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TEXTURING NEW CONCRETE PAVEMENTS

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(The opinions, findings, and conclusions expressed in this paper are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Several texturing experiments on heavily traveled portland cement concrete pavements in Virginia are described. Included in the experiments were textures imparted by a heavy burlap drag, metal tines (transverse and longitudinal striations), sprinkled aggregate, mortar removal, and imprinting. All textures were imparted to concrete in the plastic state. Some of the problems encountered in achieving the desired textures are discussed.

Evaluations of the effectiveness and acceptability of the textures included noise, roughness, and skid resistance studies. These studies resulted in the rejection for future use of several textures for one or more reasons. A consideration of all factors gave strong indications that the transversely tined grooves spaced 19 mm (3/4 in.) on centers and the longitudinally tined grooves spaced 19 mm (3/4 in.) in combination with transverse grooves spaced 76 mm (3 in.) are preferred.

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INTRODUCTION

Until the increase in traffic volumes and speed limits which accompanied the building of the interstate system, Virginia had experienced no difficulty with skid resistance on portland cement concrete (PCC) pavements. For the most part, this type of pavement was built in the eastern portion of the state where polish resistant silicious aggregates and sands abound. The stopping distance number at a test speed of 64 kph (40 mph) of 40 (SDN_{40}) that the state has attempted to provide on its primary system was easily maintained for the life of the pavement surface. In fact, there is no recollection of problems with wet pavement accidents on PCC pavements nor SDN_{40} values as low as 45 with the pre-interstate traffic volumes and speed limits. It should be remembered that prior to the building of the interstate, the maximum traffic volume on a dual-divided PCC pavement in the state was about 25,000 average vehicles per day (AVD) and the speed limit was 96 kph (60 mph). When it is realized that with the coming of the interstate system these figures were increased to about 90,000 AVD and 113 kph (70 mph), it can be understood that some relatively low SDN_{40} values of around 40 were found, and that there was a relatively high percentage of wet pavement accidents on some PCC interstate highways. (1) The relatively low skid numbers and pavement surfaces that had become rather smooth combined with bald tires and thick films of water to present a potential for hydroplaning.

In an attempt to remedy the problems accompanying increased traffic volumes and speeds, a project was undertaken to devise means of providing durable surface finishes for new concrete pavements that would provide both good skid resistance and enough texture to prevent the buildup of thick water films. Since highly polish resistant materials were already being used in Virginia's concrete pavements, it was obvious that the additional skid resistance needed, as well as the surface drainage to prevent hydroplaning, had to come from a harsh and lasting surface texture.

Little information on harshly textured concrete surfaces was found in the literature, but it was soon learned that other states were recognizing problems similar to those facing Virginia. California had learned of the grooving of airport runways and had done some experimental grooving at high wet pavement accident sites. On the basis of the apparent success in California, Virginia had considered grooving the pavement at several high wet pavement accident sites.

In addition to California's experience, it was learned that Ohio had been experimenting with finishing methods that provided a harsh texture to new concrete surfaces. Arrangements were made for a visit with the materials engineers in Ohio to inspect and discuss with them the test section they had installed.

There it was found that the Ohio Highway Department had asked the contractors to explore methods and equipment for providing a deep texture on the surface of new concrete pavements. The contractors had responded by employing four thicknesses of burlap at three or four passes; rug backing at only one pass; roping or mops attached to the burlap drag; longitudinal grooving with a coarse, plastic bristled broom; and, in some cases where the local aggregate had a low silica content, "seeding" with skid resistant aggregate on the plastic concrete.

Although it would have been desirable to do so, it was not possible to try all of the Ohio experimental finishes in Virginia at that time (1969), because the one scheduled concrete paving project in the state for that year had already been awarded. Consequently, only experimental burlap textures could be scheduled immediately, while the other finishes had to be delayed to permit inclusion of descriptions of the desired surface textures in the advertisements. Beginning with the experiments with burlap, the experimental texturing activities are discussed in the remainder of this report.

TEXTURING EXPERIMENTS

Burlap Texturing

Background

The burlap texturing experiments were conducted on some 48 km (30 mi.) of Interstate Rte. 64 around Charlottesville, Virginia, in 1969 and 1970. The roadway is a 7.3 m (24 ft.) wide by 203 mm (8 in.) thick continuously reinforced concrete pavement.

As indicated above, plans to provide special texturing on the pavement had to be made hurriedly as the paving contracts were let at approximately the same time that the need for harsher textures was realized. Furthermore, since the contracts had been bid under 1966 specifications(2) prohibiting striations more than 1.6 mm (1/16 in.) deep, it was clear that any action that would result in a harsher texture on the pavement would require negotiation with the two paving contractors involved. Subsequently, the contractors agreed to make a reasonable effort to texture the pavements as desired. There was some fear that transverse striations would create undue tire-pavement noise, so it was decided that longitudinal striations would be used. A sample texture block was prepared for the guidance of the contractors.

Procedures and Materials

Paving was begun in late 1969. Project personnel had the sample texture block for comparison purposes, and state personnel were on hand to observe the operations. The concrete met the state's specifications for class A3 paving concrete. (2)

In the paving operations, a slip-form paver placed and screeded the full 7.3 m (24 ft.) pavement width in one pass and a tube float applied the initial finish.

The float unit was equipped with a hydraulic mechanism carrying the burlap drag used to apply the final finish. Following the float was a curing unit that applied either polyethelene sheeting or a liquid membrane. All units in the paving train were remotely controlled transversely by a guideline placed on the edge of the roadway.

Several attempts were necessary before a texture of the desired harshness was achieved with the burlap drag. Success was achieved with one to four passes of the drag—depending upon the consistency of the concrete, the rate of surface drying, and the number of layers of burlap used. Project personnel were required to exercise a good deal of judgement in determining the number of passes to apply under given circumstances. On long sections of pavement, drags consisting of two layers, two or three layers, and four layers of burlap were tried. A four-layer drag with the necessary number of passes was finally determined to be the most effective procedure.

Other factors affecting the texturing procedure were the length of the trailing burlap cords and the condition of the burlap. Trailing cords of 100 mm to 150 mm (4 in. to 6 in.) in length were helpful, while burlap that had accumulated some mortar through use was found to be effective. Again, the judgement of project personnel in applying the proper number of passes was relied upon.

The major technical problems encountered with the heavy burlap texturing were failure to achieve the desired texture because of late application of the burlap drag, and obliteration of the texture by the polyethelene sheeting used for curing purposes under certain circumstances (see Figure 1 appended).

The first of these problems was eliminated easily by close attention to the time of texturing to ensure that the burlap drag was applied well before the pavement surface had achieved any significant degree of set. In fact, the concrete used in the slip-form paving operation was very uniform and necessarily of such a consistency that texturing was possible immediately after floating.

The second problem was solved by using a liquid membrane curing compound in lieu of the polyethelene sheeting. The curing compound was applied approximately at the time the sheen disappeared from the concrete surface so that the texture was not affected by the curing operation. Subsequently, polyethelene sheeting was used only in special cases, such as when it became necessary to protect the surface from heavy rains or during extremely cold weather. In the latter case, the sheeting was not applied until there was no danger of damage to the texture.

Discussion of Results

Figure 2 is a photograph of the most desirable texture achieved with the special burlap drag. For comparison purposes, Figure 3 shows a typical light burlap texture found on many of Virginia's pavements prior to the beginning of the present study. Note that the new texture is much more evident to the naked eye. As can be seen in Figure 2, the striations are randomly spaced according to the weave of the burlap. Since both contractors opined that the heavy burlap texture was practically achievable in normal paving operations, it was decided that a similar texture would be used for the remaining pavement in the contracts for I-64 in the Charlottesville area.

The burlap textured pavement was opened to traffic in September 1970. Road roughness tests conducted in the fall of 1970 dispelled suspicions that the pavement would provide a rough ride. Measured roughness values showed that two of the three contracts resulted in the best riding concrete pavements ever tested in the state. The results of these tests are indicated in Table 1, where BPR roughness values are given for each of the three textured projects along with comparative rigid pavement roughness data for the 1965 - 1969 construction seasons. There it can be seen that even the roughest of the textured projects is toward the low side of average roughness values for pavements built during the previous five-year period. A more detailed evaluation of roughness as well as skid resistance and noise is given in a later section of the paper.

TABLE 1

Textured Pavement Roughness

(1.6 km = 1 mi.)

Project No.	Length (km)	Average* BPR Roughness $\frac{\text{units}}{\text{km}}$
1	16.4	40
2	14.8	46
3	13.7	57

* Average roughness of 25 projects constructed during 1965 - 1969 is 61 units/km with a range of 54-88 units/km.

It was concluded that some initial public reactions over poor riding quality were psychologically rooted in the appearance of the texture rather than in actual roughness. There were also a few early adverse public reactions concerning occasional waviness of striations caused by side sway in the hydraulic arms carrying the burlap and the flexibility of the burlap material.

While the burlap texture seemed very satisfactory at the time the pavement was opened to traffic, after it was in service some eight months under a traffic volume of 8,000 AVD there was a significant degree of wear in the wheel paths. This wear was easily discernible from a moving automobile and seemed to be reasonably uniform throughout the pavement sections. It was noted that the loss of texture was inversely related to the initial harshness of texture. Thus, it was believed that pavements having a heavier initial texture would retain their texture longer. This tentative conclusion seems to have been borne out by the pavement's performance over the five years since the earlier observations and by laboratory studies reported by Ozyildirim. (3) Figure 4 shows the wear in the wheel paths after six years under traffic.

The relatively rapid wear of the texture caused concern and the consensus was that the limited area between the asperities tended to make the asperities weak and subject to damage through the abrasive action of vehicle tires, including a small percentage of studded tires. An indicated reduction in the rate of wear with time was believed to result when the sharp points abraded to leave the broader and stronger remains of the asperities. This finding was also supported by Czyildirim. (3) In addition, it was felt that the burlap finish did not provide sufficient channels for water drainage. These observations and tentative conclusions led to experiments with lands and grooves types of texture.

Texturing of Concrete with Metal Tines

Background

At about the time the I-64 pavement at Charlottesville was opened to traffic, contract documents were prepared for two projects totaling 35.2 km (21.9 mi.) of rural I-64 east of Richmond. This roadway was also designed as a divided 7.3-m by 203-mm (24-ft. by 8-in.) continuously reinforced concrete pavement, and it is the main route between western and central Virginia and the coastal area.

To obtain more texture in the pavement surface than either the standard specifications demanded or had been provided by the heavy burlap texture on the Charlottesville projects, the following special provision was made a part of the contract documents.

> As soon as construction operations permit, and before the water sheen has disappeared, the surface of the pavement shall be dragged longitudinally (in the direction of the concrete placement) with a coarse bristled broom or series of such brooms. The drag shall be passed over the fresh concrete one or more times as required to produce a surface texture having characteristics equivalent to the texture which has been produced on sample blocks available for inspection. The ridges and grooves of the texture shall be reasonably straight and parallel with respect to the centerline of the pavement.

Procedures

The sample blocks were prepared in the laboratory utilizing a standard push broom to produce the desired pattern. However, because of the previously noted early wear of the experimental finishes on I-64 at Charlottesville the durability of a broomed concrete surface was questioned and consideration was given to the use of grooved surfaces. The pavements that had been grooved at accident prone locations had resulted in improved safety(4) and the surfaces had proven to be quite durable. For these reasons, it was decided that the surfaces on the two projects being awarded to contract in the Richmond area would more closely approximate the grooved rather than the broomed finishing.

The contractor was approached concerning the feasibility of changing from the planned broomed finish to attempting to impart longitudinal striations similar to grooves. Thus the contractor began the project with a wire comb consisting of 3.2-mm (1/8-in.) wide metal tines on 3.2-mm (1/8-in.) centers. The tines were about 100 mm (4 in.) long. This arrangement did not produce a satisfactory land area, and it tended to displace an excessive amount of mortar. After only a few hundred feet of construction, the contractor was asked to change to a 3.2 mm (1/8 in.) wide tine mounted on 9.5 mm (3/8 in.) centers. These tines were about 180 mm (7 in.) long and set at about a 30° angle to the pavement. The tines were secured in wooden heads similar to the common rectangular push broom head. They were dragged through the fresh concrete with approximately 25 mm (1 in.) of the tine being parallel to the pavement surface. As the tine width wore to about 1.6 mm (1/16 in.), it became necessary to clip the ends to maintain the original width.(5)

From the construction standpoint, the second arrangement was much more satisfactory, but it was still felt that insufficient land area was being produced. After limited operation, the contractor was requested to bend up every other tine, which provided groove spacings on approximately 19-mm ($\frac{3}{4}$-in.) centers. It was agreed that this pattern was satisfactory, and it was used on the remainder of the project. Once the desired pattern was established, no difficulties were encountered with regard to the texturing operation.

The operation was the same as that described for the project on I-64 at Charlottesville; that is, the slip-form paver was followed by a magnesium float, a burlap drag, the texturing apparatus, and a liquid membrane seal. Of course it is realized that more curing liquid is required for the tined texture surface than for the burlapped surface. The concrete met the same specifications as those described for the burlapped project. Even with good control of the consistency of the concrete mixture, the timing of the texturing operation is crucial. The desired depth was 3.2 mm (1/8 in.) and the operator of the texturing machine quickly learned the proper time to start his operation.

Results

When Virginia first started grooving hardened pavements, complaints were received from motorcyclists and operators of compact automobiles to the effect that the grooving tended to override their steering. A review of the findings of a California study regarding motorcycle reactions to grooved pavement dispelled much of this concern;[6] but as a concession to drivers "Grooved Pavement Ahead" signs were placed before the grooved sections.

Since the Richmond projects comprised a much longer stretch of grooved pavement than had been placed before, a public relations effort was undertaken to publicize what was being done with emphasis on the safety aspects of the new type of finish. The results have been very satisfactory. A minimal number of complaints have been received and, as noted previously, they have been largely psychologically based.

The project was opened to traffic in early December 1972. After four years under a traffic volume of 14,000 AVD, the texture shows little sign of wear.

A possible disadvantage of the finish is the tendency of deicing chemicals to remain longer in the grooves than they would on pavement with a smooth surface or some transverse texture and thus cause the concrete to deteriorate at a faster than normal rate. There are no quantitative data to support such a conjecture and, in fact, Virginia concrete technologists feel that if the concrete has a low water/cement ratio and the proper air entrainment and is cured properly, there should be little concern with deterioration from salt action. On the other hand, the retention of the chemicals on the pavement may provide an ice free pavement for an extended period. A factor which could affect the durability of the texture is the use of studded tires; however, this area of Virginia has such a very low incidence of studded tires that this effect is difficult to assess. Obviously, where high percentages of studs are used, this texture, or any other, would not remain very long.

As a result of the experience with the two projects, it was decided to continue finishing concrete pavements with tined grooves until such time that other patterns could be studied. The following special provision was immediately put into effect and then included in the 1974 Virginia Road and Bridge Specifications.

> FINAL FINISH (TEXTURE): The contractor is advised that the surface of the pavement shall have more pronounced ridges and grooves than can be obtained by the normal methods of texturing with burlap or stiff bristle brooms. Prior to the beginning of paving operations, the Contractor shall prepare and submit for approval a sample texture block having a minimum size of 12" x 12" [305 mm x 305 mm], utilizing the texturing device he plans to use on the project. A surface texture having characteristics equivalent to the texture on the approved sample block shall be produced on the concrete pavement. The ridges and grooves of the texture shall be reasonably straight and parallel to the centerline of the pavement.

However, it was also decided that other texturing schemes should be tried, and planning was begun for test sites to be placed on the next PCC pavement contract to be awarded.

Test Sites on International Terminal Boulevard

Background

The advertising schedule for the next PCC pavement contract was such as to allow for the planning of comprehensive experiments. As many texturing schemes as showed promise for providing skid resistance and removing water from the tire-pavement contact area were to be included, and consideration would be given to tire-pavement noise, the practicality of applying the finishes, and costs.

The textures finally decided upon were as follows:

1. Longitudinal striations on 19-mm ($\frac{3}{4}$-in.) centers
2. Transverse striations on 76-mm (3-in.) centers
3. Exposed aggregate
4. Sprinkled aggregate, large
5. Sprinkled aggregate, small
6. Dimpled (imprinted)
7. Transverse striations on 19-mm ($\frac{3}{4}$-in.) centers
8. Combination of longitudinal striations on 19-mm ($\frac{3}{4}$-in) centers and transverse striations on 76-mm (3-in.) centers
9. Transverse striations on 38-mm ($1\frac{1}{2}$-in.) centers

10. Combination of longitudinal striations on 19-mm ($\frac{3}{4}$-in.) centers and transverse striations on 38-mm ($1\frac{1}{2}$-in.) centers

Figure 5 is a sketch of the experimental sections, which are located in the extreme southeastern part of the state where there are relatively few freeze-thaw cycles and the pavements are subjected to small quantities of deicing chemicals during the winter months. Practically no studded tires are used in the area.

The project involved the construction of dual-divided 7.3-m or 7.9-m (24-ft. or 26-ft.) lanes on International Terminal Boulevard between Rte. 564 and the International Terminal in Norfolk. The estimated AVD in 1969 was 11,160, of which 12% were tractor-trailers and busses. The projected 1992 AVD is 21,400, with 12% tractor-trailers and busses. The design speed is 72 kph (45 mph).

Procedures

The project was advertised in June 1972, and the contract was awarded in August. Since the contract was awarded to the same firm that had constructed the 35.2 km (21.9 mi.) of rural interstate just east of Richmond, the equipment was the same as that used to impart the longitudinal striations. This equipment was modified to also impart the transverse and dimpled textures. A wire comb, similar to that used on the pavement in Richmond, having properly spaced tines, was used for the longitudinal and transverse striations, and a steel drum approximately 305 mm (12 in.) in diameter and 1.82 m (6 ft.) long with properly spaced chloroprene blocks epoxyed to it was rolled transversely to produce the dimpled texture.

The exposed aggregate surface was produced by spraying the finished concrete with approximately 32 l/m^2 (7 gal.yd.^{2}) of a commercial retarder and water mixed at a ratio of 5:3 by volume. The retarding mixture was allowed to stand overnight and the mortar was washed from the surface on the day following placement.

The sprinkled surface was obtained by hand distributing the aggregate over the surface of the plastic concrete at an approximate rate of 2.7 ka/m^2 (5 lb.yd.^{2}), Sites 4 and 5 were 45.7 m (150 ft.) long, with site 4 having 19-mm ($\frac{3}{4}$-in.) aggregate and site 5 having 13-mm ($\frac{1}{2}$-in.) aggregate as the sprinkle material. The aggregate was precoated with a cement and water paste, and was rolled into the finished surface of the plastic concrete with a roller 1.8 m (6 ft.) long, 205 mm (12 in.) in diameter, and weighing approximately 113 kg (250 lb.).

Results

Figures 6 through 15 show the textures obtained on the experimental test sections. The caption for each photograph identifies the texture site number assigned in Figure 5. It should be noted that site 1 (Figure 6) was the standard texture at the time the International Terminal Boulevard test sections were installed. Note also that the sprinkle textures on sites 4 and 5 (Figures 9 and 10) are the harshest produced.

While other characteristics of these textures are discussed later, it is of some interest to note the contrast during rain between a section with both transverse and longitudinal striations and one with only a longitudinally tined texture. Figure 16 is a photograph taken during a steady rain with site 8 in the foreground and the conventional longitudinal texture in the background. Note that the transverse texture of site 8 is providing excellent drainage; the pavement appears dry compared to the pavement in the background.

NOISE AND ROUGHNESS STUDIES

In an effort to determine any potential noise or roughness related aversions to the various types of texture, both noise and roughness studies were conducted on each of them. These studies were felt to be essential to the final selection of a texture type for routine paving operations.

Noise Studies

Measurements

Both roadside and interior car noise measurements were conducted on the experimentally textured sections and on several asphaltic concrete surfaces used for comparative purposes. The details of these studies in which a change in noise level (dBA) of 2.5 units was considered significant have been given in separate reports by Noble.[7,8]

The roadside tests were normalized at 77 kph (48 mph) and were conducted with a sound sensing device located 7.6 m (25 ft.) from the center of the traveled lane. These were conducted with both ribbed and snow tires. The interior noise measurements were conducted with only ribbed tires and at a speed of 89 kph (55 mph), with the microphone positioned at approximately the ear level of front seat passengers. In both series of tests, tire pressures were maintained at 19×10^4 to 21×10^4 Pa (28 psi to 30 psi).

The results of both series of tests, summarized in Table 2, can be seen to be generally inconclusive. Although there are some significant differences in the noise levels generated, they are usually related to types of tires or to pavement wear. The exposed aggregate, sprinkle, and dimpled textures tend to be somewhat louder than either the tined textures or the bituminous concrete pavements which generate noises of similar intensities. None of the tined textures were significantly different in noise level except the worn 19-mm ($\frac{3}{4}$-in.) longitudinally tined texture on I-64, which was slightly quieter.

These inconclusive findings led to the conduct of frequency analyses from which it was concluded, in part, that some of the transversely tined textures and the dimpled texture generated noises of relatively pure tones in a frequency range (1000 H_z and greater) where they are more noticeable than noises of equal intensity but of lower frequencies.[7,8] The implication of the finding was that some textures may generate noises objectionable to the human ear, even though of a relatively low noise intensity. For this reason, a subjective evaluation was conducted.

TABLE 2

Summary of Noise (Sound Pressure) Levels and Roughness Tests

(25.4 mm = 1 in.)

Pavement Type	Location	Texture	dBA Roadside Rib Tire	dBA Roadside Snow Tire	dBA In-car Rib Tire	Mays Ride Meter Roughness (units/km)
Bit. Concrete	Various	13 mm max. size	78.8	80.9	61.8	—
Bit. Concrete	Various	19 mm max. size	79.2	81.8	—	—
Surface Treat.	Various	Protruding Agg.	84.3	84.7	61.6	—
PCC	I-64	Harsh Burlap (worn)	—	—	61.6	47
PCC	I-64	19 mm L[a] (worn)	—	—	59.8	44
PCC	Int. Blvd.	19 mm L	82.5	81.1	61.0	64
PCC	Int. Blvd.	76 mm T[b]	79.6	86.3	61.0	61
PCC	Int. Blvd.	19 mm T	—	82.3	60.8	69
PCC	Int. Blvd.	19 mm L + 76 mm T	79.6	84.4	62.3	60
PCC	Int. Blvd.	38 mm T	—	—	61.9	56
PCC	Int. Blvd.	19 mm L + 38 mm T	80.7	83.7	62.2	49
PCC	Int. Blvd.	Exp. Agg.	85.8	84.5	60.0	71
PCC	Int. Blvd.	Sprinkle[c]	85.8	84.5	62.6	108
PCC	Int. Blvd.	Dimpled	86.9	85.1	60.3	53

[a] L = longitudinally tined texture, [b] T = transversely tined texture, [c] The two sprinkle mix sections were treated as one section in both roadside and in-car tests.

Subjective Evaluation

The subjective evaluation was made for only the International Terminal Boulevard texturing experiment. It consisted of roadside and interior car evaluation by five persons involved in the planning of the experiments and the Research Council's noise measurement expert.

The roadside evaluation consisted of 5-minute evaluation periods at each site while normal traffic traversed the site. During these periods the evaluation team stood approximately 7.6 m (25 ft.) from the pavement edge. Each member of the team was asked to consider, for each texture, the noise intensity and pitch, the degree of annoyance, background noise, and the relationships between pavement-tire noise and engine and exhaust noise.

The interior car evaluation was conducted by having the evaluation team ride over the variously textured sections at approximately the 72 kph (45 mph) speed limit in a medium-size car and in a full-size car.

From the subjective evaluations the team reached a strong consensus on the observations given below.

1. Roadside Observation

   (a) For trucks and busses, the engine and exhaust noise completely masked the tire-pavement noise; no effect of pavement texture was discernible.

   (b) For automobiles, while most of the experimental textures were slightly louder than the 19-mm ($\frac{3}{4}$-in.) longitudinally tined texture, the standard at the time, only the sprinkled texture was considered objectionable.

2. Interior Car Cbservation

   (a) The sprinkled, the dimpled, and the 38 mm ($1\frac{1}{2}$ in.) spacing of the tined transverse texture produced discernibly more intense noise, but only the 38-mm ($1\frac{1}{2}$-in.) tined texture was considered objectionable.

Roughness Studies

Roughness tests were conducted in August 1976 on all the experimentally textured sections. These tests were run at 64 kph (40 mph) with a Mays Ride Meter and the results are summarized in Table 2.

The tests were conducted in all lanes included in the texturing experiment. Thus, the results given for the I-64 projects represent the average roughness for 4-lanes, while those given for the International Terminal Boulevard represent the average roughness for 2-lanes.

From the results given, it appears that the worn longitudinally tined textures on I-64 were somewhat smoother than the new textures on the International Terminal

Boulevard. With the exception of the sprinkled aggregate section on the International Terminal Boulevard, all roughnesses measured were in the range considered acceptable for Virginia. The sprinkle aggregate roughness of 108 units/km is significantly rougher than that for any other test section, and probably reflects the difficulty in spreading the aggregate uniformly on the pavement surface and the undulations created by attempting to roll the aggregate into the surface. None of the tined textures had roughness values outside the normally expected range, and the variations occurring very likely were related to problems inherent in constructing the very short sections represented by the tests. These findings are in agreement with those from a similar study conducted in Louisiana.[9]

From the tests and the above discussion it is concluded that roughness considerations would not dictate the type of texture desired, with the exception of eliminating sprinkle type applications.

SKID RESISTANCE STUDIES

There are two major areas of concern when designing pavement surfaces that will provide enough tire-pavement friction to assure vehicle stability. The first is to fabricate the surface with polish resistant materials so that sufficient friction can be maintained between the tire and pavement surface when thin films of water are present. As mentioned earlier, this consideration has not presented a problem in building PCC pavements in Virginia, since highly polish resistant silicious aggregates abound in the eastern portion of the state where such pavements are popular. The second concern is to provide sufficient means for water drainage so that only thin films of water will be encountered.

The potential skid resistance can be measured through the use of ASTM Test Method E274-70 but, since the tire used in this test method has good tread and thus provides channels for water passage, the test method is inadequate for evaluating the capacity of the pavement surface to provide drainage. To circumvent this problem, the authors performed skid tests with two types of tires—treaded for the evaluation of skid resistance and bald or untreaded tires for the evaluation of the surface drainage potential.

It should be remembered that in the ASTM E 274-70 Test Method only a thin film of water is applied and therefore there is little need for water escape passages for low test speeds. However, as test speeds increase, the escape channels are needed more and more and, even with the thin films of water used in the ASTM test, skid numbers will deteriorate rapidly when bald tires are employed—unless the pavement surface provides a good means for water escape.

Skid tests were conducted on all the experimental test sections on several occasions, at multiple speeds, and with both the treaded and untreaded tires. However, on only one occasion were the tests performed on all of the section during the same week. As is well known, skid numbers vary with varying weather conditions; so for reasons of clarity and simplicity, only the tests performed between July 29 and August 4, 1976, are discussed here. The reader is assured that no data have been omitted which would change the findings. The skid data are shown in Table 3.

TABLE 3

Skid Number as a Function of Texture, Vehicle Speed and Tire Tread
(25.4 mm = 1 in. : 1 kph = 0.60 mph)

Texture	Vehicle Speed									
	32 kph		48 kph		64 kph		80 kph		96 kph	
	T. T.[a]	B. T.[b]	T. T.	B. T.	T. T.	B. T.	T. T.	B. T.	T. T.	B. T.
I-64 Burlapped										
Traffic Lane	62	42	58	29	51	20	46	19	42	16
Passing Lane	71	50	69	39	61	35	56	28	54	23
I-64, 19 mm L[c]	62	48	62	46	56	36	54	34	52	30
Int. Blvd., 19 mm L	58	48	54	41	50	33	46	32		
Int. Blvd., 76 mm T[d]	63	52	52	42	49	37	47	34		
Int. Blvd. Washed Mortar	56	51	52	47	48	33	46	37		
Int. Blvd. Sprinkle Agg. (small)	57	49	51	42	46	39	43	39		
Int. Blvd. Sprinkle Agg. (large)	53	47	49	41	43	37	42	37		
Int. Blvd. Dimpled	62	45	55	33	51	26	46	23		
Int. Blvd., 19 mm T	66	58	60	51	54	47	52	39		
Int. Blvd. 19 mm L + 76 mm T	63	58	60	51	57	43	53	40		
Int. Blvd., 38 mm T	62	56	60	50	55	41	50	37		
Int. Blvd. 19 mm L + 38 mm T	62	59	59	50	56	47	52	43		

[a] Treaded tire = T. T.
[b] Bald tire = B. T.
[c] L = Longitudinally tined texture
[d] T = Transversely tined texture

The first thing to note in the table is that the skid numbers for the treaded tire tests are excellent for all surfaces, regardless of the texture; in fact, the highest number shown is for the passing lane of the burlapped surface. These findings should be expected when it is remembered that the tires provide ample escape for the thin films of water applied for the ASTM test. On the other hand, the bald tire test results for the burlapped and the dimpled surfaces are quite low. Not only does this indicate that with bald tires one could expect little tire-pavement friction in a moderate rain, but that during a heavy rain a well-worn tire might also lack friction, as the tread might be insufficient to provide escape for the water.

Each of the other surfaces provided good to very good skid resistance. When the bald tire test results are examined carefully, the surfaces are rated in the following order.

1. 19 mm L + 38 mm T ($\frac{3}{4}$ in. L + $1\frac{1}{2}$ in. T)
2. 19 mm T ($\frac{3}{4}$ in. T)
3. 19 mm L + 76 mm T ($\frac{3}{4}$ in. L + 3 in. T)
4. 38 mm T ($1\frac{1}{2}$ in. T)
5. Sprinkled aggregate
6. Washed mortar
7. 76 mm T (3 in. T)
8. 19 mm L ($\frac{3}{4}$ in. L)
9. Dimpled
10. Burlapped

While at least the first eight of these surfaces appear to be acceptable with respect to skid resistance, there are other factors, some of which have already been mentioned, that need to be considered. The authors feel that even though the washed mortar surface provides good skid resistance, it will wear rather rapidly and approach the same condition as the burlapped surface in a very few years. Further, there is quite a bit of additional expense in this finishing process.

The sprinkled aggregate surfaces also add considerable expense to the finishing operation and, as discussed earlier, produce more noise than some of the other surfaces. Since Virginia has a sufficient quantity of polish resistant aggregate, sprinkling does not seem feasible; but for states where polish resistant aggregates are scarce, this means of providing skid resistance might prove to be quite desirable.

As mentioned earlier, the 38-mm ($1\frac{1}{2}$-in.) transverse surface produces an undesirable noise inside the traveling vehicle. Since other surfaces provide as good or better skid resistance, this surface should not be considered. This finding would, of course, also eliminate the 19 mm ($\frac{3}{4}$ in.) longitudinal + 38 mm ($1\frac{1}{2}$ in.) transverse surface.

For the remaining four surfaces — 19 mm ($\frac{3}{4}$ in.) longitudinal, 76 mm (3 in.) transverse, 19 mm ($\frac{3}{4}$ in.) transverse, and the 19 mm ($\frac{3}{4}$ in.) longitudinal + 76 mm (3 in.) transverse — the limited amount of data available appear to indicate that the latter two provide the better skid resistance. Both of these surfaces provide channels for lateral runoff, while the last named also has been credited with providing lateral stability on curves. Of course, the 19 mm ($\frac{3}{4}$ in.) transverse surface provides the most channels for lateral runoff, and the 19 mm ($\frac{3}{4}$ in.) longitudinal + 76 mm (3 in.) transverse finish may add to lateral stability on curves. The operation required to provide either of these two finishes should add little or no cost to the placement of the pavement.

CONCLUSIONS

Prior to itemizing the conclusions of the paper, the authors wish to remind the reader that in providing a skid resistant pavement the most important requirement is that the surface be fabricated with polish resistant aggregates. The best texturing techniques known can be applied, but if the aggregates are polish susceptible, the pavement will become slippery. With this thought in mind the following conclusions are presented.

1. With present-day traffic volumes, a burlap drag alone does not provide the initial harshness desired on a PCC riding surface.

2. The burlap drag finish applied to I-64 at Charlottesville was much harsher than previous burlap finished surfaces in Virginia, but the wear with age was substantial.

3. Since the tined surface on I-64 east of Richmond has been subjected to 14,000 AVD for four years and has shown little wear, it is felt that, in the absence of studded tire traffic, tined surfaces will provide an adequately harsh surface for many years under most traffic conditions.

4. The surfaces in this study provide a good to very good skid resistance. A careful examination of the bald tire test results shows that the highest ratings were given (1) the tined surface with longitudinal striations 19 mm ($\frac{3}{4}$ in.) on centers and transverse striations 38 mm ($1\frac{1}{2}$ in.) on centers; (2) the transversely tined surface with striations 19 mm ($\frac{3}{4}$ in.) apart; (3) the surface with longitudinal striations 19 mm ($\frac{3}{4}$ in.) on centers and transverse striations 76 mm (3 in.) on centers; and (4) the surface with transverse striations 38 mm ($1\frac{1}{2}$in.) on centers. In addition, all the surfaces except those with a dimpled finish and a burlaped finish are certainly good from a skid resistance standpoint.

5. Even though the washed mortar surface provides good skid resistance, it is believed that it will wear rapidly and approach the same condition as the burlapped surface in a few years. Further, there is quite a bit of additional expense in this finishing process.

6. The sprinkled aggregate surface also adds considerable expense to the finishing operation and produces more noise than some of the other surfaces.

7. In noise tests conducted by Noble[7,3] the exposed aggregate, sprinkle, and dimpled textures tended to be somewhat louder than any of the tined surfaces or bituminous concrete surfaces found in Virginia which generate noises of similar intensities.

8. In a subjective noise evaluation, it was concluded from roadside observations that—

   (a) for trucks and busses, the engine and exhaust noise completely masked the tire-pavement noise; and

   (b) most of the experimental textures were slightly louder than the 19 mm ($\frac{3}{4}$ in.) longitudinally tined surface that was then the standard texture, but only the sprinkled texture was considered objectionable.

Observations made from within the car led to the conclusions that

> the sprinkled, the dimpled, and the transversely tined grooves spaced 38 mm ($1\frac{1}{2}$ in.) apart produced a discernibly intense noise, but only the noise from the 38 mm ($1\frac{1}{2}$ in.) transversely tined textured was considered objectionable.

9. From roughness tests conducted at 64 kph (40 mph) with a Mays Ride Meter, it was concluded that roughness considerations would not dictate the type texture desired, with the exception of sprinkle type applications, which in this study were significantly rougher than any of the other test surfaces.

10. All things considered, the two most desirable surfaces are the transversely tined surface with striations 19 mm ($\frac{3}{4}$ in.) apart and the surface with longitudinally tined striations 19 mm ($\frac{3}{4}$ in.) apart and transverse striations 76 mm (3 in.) apart. Both of these surfaces provide channels for lateral runoff, while the latter has been said to provide lateral stability on curves. The surface with 19 mm ($\frac{3}{4}$ in.) transverse striations provides the most channels for lateral runoff.

RECOMMENDATIONS

Based on the above conclusions the authors recommend that the Department modify Sections 321.12g and 404.19f of the Road and Bridge Specifications as follows:

Pavements

Modification of Section 321.12g of the Road and Bridge Specifications

The riding surface of the pavement shall be textured with uniformly pronounced grooves approximately 1/8" deep by 1/8" wide on approximately 3/4" centers and transverse to the pavement centerline, or with a combination of uniformly pronounced grooves approximately 1/8" wide on approximately 3/4" centers and longitudinal to the pavement centerline and additional 1/8" deep by 1/8" wide grooves on approximately 3" centers and transverse to the pavement centerline. Prior to grooving, multiple-ply damp fabric shall be dragged over the pavement surface to provide a gritty texture on the ridges between the grooves.

Bridge Decks

Modification of Section 404.19f of the Road and Bridge Specifications

Bridge decks shall be textured with uniformly pronounced grooves approximately 1/8" deep by 1/8" wide on approximately 3/4" centers and transverse to the bridge centerline, or with a combination of uniformly pronounced grooves approximately 1/8" deep by 1/8" wide on approximately 3/4" centers and longitudinal to the bridge centerline and additional 1/8" deep by 1/8" wide grooves on approximately 3" centers and transverse to the bridge centerline. Prior to grooving, multiple-ply damp fabric shall be dragged over the deck surface to provide a gritty texture on the ridges between the grooves.

REFERENCES

1. Virginia Department of Highways and Transportation, Average Daily Traffic Volumes on Interstate, Arterial and Primary Routes, 1975.

2. Virginia Department of Highways, Road and Bridge Specifications, Commonwealth of Virginia, 1966.

3. Ozyildirim, Celik, Durability of Certain Configurations for Providing Skid Resistance on Concrete Pavements, Virginia Highway Research Council, June 1974.

4. An Accident Evaluation of the Effectiveness of Longitudinal Grooving on Virginia's Interstate System, Traffic and Safety Division, Virginia Department of Highways, July 1973.

5. Letter from M. B. Vann, Resident Engineer during time of construction, to F. L. Burroughs, Construction Engineer, dated April 10, 1973.

6. Sherman, George B. et al., Effect of Pavement Grooving on Motorcycle Rideability, Materials and Research Department, State of California, Division of Highways, November 1969.

7. Noble, D. F., "Effect of Pavement Texture on Tire-Road Noise," Virginia Highway and Transportation Research Council, July 1975.

8. Noble, D. F., "Interior Car Noise Created by Textured Pavement Surfaces," Virginia Highway and Transportation Research Council, October 1975.

9. Ross, J. E., and S. M. Law, "Texturing of Concrete Pavements," Louisiana Department of Highways, Research and Development Section, September 1976.

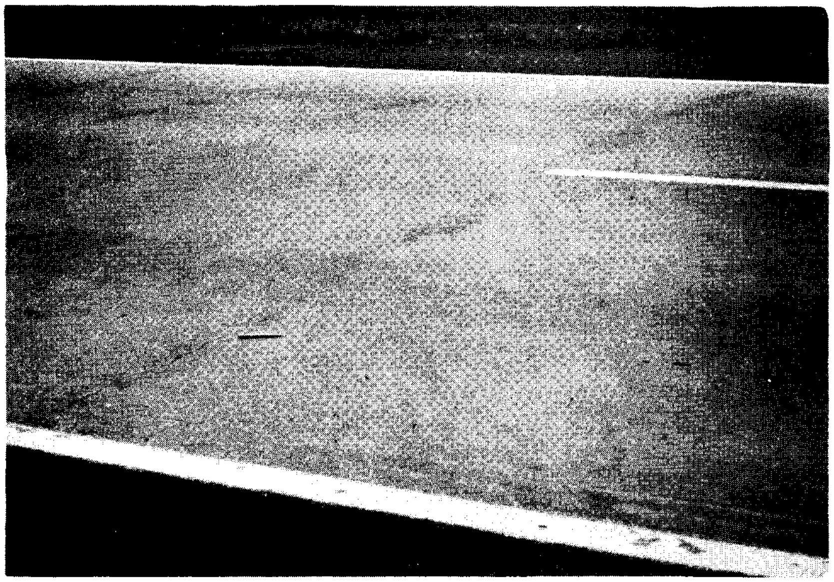

Figure 1. Obliteration of burlap texture by polyethelene sheeting.

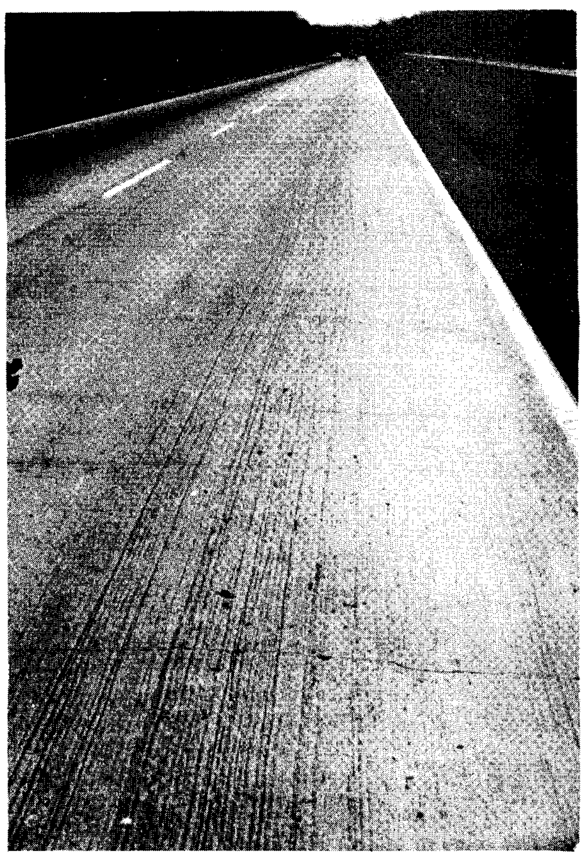

Figure 2. Heavy burlap texture.

2045

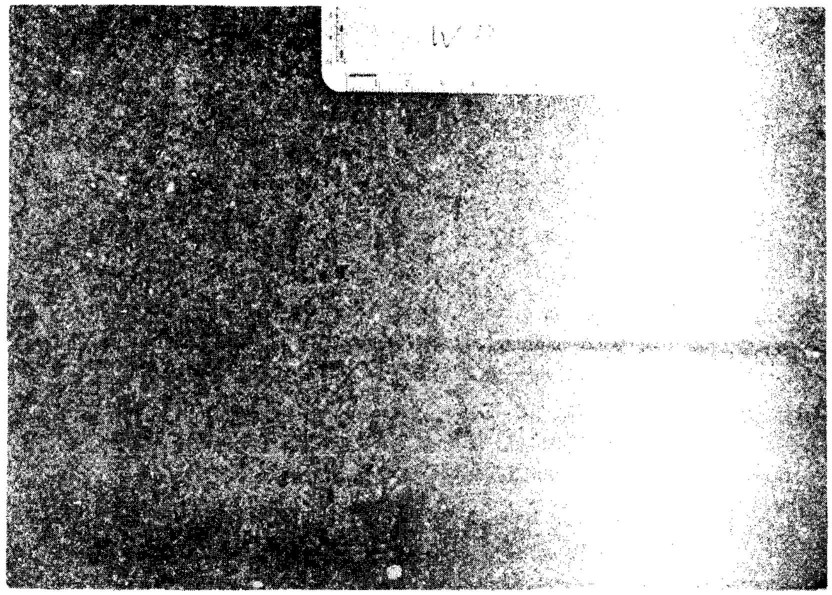

Figure 3. Light burlap texture used prior to [illegible] ments.

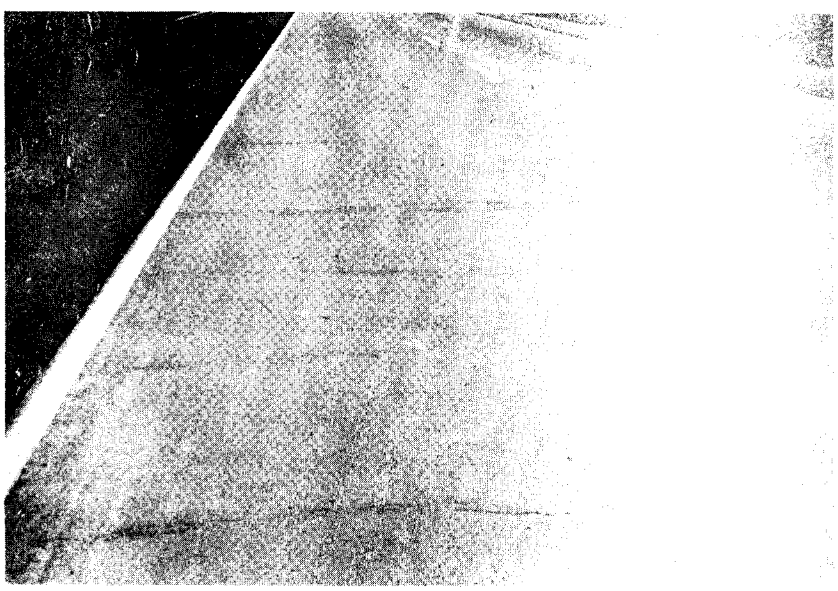

Figure 4. Heavy burlap texture after [illegible]

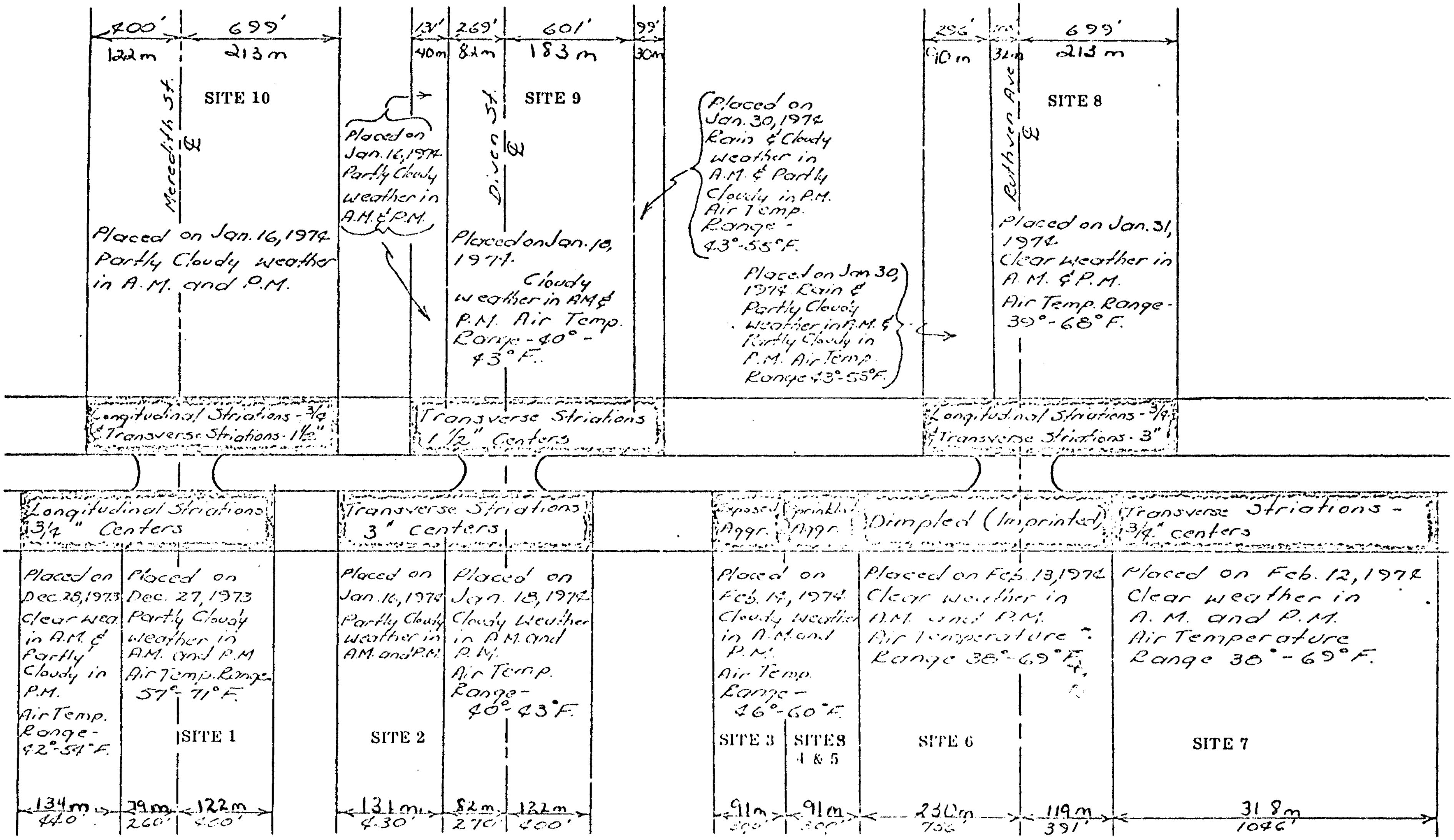

Figure 5. International Terminal Boulevard test sites. ' Not to scale-distances are approximate.

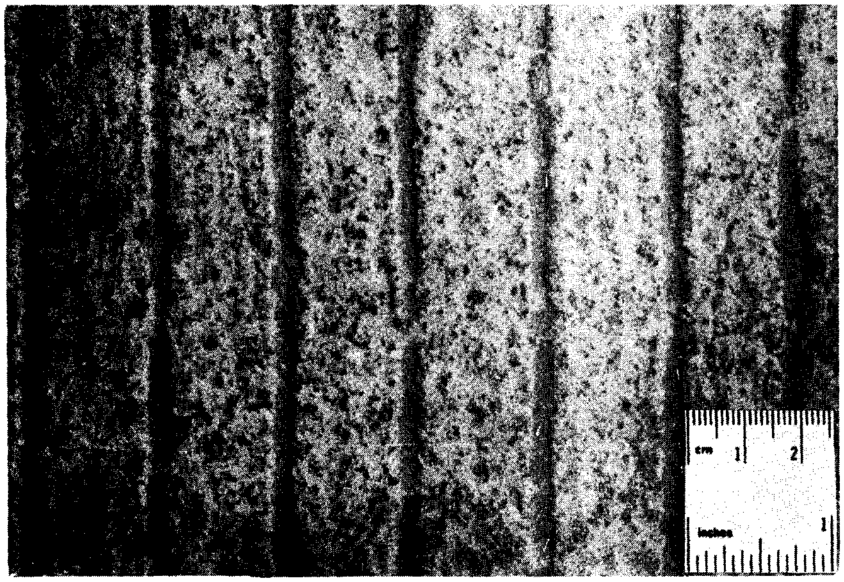

Figure 6. Longitudinally tined texture, grooves spaced on 19 mm (3/4 in.) centers. Site 1.

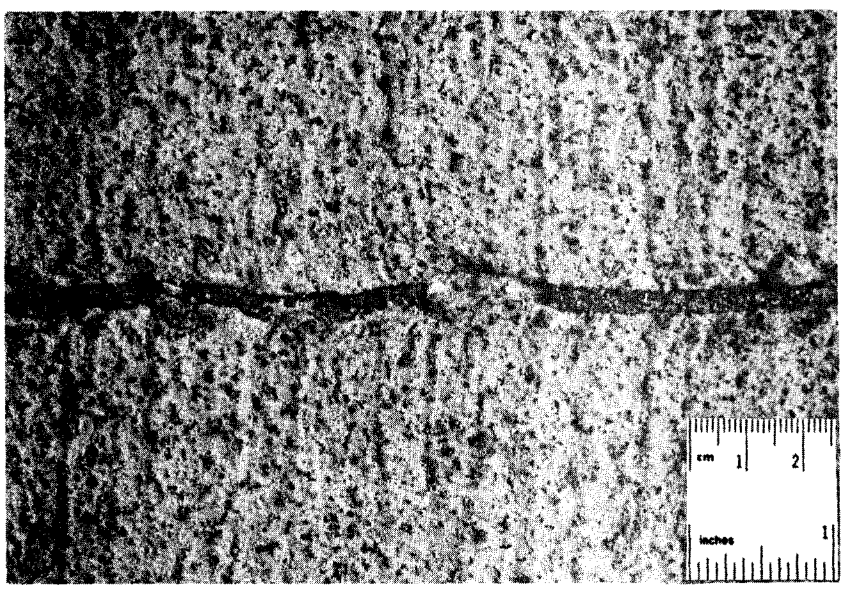

Figure 7. Transversely tined texture, grooves spaced on 76 mm (3 in.) centers. Site 2.

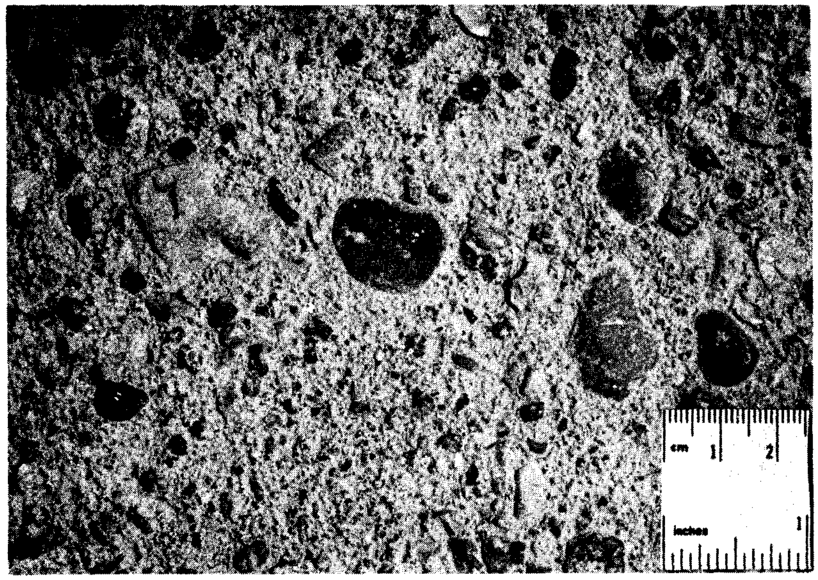

Figure 8. Exposed aggregate texture. Site 3.

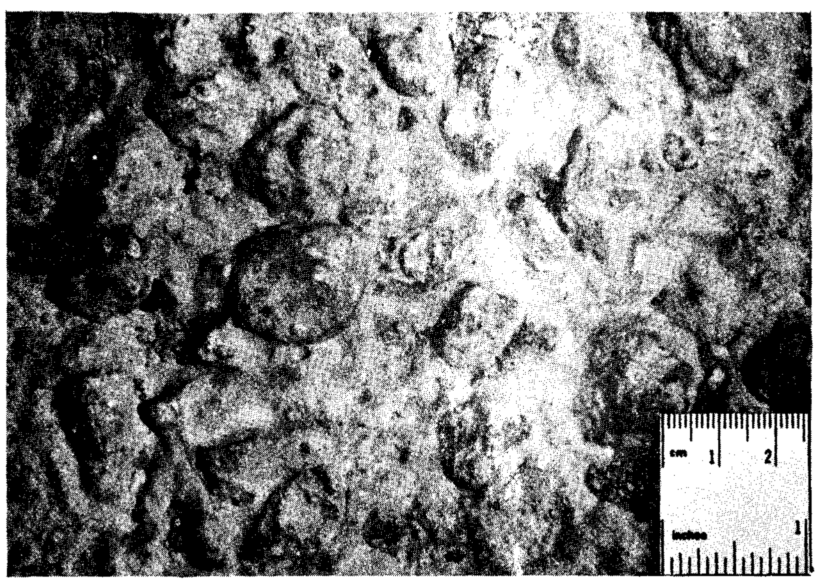

Figure 9. Sprinkled aggregate texture with 19 mm (3/4 in.) maximum size aggregate. Site 4.

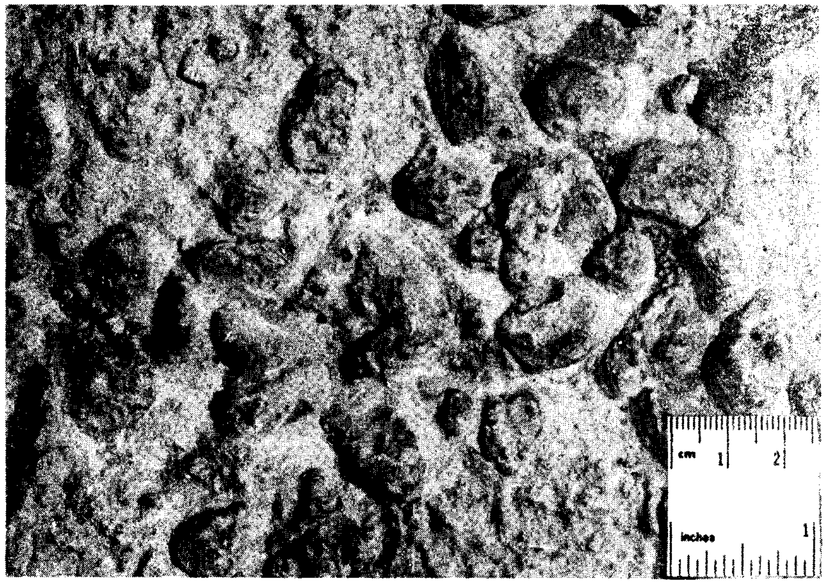

Figure 10. Sprinkled aggregate texture with 13 mm (1/2 in.) maximum size aggregate. Site 5.

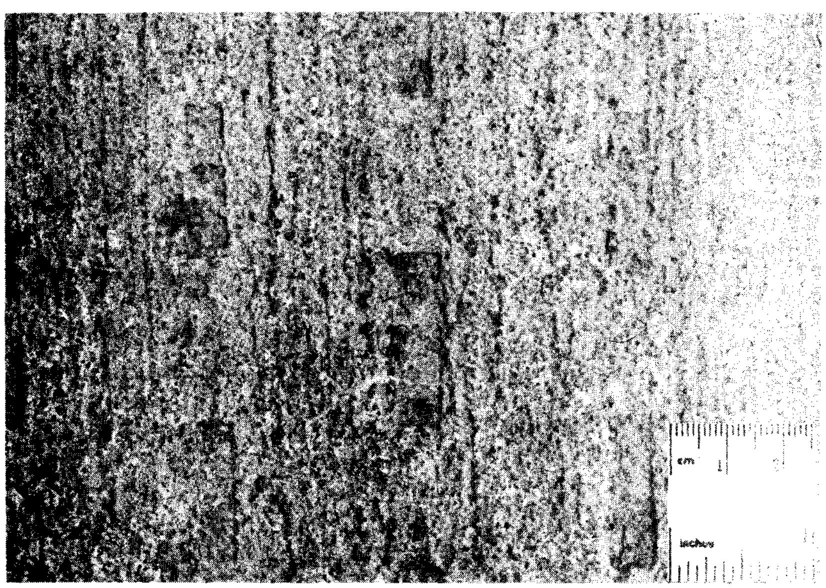

Figure 11. Dimpled texture. Site 6.

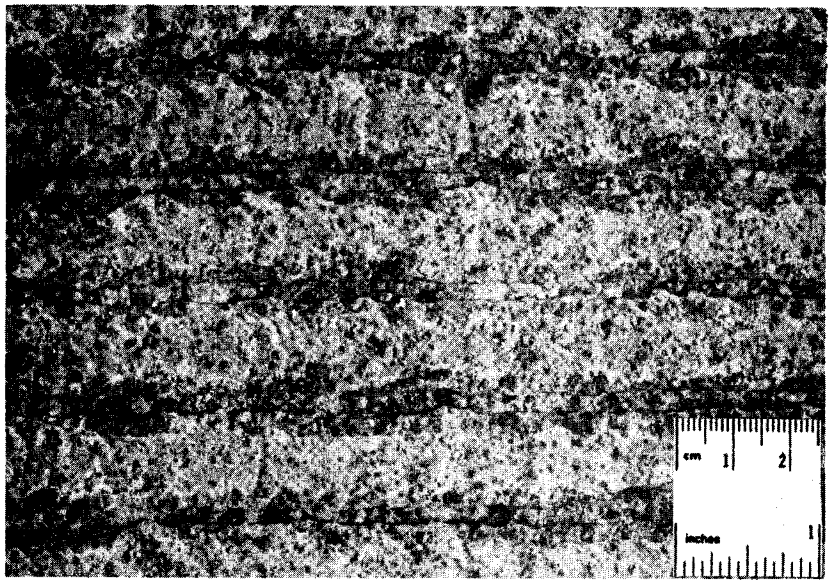

Figure 12. Transversely tined texture, grooves spaced on 19 mm (3/4 in.) centers. Site 7.

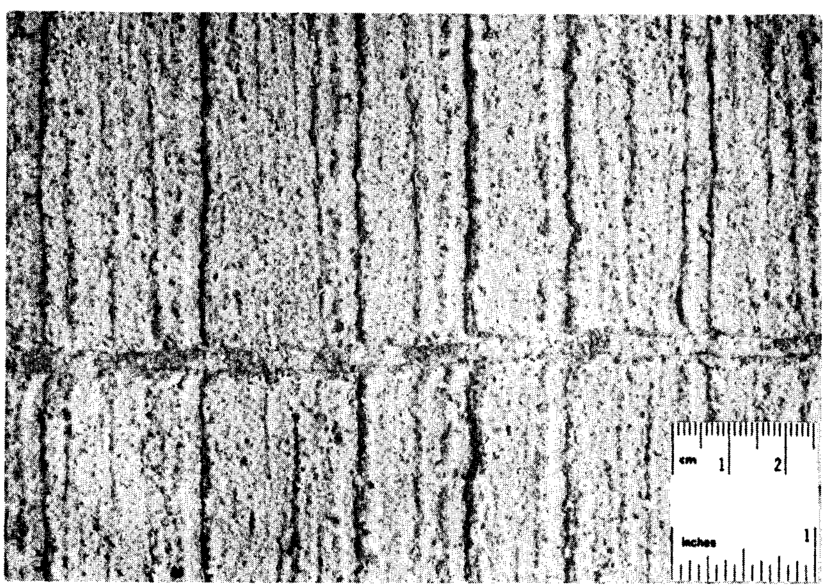

Figure 13. Tined texture with grooves spaced on 19 mm (3/4 in.) centers longitudinally and 76 mm (3 in.) centers transversely. Site 8.

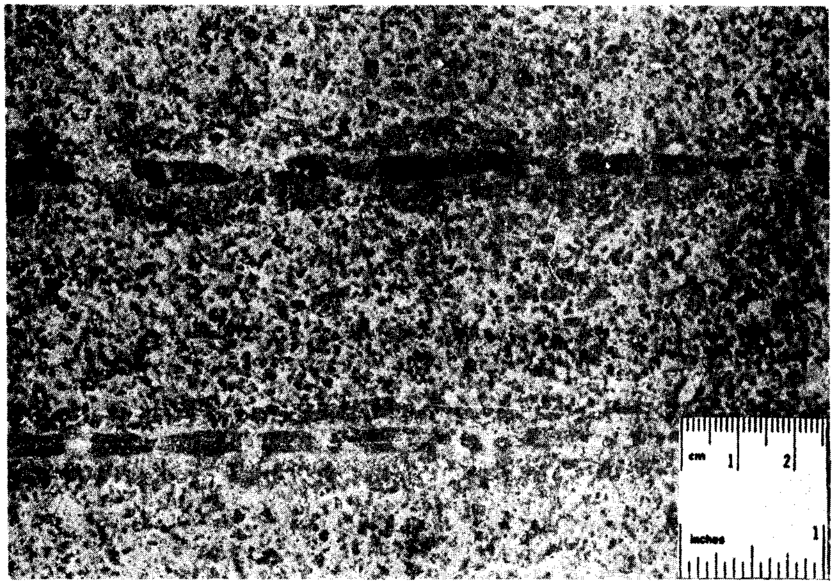

Figure 14. Transversely tined texture with grooves on 38 mm (1 1/2 in.) centers. Site 9.

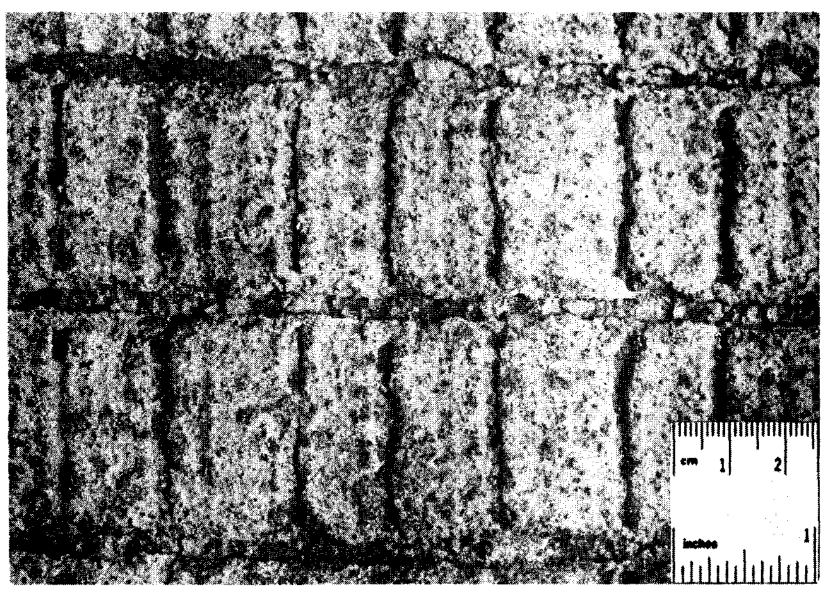

Figure 15. Tined texture with grooves spaced on 19 mm (3/4 in.) centers longitudinally and 38 mm (1 1/2 in.) centers transversely. Site 10.

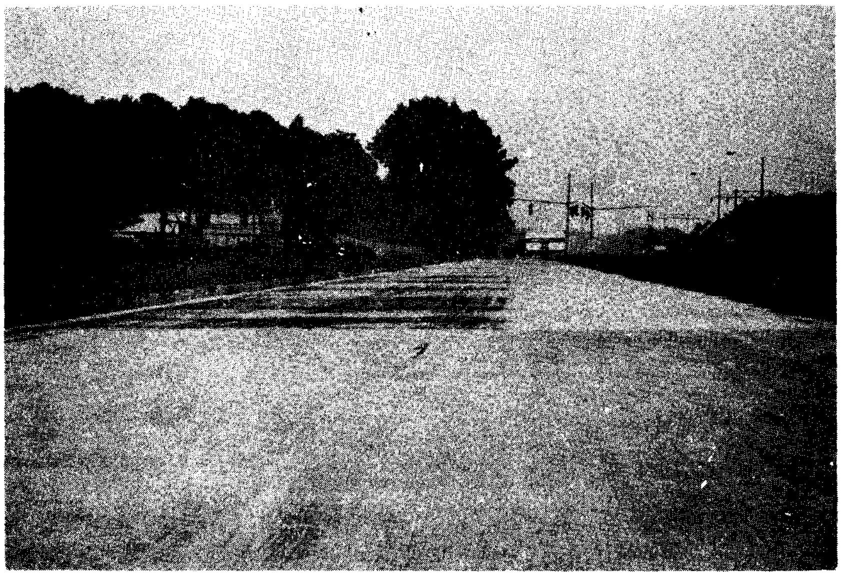

Figure 16. Contrast during rain between tined texture with grooves on 19 mm (3/4 in.) centers longitudinally (background) and tined texture with grooves on 19 mm (3/4 in.) centers longitudinally with 76 mm (3 in.) centers transversely (foreground).