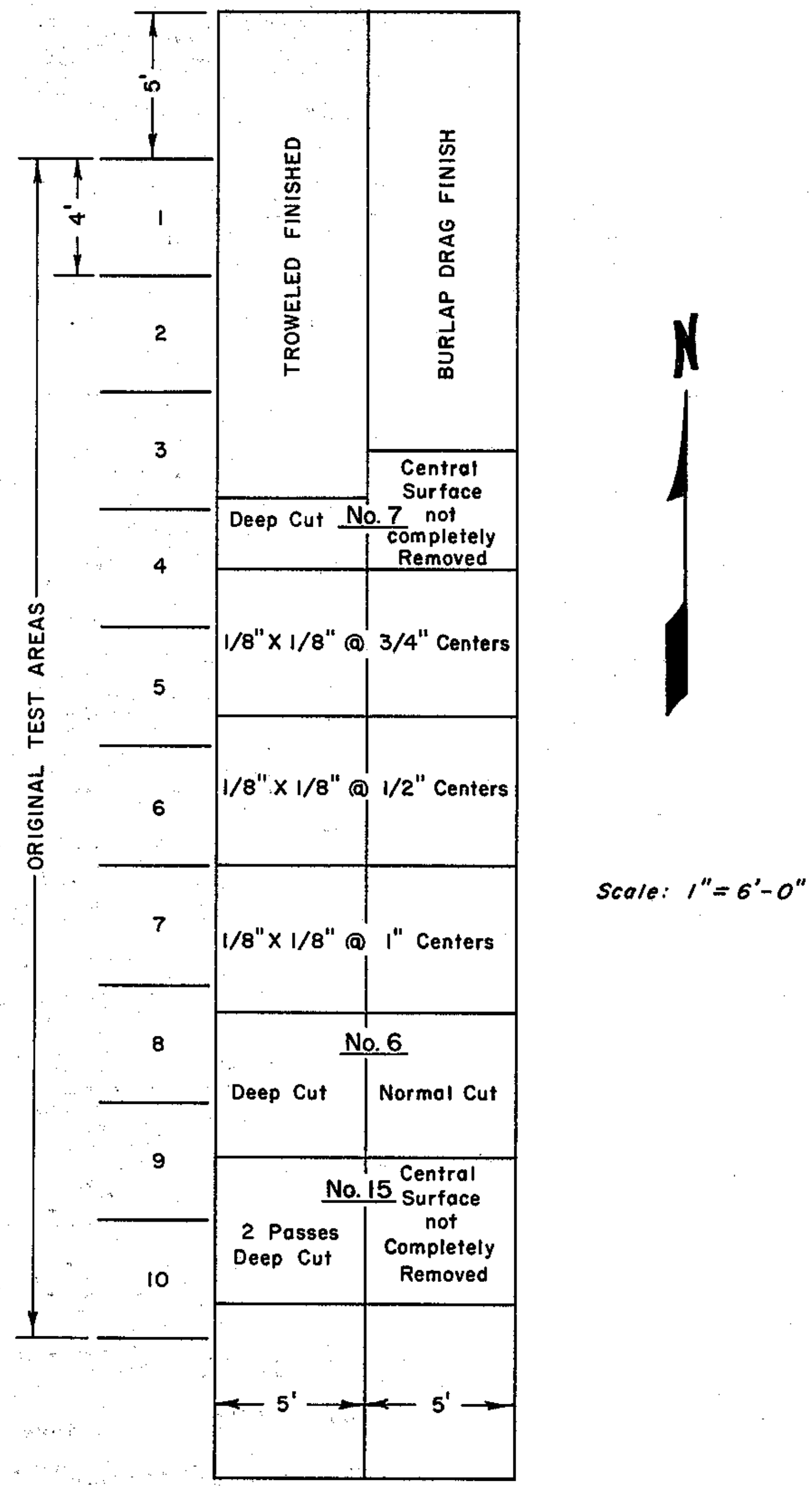


Figure 4

CHRISTENSEN STYLE 6 GROOVES

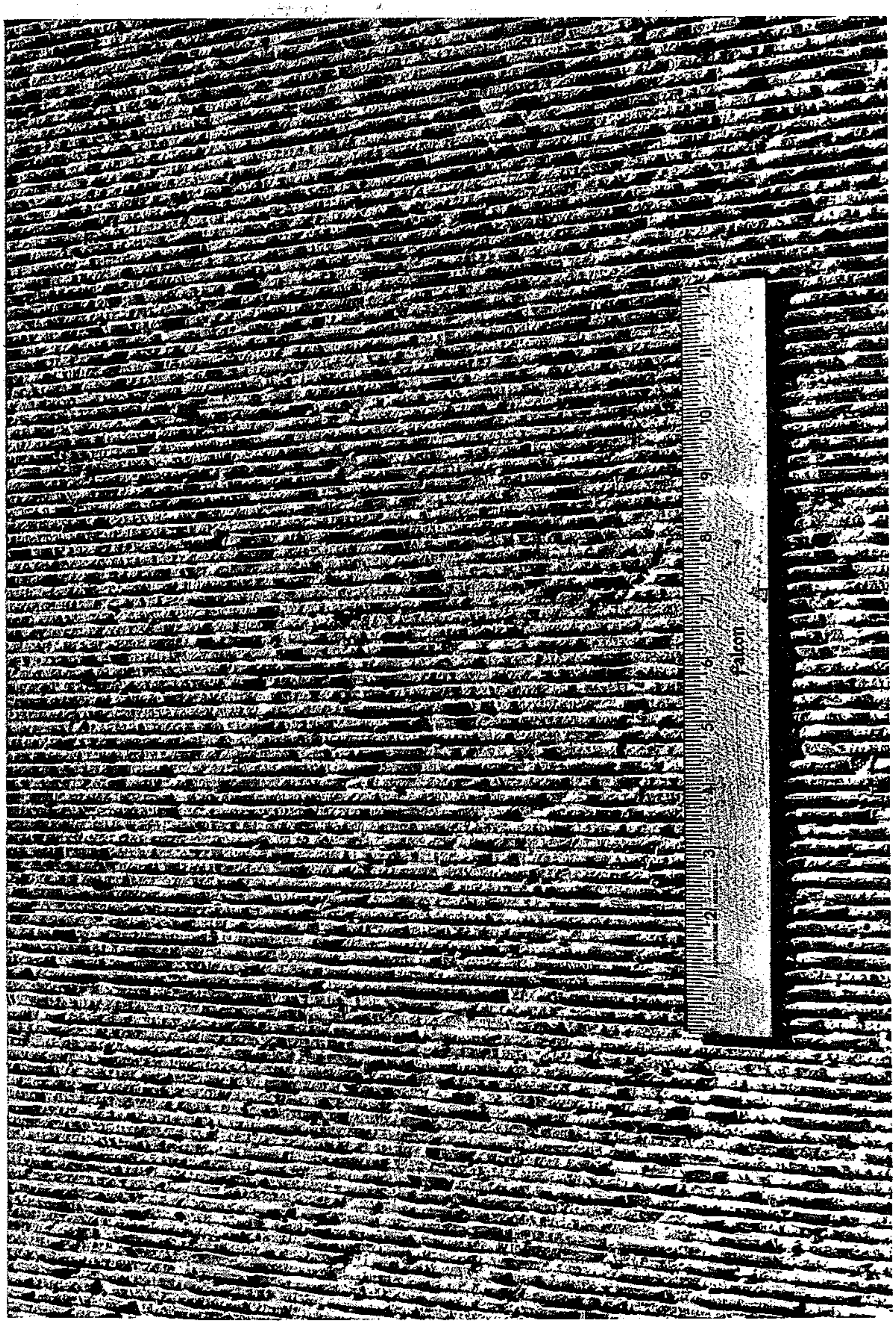


Figure 5

1/8" X 1/8" GROOVES AT 1" CENTERS

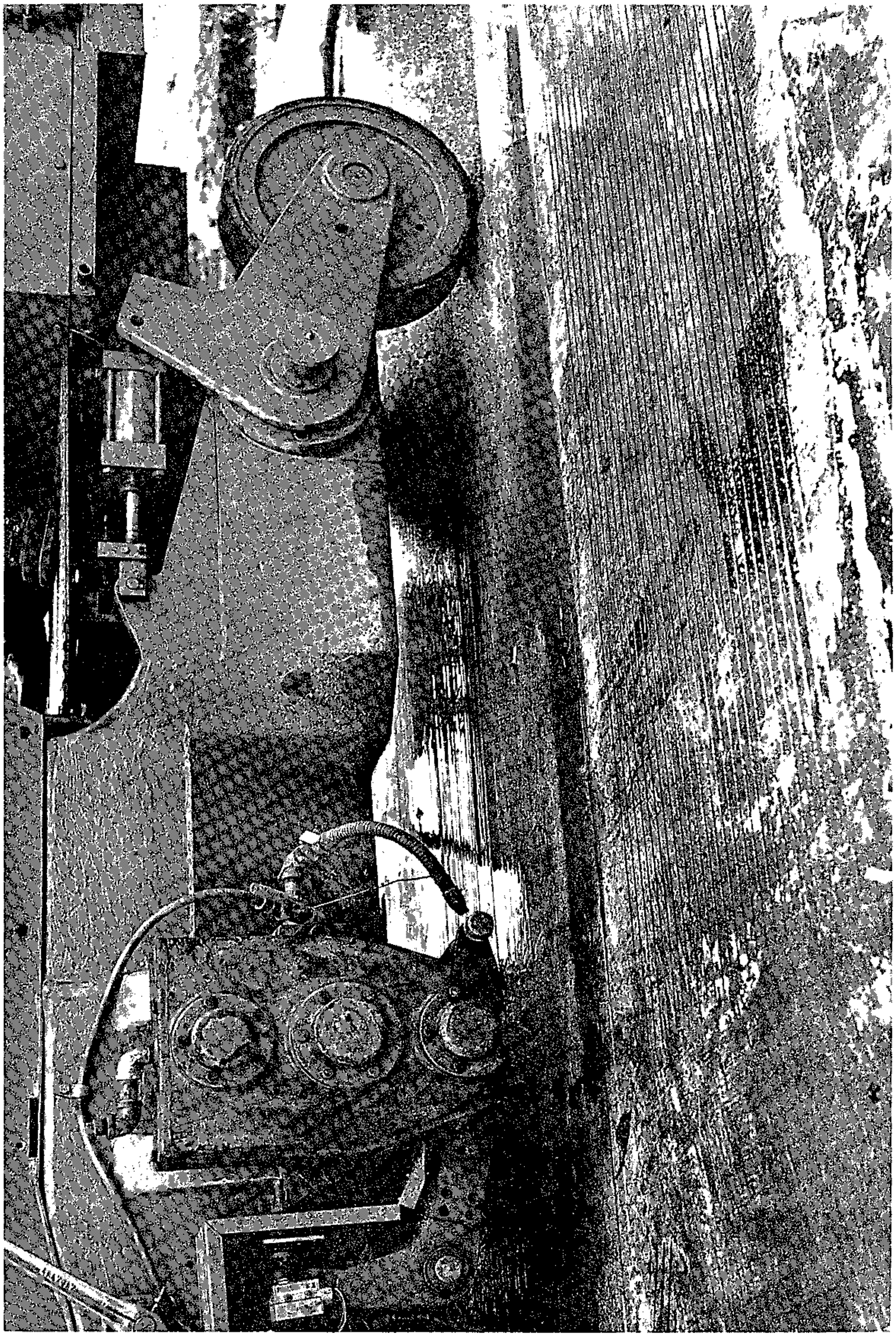
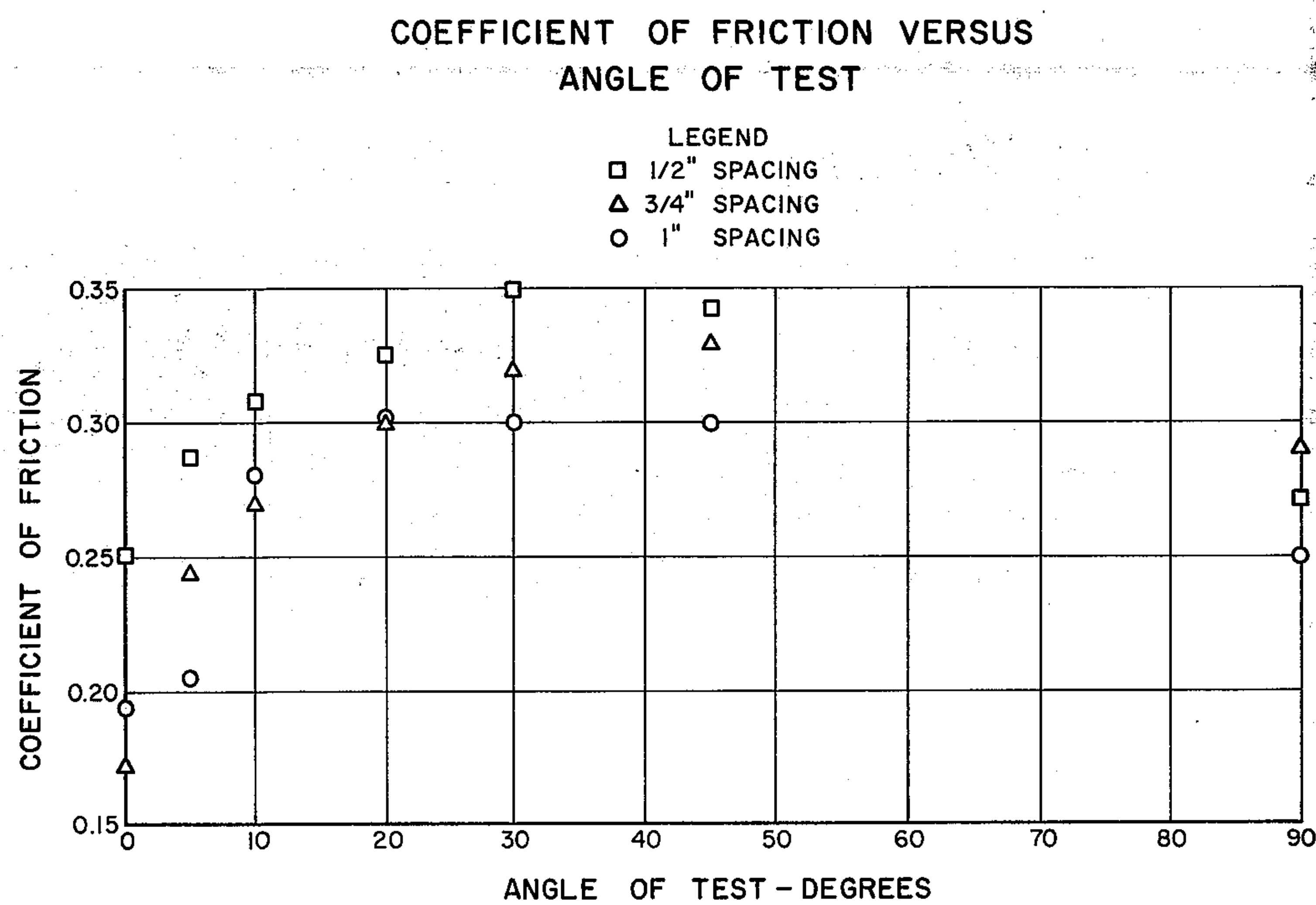


Figure 6


COEFFICIENT OF FRICTION VERSUS
ANGLE OF TEST
LEGEND
1/2" SPACING
3/4" SPACING
1" SPACING
COEFFICIENT OF FRICTION
0.35
0.30
0.25
0.20
0.15
0
10
20
30
40
50
60
70
80
90
ANGLE OF TEST - DEGREES