Texturing New Concrete Pavements

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Several texturing experiments on heavily traveled portland cement concrete pavements in Virginia are described. Included in the experiments were textures imparted by using 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 the 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 transversely tined grooves spaced 19 mm (0.75 in) apart (center-to-center) would be preferable on tangent roadway sections whereas longitudinally tined grooves spaced 19 mm apart in combination with transverse grooves spaced 76 mm (3 in) apart would be preferable on curves.

Until the increase in traffic volumes and speed limits that accompanied the building of the Interstate highway 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 siliceous aggregates and sands abound. The stopping distance number (SDN) at a test speed of 64 km/h (40 mph), i.e., 40 (SDN_{40}), which 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 of SDN_{40} values as low as 45 at pre-Interstate traffic volumes and speed limits. It should be remembered that prior to the building of the Interstate system, the maximum daily traffic volume on a dual-divided PCC pavement in the state was about 25 000 vehicles, and the speed limit was 96 km/h (60 mph). With the coming of the Interstate system, the figures for average daily traffic (ADT) were increased to about 90 000 vehicles/d and 113 km/h (70 mph); it is thus understandable 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 create a potential for hydroplaning.

In an attempt to remedy the problems that accompany 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. Because highly polish-resistant materials were already being used in concrete pavements in Virginia, the additional skid resistance needed as well as the surface drainage to prevent hydroplaning obviously 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 learned that other states were recognizing similar problems. California had learned about the grooving of airport runways and had done some experimental grooving at sites where there was a high rate of wet-pavement accidents. On the basis of the apparent success of the California effort, Virginia had considered grooving the pavement at several such sites.

Ohio had been experimenting with finishing methods that imparted 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. It was found that the Ohio Department of Transportation 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 making three or four passes using four thicknesses of burlap; one pass with rug backing; 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, in 1969 it was not possible to try all of the Ohio experimental finishes in Virginia because the one scheduled concrete paving project in the state for that year had already been awarded. Thus, only experimental burlap textures could be scheduled immediately. The other finishes had to be delayed so that descriptions of the desired surface textures could be included in advertisements. This paper discusses experimental texturing activities in Virginia, beginning with the experiments with burlap.

TEXTURING EXPERIMENTS

Use of Burlap

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

Because the paving contracts were let at approximately the same time that the need for harsher textures was realized, plans to provide special texturing on the pavement had to be made hurriedly. Furthermore, because the contracts had been bid under 1966 specifications that prohibited striations more than 1.6 mm (0.062 in) deep (2), any action that would result in a harsher texture on the pavement would clearly have to be negotiated with the two paving contractors. The contractors agreed to make a reasonable effort to texture the pavements as desired. It was decided that longitudinal striations would be used because transverse striations might create undue tire-pavement noise. 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 that carried the burlap drag used to apply the final finish. Following the float was a curing unit that applied either polyethylene 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 by using the burlap drag. Success was achieved with one to four passes depending on the consistency of the concrete, the rate of surface drying, and the number of layers of burlap used.

Figure 1. Obliteration of burlapped texture by polyethylene sheeting.

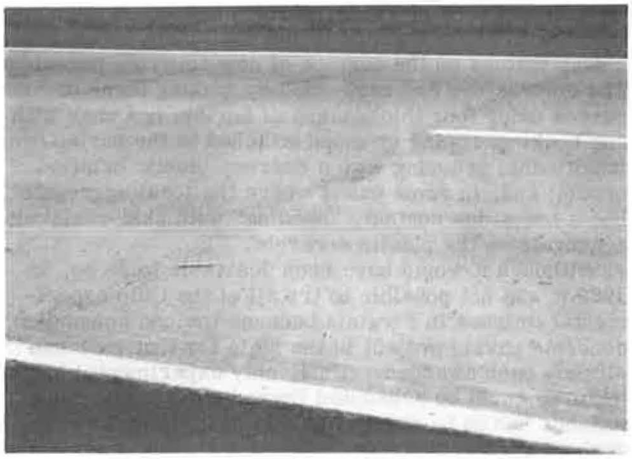
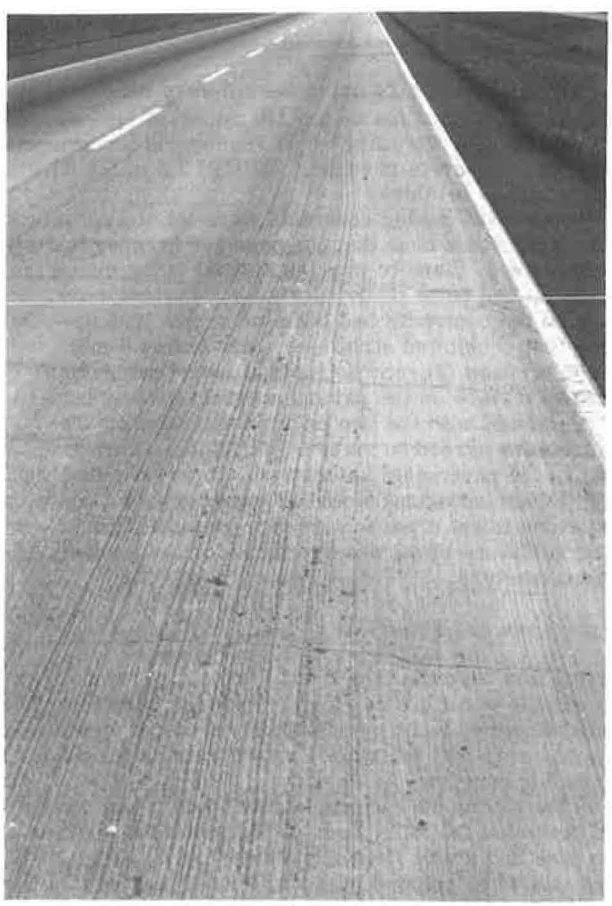


Figure 2. Texture achieved by using heavy burlap.



Project personnel were required to exercise a good deal of judgment 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 that affected the texturing procedure were the length of the trailing burlap cords and the condition of the burlap. Trailing cords 100 to 150 mm (4 to 6 in) in length were helpful, and burlap that had accumulated some mortar through use was found to be effective. Again, the judgment of project personnel was relied on for the proper number of passes to be applied.

The major technical problems encountered with heavy burlap texturing were a failure to achieve the desired texture because of late application of the burlap drag and, under certain circumstances, obliteration of the texture by the polyethylene sheeting used for curing purposes (Figure 1). The first of these problems was easily eliminated by paying 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 place of the polyethylene 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, polyethylene 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 event of cold weather, the sheeting was not applied until there was no danger of damage to the texture.

Results

Figure 2 is a photograph of the most desirable texture achieved by using the special burlap drag. For comparison purposes, Figure 3 shows a typical texture caused by the use of light burlap, which could be found on many Virginia pavements before this study was begun. The new texture is much more evident to the naked eye. As Figure 2 shows, the striations are randomly spaced according to the weave of the burlap. Both contractors were of the opinion that the heavy-burlap texturing could be achieved in normal paving operations; it was thus decided to use a similar texture 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 showed that two of the three pavement projects resulted in the best riding concrete pavements ever tested in the state. The results of these tests are given below and include Bureau of Public Roads (BPR) roughness values for each of the three textured projects (1 km = 0.62 mile):

Project Number	Length (km)	Average BPR Roughness (units/km)
1	16.4	40
2	14.8	46
3	13.7	57

The BPR roughness of 25 projects constructed between 1965 and 1969 ranges from 54 to 88 units/km; the average roughness of these projects is 61 units/km.

The roughness value for even the roughest of the textured projects is toward the low side of average roughness values for pavements built during the previous 5-year period. A more detailed evaluation of roughness, skid resistance, and noise is given later in this paper.

Some initial public observations of poor riding quality were felt to be a psychological reaction attributable to the appearance of the pavement texture rather than to actual roughness. There were also a few early adverse public reactions concerning the occasional waviness of the striations, which was caused by side sway in the hydraulic arms carrying the burlap and by the flexibility of the burlap material.

Although the burlapped texture seemed very satisfactory at the time the pavement was opened to traffic, after it had been in service about 8 months under an ADT of 8000 vehicles/d, there was a significant degree of wear in the wheel paths that was easily discernible from a moving automobile and that 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 concluded 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 5 years since the earlier observations and by laboratory studies reported by Ozyildirim (3). Figure 4 shows the wear in the wheel paths after 6 years under traffic.

Figure 3. Light-burlapped texture used before texturing experiments.

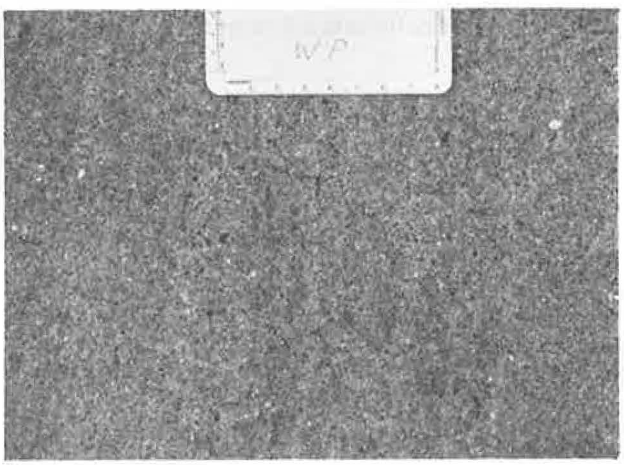


Figure 4. Heavy-burlapped texture after 6 years under traffic.

The relatively rapid wear of the texture caused concern, and the consensus was that the limited area between the asperities in the texture tended to make the asperities weak and subject to damage from 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 in the texture abraded, leaving the broader and stronger remains of the asperities. This finding was also supported by Ozyildirim (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 textures.

Use of Metal Tines

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 miles) of rural I-64 east of Richmond. This roadway, which is the main route between western and central Virginia and the coastal area, was also designed as a divided 7.3-m (24-ft) wide by 203-mm (8-in) thick CRCP.

So that more texture could be obtained in the pavement surface than the standard specifications demanded or the heavy burlap texture provided 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 by using a standard push broom to produce the desired pattern. However, because of the 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 using grooved surfaces. Pavements that had been grooved at accident-prone locations had resulted in improved safety (4), and the grooved surfaces had proved to be quite durable. For these reasons, it was decided that the surfaces for the two projects being awarded in the Richmond area would more closely approximate the grooved rather than the broomed finishing.

The contractor was approached about the feasibility of changing from the planned broomed finish to longitudinal striations similar to grooves. The contractor thus began the project by using a wire comb consisting of metal tines 3.2 mm (0.125 in) wide and spaced 3.2 mm apart, center-to-center (throughout this paper, groove- and tine-spacing measurements indicate center-to-center spacing). The tines were about 100 mm (4 in) long. This arrangement did not cover a satisfactory land area and tended to displace an excessive amount of mortar. After only a short distance had been constructed, the contractor was asked to change to 3.2-mm-wide tines spaced 9.5 mm (0.375 in) apart. 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 parallel to the pavement surface. According to Vann, a resident engineer at the time of construction, as the tine width wore to about 1.6 mm (0.062 in), it became necessary to clip the ends to maintain the original width.

From the construction standpoint, the second arrangement was much more satisfactory, but it was still felt that insufficient land area was being covered. After limited operation, the contractor was requested to bend up every other tine; this provided groove spacings of approximately 19 mm (0.75 in). This pattern was satisfactory and was used on the remainder of the project. Once the desired pattern was established, no difficulties were encountered in 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, more curing liquid is required for the tined surface than for the burlapped surface. The concrete met the same specifications as those described for the burlapped project. Even if the consistency of the concrete mixture is well controlled, the timing of the texturing operation is crucial. The desired depth was 3.2 mm (0.125 in), and the operator of the texturing machine quickly learned the proper time to start that operation.

Results

When the state of 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 on motorcycle reactions to grooved pavement (5) dispelled much of this concern but, as a concession to drivers, GROOVED PAVEMENT AHEAD signs were placed before the grooved sections.

Because 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, emphasizing 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 4 years under an ADT of 14 000 vehicles/d, 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 to 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 properly cured, deterioration from salt action should cause little concern. On the other hand, the retention of the chemicals on the pavement may provide an ice-free pavement for an extended period.

One factor that could affect the durability of the texture is the use of studded tires; this area of Virginia, however, has such a low incidence of studded tires that the 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 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 (9):

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 included in the next PCC pavement contract to be awarded.

Test Sites on International Terminal Boulevard

The advertising schedule for the next PCC pavement contract allowed 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 on were as follows (1 mm = 0.039 in):

Site	Texture
1	Longitudinal striations spaced 19 mm apart
2	Transverse striations spaced 76 mm apart
3	Exposed aggregate
4	Sprinkled aggregate (large)
5	Sprinkled aggregate (small)
6	Dimpled (imprinted)
7	Transverse striations spaced 19 mm apart
8	Combination of longitudinal and transverse striations spaced 19 and 76 mm apart respectively
9	Transverse striations spaced 38 mm apart
10	Combination of longitudinal and transverse striations spaced 19 and 38 mm apart respectively

The experimental sections 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 lanes 7.3 or 7.9 m (24 or 26 ft) wide on International Terminal Boulevard between I-564 and the International Terminal in Norfolk. Estimated ADT in 1969 was 11 160 vehicles/d, of which 12 percent were tractor-trailers and buses. Projected 1992 ADT is 21 400 vehicles/d (12 percent tractor-trailers and buses). The design speed is 72 km/h (45 mph).

Procedures

The project was advertised in June 1972, and the contract was awarded in August. Because the contract was awarded to the same firm that had constructed the 35.2 km (21.9 miles) of rural Interstate east of Richmond, the equipment used was the same as that used to impart the longitudinal striations. This equipment was modified to impart the transverse and dimpled textures as well. A wire comb similar to that used on the pavement in Richmond, with 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 epoxied to it, was rolled transversely to produce the dimpled texture.

The exposed-aggregate surface was produced by spraying the finished concrete with approximately 31.5 dm^3/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 kg/m^2 (5 lb/yd^2). These sections were 45.7 m (150 ft) long; the sprinkle material used was 19-mm (0.75-in) aggregate on one section and 13-mm (0.5-in) aggregate on the other. The aggregate was precoated by using a cement-and-water paste and was rolled into the finished surface of the plastic concrete by a roller 1.8 m (6 ft) long, 205 mm (12 in) in diameter, and approximately 113 kg (250 lb) in weight.

Results

Figures 5 through 14 show the textures obtained on the experimental test sections. The texture shown in Figure 5 was the standard texture at the time the International Terminal Boulevard test sections were installed. Note also that the sprinkled textures shown in Figures 8 and 9 are the harshest ones produced.

The contrast during rainfall between a section with both transverse and longitudinal striations and one with only a longitudinally tined texture is of special interest. Figure 15, a photograph taken during a steady rain, shows a texture longitudinally and transversely grooved with 19-mm (0.75-in) spacing between grooves (in the foreground) and the conventional, longitudinally tined texture produced by 19-mm groove spacing (in the background). Note that the transverse texture is providing excellent drainage; compared to the pavement in the background, it appears to be dry.

NOISE AND ROUGHNESS STUDIES

In an effort to determine potential noise- or roughness-related problems with the various types of texture, 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

Noise measurements for both the roadside and the interior of an automobile were conducted on the experimentally textured sections and on several asphalt concrete surfaces that were 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 two reports by Noble (6, 7).

The roadside tests were normalized at 77 km/h (48 mph). The sound-sensing device was located 7.6 m (25 ft) from the center of the traveled lane. Although both ribbed and snow tires were used, the automobile-interior noise measurements were conducted using ribbed tires only, at a speed of 89 km/h (55 mph), the microphone being positioned at approximately the ear level of front-seat passengers. In both series of tests, tire pressures were maintained at 200 to 210 kPa (28 to 30 lbf/in^2).

The results of both series of tests, a summary of which is given in Table 1, are 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 noise levels for exposed-aggregate, sprinkled, and dimpled textures tend to be somewhat greater than those for either the tined textures or the bituminous concrete pavements, which generate noises of similar intensities. None of the tined textures was significantly different in noise level except the worn, longitudinally tined texture with 19-mm (0.75-in) groove spacing on I-64, which rode slightly quieter.

These inconclusive findings led to the conducting of frequency analyses, from which it was concluded, in part, that some of the transversely tined textures and the dimpled texture generated noise of a relatively pure tone in a frequency range (1000 Hz and greater) in which the noise is more noticeable than noise of equal intensity but of lower frequency (6, 7). The implication of the finding was that some textures may generate noises that, though they are of relatively low intensity, are objectionable to the human ear. For this reason, a subjective evaluation was conducted.

Subjective Evaluation

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

The roadside evaluation consisted of 5-min 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 pavement texture, the intensity and the pitch of noise, the degree of annoyance, the background noise, and the relations between pavement-tire noise and engine and exhaust noise. The evaluation inside the automobile was conducted by having the evaluation team ride over the variously textured sections at approximately a 72-km/h (45-mph) speed limit in a medium-size and a full-size automobile.

The evaluation team reached a strong consensus on the following observations:

1. Roadside observation—(a) For trucks and buses, engine and exhaust noise completely masked tire-pavement noise, and no effect of pavement texture was discernible; (b) for automobiles, although most of the experimental textures were slightly louder than the longitudinally tined texture with 19-mm (0.75-in) groove spacing (the standard at the time), only the sprinkled texture was considered objectionable.
2. Observation inside the automobile—The sprinkled and the dimpled textures and the 38-mm (1.5-in) groove spacing of the transversely tined texture produced a discernibly more intense level of noise, but only the latter was considered objectionable.

Roughness Studies

Roughness tests were conducted in August 1976 on all the experimentally textured pavement sections. These tests were run at a speed of 64 km/h (40 mph) with a Mays roadmeter, and a summary of the results is given in Table 1.

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

It appears from the results that the worn, longitudinally tined textures on I-64 were somewhat smoother than the new textures on International Terminal Boulevard. With the exception of the sprinkled-aggregate section on International Terminal Boulevard, all the roughnesses measured were in the range considered acceptable for Virginia. The 108-units/km roughness of the sprinkled aggregate is significantly rougher than

Figure 5. Longitudinally tined texture with 19-mm (0.75-in) groove spacing.

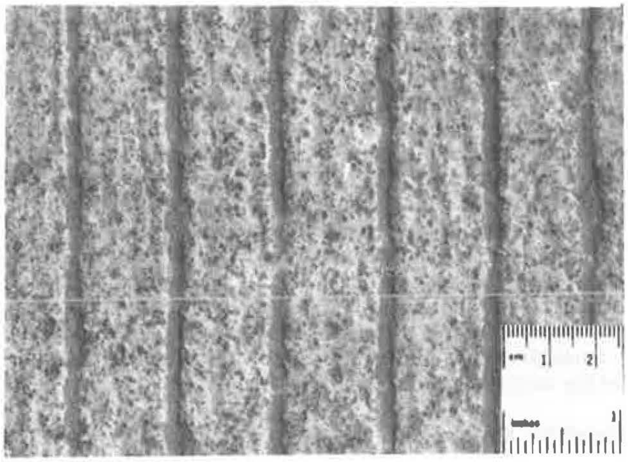


Figure 6. Transversely tined texture with 76-mm (3-in) groove spacing.

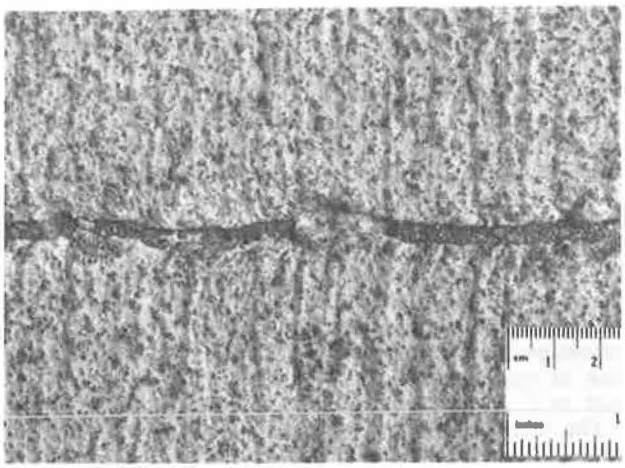


Figure 7. Exposed-aggregate texture.

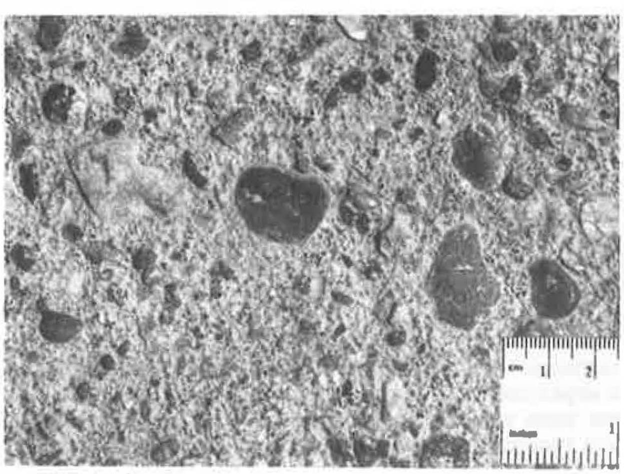


Figure 8. Sprinkled-aggregate texture with maximum aggregate size of 19 mm (0.75 in).

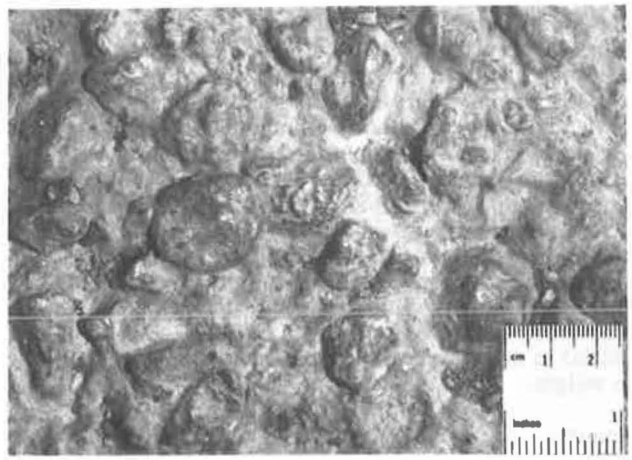


Figure 9. Sprinkled-aggregate texture with maximum aggregate size of 13 mm (0.5 in).

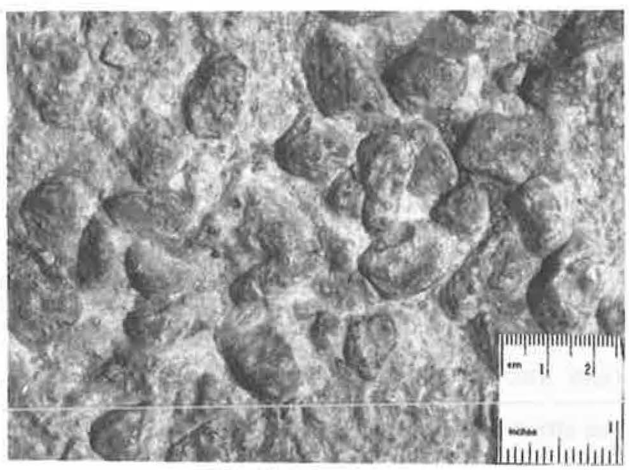
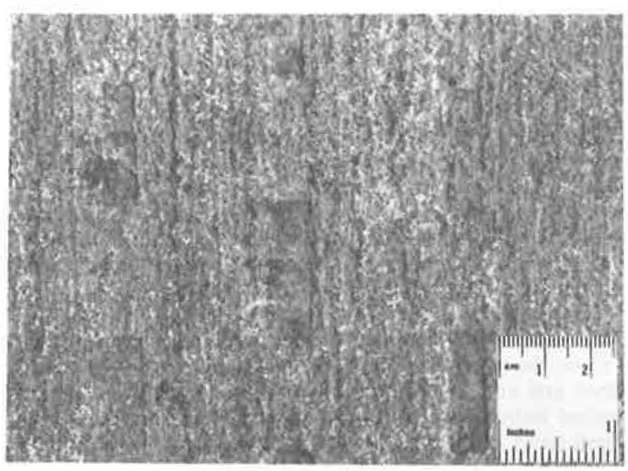


Figure 10. Dimpled texture.



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 were very likely related to problems inherent in constructing the short sections represented by the tests. These findings are in agreement with those from a similar study conducted in Louisiana (8).

As a result of the tests and the above discussion, it is concluded that roughness considerations would not dictate the type of texture desired except that they would eliminate sprinkle-type applications.

SKID-RESISTANCE STUDIES

In the design of pavement surfaces that will provide enough tire-pavement friction to ensure vehicle stability, there are two major areas of concern. The first is fabricating the surface with polish-resistant materials so that sufficient friction can be maintained between the tire and the 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 because highly polish-resistant, siliceous aggregates abound in the eastern portion of the state where such pavements are popular. The second concern is providing sufficient means for water drainage so that only thin films of water will be encountered.

Potential skid resistance can be measured by using the ASTM E 274-70 test method but, because the tire used in this test method has good tread and thus provides channels for the passage of water, the test method is inadequate for evaluating the capacity of the pavement surface to provide drainage. To circumvent this problem, the skid tests performed used two types of tires—treaded for the evaluation of skid resistance and bald or untreaded for the evaluation of 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 at low test speeds there is little need for escape passages for the water. However, as test speeds increase, the escape channels are needed more and more. Even the thin films of water used in the ASTM test will result in rapid deterioration of skid numbers when bald tires are used unless the pavement surface provides a good means by which water can escape.

Skid tests were conducted on several occasions, at multiple speeds, and with both treaded and untreaded tires on all experimental test sections. Only once, however, were the tests performed on all of the sections

Figure 11. Transversely tined texture with 19-mm (0.75-in) groove spacing.

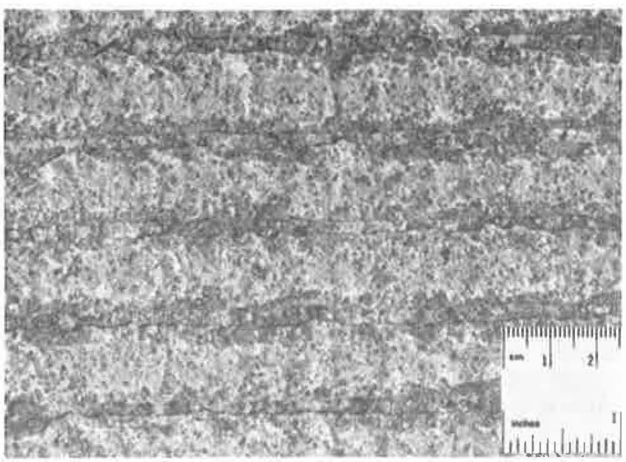


Figure 12. Texture with longitudinally tined and transversely tined grooves spaced 19 and 76 mm (0.75 and 3 in) apart respectively.

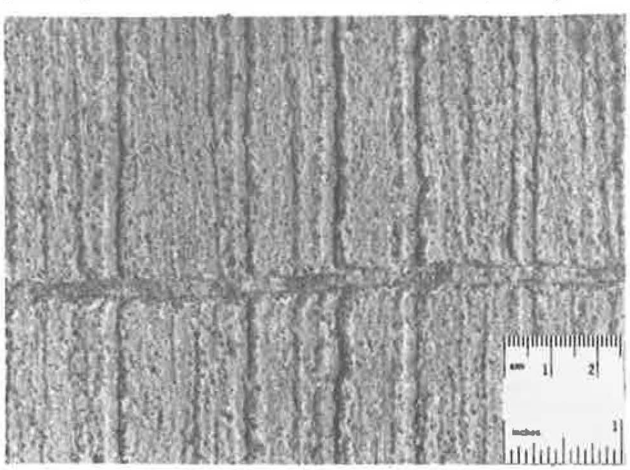


Figure 13. Transversely tined texture with 38-mm (1.5-in) groove spacing.

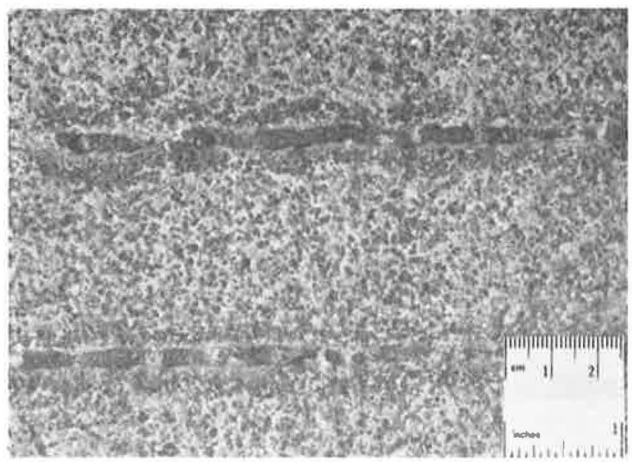
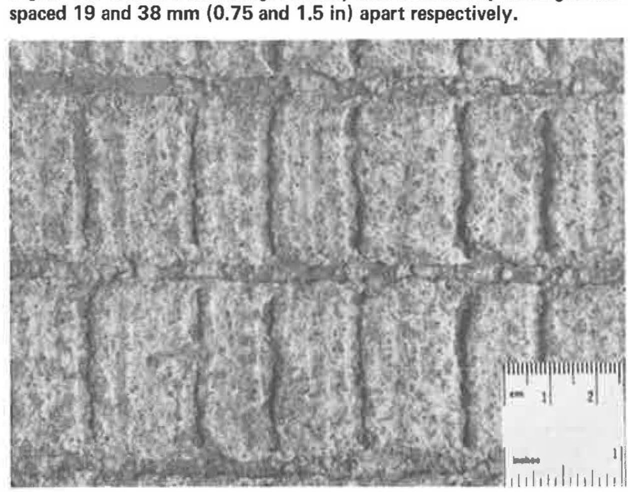


Figure 14. Texture with longitudinally and transversely tined grooves spaced 19 and 38 mm (0.75 and 1.5 in) apart respectively.



during the same week. Because skid numbers are known to vary with varying weather conditions, only the tests performed between July 29 and August 4, 1976, are discussed here for reasons of clarity and simplicity. The reader is assured that no data have been omitted that would change the findings.

Skid data are given in Table 2. Note 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 that 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 in the ASTM test. On the other hand, the bald-tire test results for the burlapped and the dimpled surfaces are quite low. This indicates not only that if bald tires are used little tire-pavement friction will occur in a moderate rain but also that during a heavy rain a well-worn tire might lack friction because 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 test results for bald tires are carefully examined, the surfaces are rated in the following order (1 mm = 0.039 in):

Figure 15. Contrast during rainfall between longitudinally and transversely tined texture (foreground) and conventional, longitudinally tined texture (background).

Rating	Surface
1	Longitudinally tined with 19-mm groove spacing plus transversely tined with 38-mm groove spacing
2	Longitudinally tined with 19-mm groove spacing
3	Longitudinally tined with 19-mm groove spacing
4	Transversely tined with 38-mm groove spacing
5	Sprinkled aggregate
6	Washed mortar
7	Transversely tined with 76-mm groove spacing
8	Longitudinally tined with 19-mm groove spacing
9	Dimpled
10	Burlapped

Although at least the first 8 of these surfaces appear to be acceptable with respect to skid resistance, other factors—some of which have already been mentioned—need to be considered. The authors feel that, 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 few years. It also involves an expensive 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. Because the state of Virginia has a sufficient supply of polish-resistant aggregate, sprinkling does not seem necessary; but in states where polish-resistance aggregates are scarce, this means of providing skid resistance might prove desirable.

As mentioned earlier, the transversely tined surface with 38-mm (1.5-in) groove spacing produces an undesirable noise level inside the traveling vehicle. Because other surfaces provide as good or better skid resistance, this surface should not be considered. This finding would, of course, also eliminate the surface that is longitudinally tined with 19-mm (0.75-in) groove spacing and transversely tined with 38-mm groove spacing.

The limited data available for the four remaining surfaces appear to indicate that the transversely tined surface with 19-mm groove spacing and the surface that is longitudinally tined with 19-mm groove spacing and transversely tined with 76-mm groove spacing provide better skid resistance. Both of these surfaces provide channels for lateral water runoff; the second one also has been credited with providing lateral stability on curves. Of course, the transversely tined surface with 19-mm groove spacing provides the most channels for lateral runoff of water. The authors there-

Table 1. Summary of noise (sound pressure) levels and roughness tests.

			Sound Pressure (dBA)			
			Roadside			Mays Roadmeter Roughness (units/km)
Pavement Type	Location	Texture	Rib Tire	Snow Tire	Interior of Automobile (rib tire)	
Bituminous concrete	Various	13-mm maximum size	78.8	80.9	61.8	—
Bituminous concrete	Various	19-mm maximum size	79.2	81.8	—	—
Surface treatment	Various	Protruding aggregate	84.3	84.7	61.6	—
PCC	I-64	Harsh burlap (worn)	—	—	61.6	47
PCC	I-64	19-mm longitudinally tined (worn)	—	—	59.8	44
PCC	International Boulevard	19-mm longitudinally tined	82.5	81.1	61.0	64
PCC	International Boulevard	76-mm transversely tined	79.6	86.3	61.0	61
PCC	International Boulevard	19-mm transversely tined	—	82.3	60.8	69
PCC	International Boulevard	19-mm longitudinally tined plus 76-mm transversely tined	79.6	84.4	62.3	60
PCC	International Boulevard	38-mm transversely tined	—	—	61.9	56
PCC	International Boulevard	19-mm longitudinally tined and 38-mm transversely tined	80.7	83.7	62.2	49
PCC	International Boulevard	Exposed aggregate	85.8	84.5	60.0	71
PCC	International Boulevard	Sprinkle[a]	85.8	84.5	62.6	108
PCC	International Boulevard	Dimpled	86.9	85.1	60.3	53

Note: 1 km = 0.62 mile; 1 mm = 0.039 in.

[a] The two sprinkle-mix sections were treated as one section in both roadside and automobile-interior tests.

Table 2. Skid number as a function of texture, vehicle speed, and tire tread.

Location	Texture	Skid Number 32 km/h Treaded Tire	32 km/h Bald Tire	48 km/h Treaded Tire	48 km/h Bald Tire	64 km/h Treaded Tire	64 km/h Bald Tire	80 km/h Treaded Tire	80 km/h Bald Tire	96 km/h Treaded Tire	96 km/h Bald Tire
I-64											
Traffic lane	Burlapped	62	42	58	29	51	20	46	19	42	16
Passing lane	Burlapped	71	50	69	39	61	35	56	28	54	23
	19-mm longitudinally tined	62	48	62	46	56	36	54	34	52	30
International Boulevard	19-mm longitudinally tined	58	48	54	41	50	33	46	32		
	76-mm transversely tined	63	52	52	42	49	37	47	34		
	Washed mortar	56	51	52	47	48	33	46	37		
	Sprinkled aggregate (small)	57	49	51	42	46	39	43	39		
	Sprinkled aggregate (large)	53	47	49	41	43	37	42	37		
	Dimpled	62	45	55	33	51	26	46	23		
	19-mm transversely tined	66	58	60	51	54	47	52	39		
	19-mm longitudinally tined and 76-mm transversely tined	63	58	60	51	57	43	53	40		
	38-mm transversely tined	62	56	60	50	55	41	50	37		
	19-mm longitudinally tined and 38-mm transversely tined	62	59	59	50	56	47	52	43		

Note: 1 km = 0.62 mile; 1 mm = 0.039 in.

fore feel it would be desirable to use that surface on tangents and use the other surface—i.e., the longitudinally tined with 19-mm groove spacing and transversely tined with 76-mm groove spacing—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

The most important requirement in providing a skid-resistant pavement 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 still become slippery. With this thought in mind, the following conclusions are presented.

1. In view of current 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 finishes applied to surfaces in Virginia, but the wear with age was substantial.
3. Because the tined surface on I-64 east of Richmond has been subjected to an ADT of 14 000 vehicles/d for 4 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 good to very good skid resistance. When the bald-tire test results are examined carefully, the tined surface with a combination of longitudinal and transverse striations spaced 19 mm and 38 mm (0.75 and 1.5 in) apart respectively rates best, followed by the transversely tined surface with striations 19 mm apart. In addition, all the surfaces except those with a dimpled or a burlapped finish are certainly good from a skid-resistance standpoint.
5. Although 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, this finishing process involves considerable added expense.
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 (6, 7), noise level for exposed-aggregate, sprinkled, and dimpled textures tended to be somewhat greater than those for any of the tined surfaces or bituminous concrete surfaces found in Virginia that generate noises of similar intensities.
8. In a subjective noise evaluation, it was concluded from roadside observations that (a) for trucks and buses, engine and exhaust noise completely masked tire-pavement noise and (b) noise levels for most of the experimental textures were slightly greater than those for the longitudinally tined surface with 19-mm groove spacing, which was then the standard texture, but only the sprinkled texture was considered objectionable. Observations made from inside the automobile led to the conclusion that the sprinkled and the dimpled surfaces and the surface transversely tined with grooves spaced 38 mm (1.5 in) apart produced a discernibly intense noise, but only the noise from the transversely tined texture was considered objectionable.
9. As a result of roughness tests conducted at 64 km/h (40 mph) with a Mays roadmeter, it was concluded that roughness considerations would not dictate the type of texture desired except in the case 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 surface with transversely tined striations 19 mm apart and the surface with longitudinally tined striations 19 mm apart and transverse striations 76 mm (3 in) apart. Both of these surfaces provide channels for lateral runoff of water; the latter one also has been said to provide lateral stability on curves. Of course, the surface with transverse striations spaced 19 mm apart provides the most channels for lateral water runoff. We thus feel that it would be desirable to use that surface on tangents and the other of the two on curves.

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Two-Course Construction of an Internally Sealed Concrete Bridge Deck

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A unique form of two-course construction—placement of a 51-mm (2-in) wax-bead concrete overlay on a fresh, conventional-concrete lower course after a 1-h wait period—was used in construction of a bridge deck near Seattle, Washington. Construction and evaluation of test slabs before placement of the deck showed that the direct tensile bond developed between the two courses was as great as the direct tensile strength of the wax-bead concrete. Other test-slab construction and evaluation work showed that the more conventional approach of placing a 51-mm overlay on a 1-d-old hardened lower course (after a water-and-sand blast and grout placement) also resulted in adequate bond. Cores evaluated after construction and heating of the deck confirmed the adequacy of the bond and the complete sealing of the top 13 to 25 mm (0.5 to 1.0 in) of the concrete overlay.

This report describes two-course construction techniques used in the construction of an experimental project undertaken by the Washington State Department of Highways using internally sealed concrete (1). The project required the use of wax beads in the top 51 mm (2 in) of a concrete bridge deck to develop an internally sealed concrete for the protection of the reinforcing steel of the deck. The structure itself—a three-span continuous structure with spans of 22.6, 24, and 22.6 m (74, 80, and 74 ft)—is a railroad overcrossing on I-90 in the western foothills of the Cascade Mountains approximately 48 km (30 miles) east of Seattle. The northern spans of the twin prestressed concrete girder bridges, which received the internally sealed concrete bridge-deck treatment, carry the westbound lanes of traffic. The structure has a 180-mm (7-in) thick, cast-in-place, reinforced concrete roadway slab supported by precast, prestressed concrete girders. The 180-mm-thick concrete deck is comprised of 127 mm (5 in) of Washington State standard structural class AX concrete, and the top 51 mm (2 in) is internally sealed with wax. The structure is 69.5 m (228 ft) in length and has a roadway width of 15.8 m (52 ft) between the concrete curbs. The roadway is on a curve with a radius of 914 m (3000 ft), and the piers are constructed at a skew angle of approximately 47° to the centerline of the roadway. The deck reinforcement consists of No. 6 reinforcing bars spaced 180 mm center to center, both top and bottom. The specified thickness of the concrete cover over the top transverse reinforcing steel is 51 mm.

MATERIALS

The concrete used in this project met Washington State specifications for class AX concrete, which is designed for a compressive strength of 27.6 MPa (4000 lbf/in^2). The sand has a fineness modulus of about 3.2; the grading for Washington State No. 5 coarse aggregate is as follows:

Sieve	Percent Passing by Weight: Minimum	Percent Passing by Weight: Maximum
25 mm (1 in)	100	–
19 mm (¾ in)	80	100
10 mm (⅜ in)	10	40
4.8 mm (No. 4)	0	4

All slab concrete is non-air-entrained because the internal sealing will provide the necessary freeze-thaw