Techniques for Increasing the Skid Resistance of Bridge Decks

MICHAEL M. SPRINKEL

ABSTRACT

Prior to 1970 many bridge decks in Virginia were constructed with aggregates that polish when subjected to traffic. In the seventies many decks were constructed with insufficient macrotexture to provide a good bald tire skid number. To provide adequate macrotexture, a tined texture has been applied to most decks constructed in the eighties. Because of problems with achieving a uniform texture with tining, grooves were being sawcut on new decks constructed in the latter part of 1989. Other techniques that have been used experimentally to increase the skid resistance of decks include shotblasting and sealing, application of a latex modified slag slurry and application of thin polymer overlays. The paper describes the techniques and compares them from the standpoint of skid number, the permeability to chloride ion of the top 2 in of the deck, cost, and application requirements.

INTRODUCTION

To provide good skid resistance bridge decks must have adequate microtexture and macrotexture (*1*). A sharp microtexture is required to provide friction between the tire and the surface. A deep macrotexture is required to drain the water from the surface so that friction can occur between the tire and the high points of the surface and hydroplaning can be avoided.

In Virginia prior to 1970, many bridge decks were constructed with aggregates such as limestone and dolomite that polish when subjected to traffic. In the seventies, new decks were constructed with nonpolishing aggregates such as siliceous, basalt, and granite or constructed with a 1.25 inch minimum thickness latex modified concrete overlay that contained nonpolishing aggregates. Older decks were rehabilitated with a 1.25 inch minimum thickness latex modified concrete overlay that contained nonpolishing aggregates that provide adequate microtexture.

In the late seventies it was recognized that new decks and overlays should be grooved to provide adequate macrotexture (*2*). Grooves approximately 1/8 in wide by 1/8 in deep and spaced at approximately 3/4 in on center were applied to the deck by dragging a tining device across the surface of the plastic concrete prior to placing the curing materials (*3*). In the latter part of 1989, because of problems with obtaining a uniform texture and because the tining operation delayed the application of the curing materials, causing an increase in the incidence of plastic shrinkage cracking, grooves were sawcut into the surface of decks and overlays after the concrete had cured for a minimum of 14 days (*4*). Other techniques that have been used experimentally in the eighties to increase the skid resistance of decks constructed with insufficient microtexture and macrotexture include shotblasting and application of a penetrating sealer, application of a latex modified slag slurry, and application of thin polymer concrete overlays (*5*).

Virginia Transportation Research Council, Box 3817 University Station, Charlottesville, Va. 22903

OBJECTIVE

The objective of this paper is to describe the techniques used in Virginia to increase the skid resistance of bridge decks and to compare the techniques from the standpoint of skid number, permeability to chloride ion of the top 2 in of the deck, cost and application requirements.

DESCRIPTION OF TECHNIQUES

Tining Plastic Concrete

Grooves 1/8 in wide by 1/8 in deep and spaced at approximately 3/4 in on centers are placed in the plastic concrete by dragging a tining device over the surface prior to placing the curing materials (see Figure 1) (*3*). The technique is limited to use on freshly placed concrete. Uniform textures can be achieved when the concrete on the surface is workable and uniform at the time the tining is done. However, the degree of macrotexture usually varies over the surface of most decks because the concrete tends to vary over the surface due to the differences in the physical properties between batches, the location of the batches on the surface, and the time between adding water to the mixture and the placing, consolidation, striking off and tining of the concrete. The variability of the concrete on the surface is greatest for decks constructed with long longitudinal screed spans, slow concrete placement methods, and long concrete haul distances; for decks constructed when the evaporation rate from the freshly placed concrete surface is high; and for decks constructed with mixtures that have a low water to cement ratio. These factors increase the chance that the concrete on the surface will have insufficient workability at the time it is struckoff and textured to provide a suitable texture. The cost of tining is negligible since it is done as the concrete is placed. There may be a hidden cost associated with tining if contractors are required to repair areas that are not textured properly or to repair areas that contain plastic shrinkage cracks caused by the delay in application of curing material to accommodate the tining operation. Tined surfaces constructed with polishing aggregates will not have adequate microtexture once the aggregates polish.

Sawcut Grooves

Adequate macrotexture can be obtained by sawcutting grooves in the hardened concrete in the transverse direction 3/16 in deep by 1/8 in wide and approximately 3/4 in on center (see Figure 2) (*2*). Although VDOT specifications require a depth of 3/16 in + 1/16 in, it is difficult to meet the requirement on some decks because the tolerance to which decks are constructed is 1/8 in 10 ft (*3*, *4*). An area that is 1/8 in low may get a groove that is 1/16 in deep if the sawcut is set for 3/16 in. The sharp corners left by the sawcut will usually spall at a angle of 45 degrees and leave a land area as little as 1/4 in wide. Groove spacings up to 1 1/2 in on center can provide adequate skid numbers and are being examined to increase the land area left after corner spalling occurs (2). The grooves cause some reduction in cover over the rebar and the technique may not be suitable for decks that have less than 2 in of cover (less than 1.25 in for latex modified concrete). Also, sawcutting grooves in decks constructed with polishing aggregate would not provide adequate microtexture. New concretes should have a strength suitable for traffic prior to grooving. The VDOT requires a 14-day cure prior to grooving (4). An advantage is that once grooved, the surface can be opened to traffic immediately.

Shotblasting and Sealing

On the afternoon of May 18, 1989, the travel lane and passing lane of a 3-span bridge, 113 ft long, located on the southbound lane of I-81 in Botetourt County, Virginia was shotblasted to increase the skid resistance. The surfaces were blasted at the rate of 1.4 yd^2/min. Because of concern about reducing the cover over the rebar and increasing the permeability of the concrete to chloride ion by removing approximately 1/8 to 1/4 in of the top surface mortar, two penetrating sealers were applied to spans B & C of the bridge. A 30% solids synthetic gum resin was applied to the travel lane of span B at the rate of 140 ft^2/gal. A poly-siloxane resin was applied at the rates of 162 ft^2/gal (span C of travel lane) and 192 ft^2/gal (spans B and C of passing lane). It was sunny and 85°F at the time of the applications. The gum resin was still tacky when opened to traffic after 3 hours of cure. The siloxane was tack free in 30-60 minutes.

A sand patch test (ASTM E965) was used to measure the macrotexture depth of the shotblasted surfaces (6). Prior to shotblasting the average diameter of the sand patch was 12.8 in. After shotblasting it was 7.4 in. After application of the penetrating sealers average sand patch diameters of 7.2 in and 7.5 in were measured for the gum resin and siloxane treated surfaces, respectively. The shotblasting increased the macrotexture by removing the mortar between the coarse aggregates and increased the microtexture by abrading the surface of the coarse aggregate (see Figure 3). It is believed the improvement in microtexture will be lost as the aggregates polish. An advantage of the technique is that once the sealers are tack free the surface can be opened to traffic.

Latex Modified Portland Cement Slag Slurry

On May 17, 1989, two 300-ft sections, one in the passing lane and one in the travel lane, of the northbound lane of I-81 in Botetourt County were shotblasted to increase the skid resistance. Another 300-ft section in the travel lane was shotblasted on the morning of May 18. Because of a concern that the microtexture applied to the polishing coarse aggregate would be lost in several years, a latex modified portland cement slag slurry was applied to the first section blasted in the travel lane. The latex modified slag slurry was placed between 3:30 and 4:30 p.m. on May 17. It was sunny and 82°F at the time of the application. The lane was opened to traffic on May 19 after 42 hours of cure.

On October 31, 1989 the passing lane of structure 2016 located on the northbound lane of I-81 in Rockbridge County (over Rte. 679 south of milepost 184 and Buffalo Creek) was shotblasted and overlaid with a latex modified slag slurry. The average tensile rupture strength (ACI 503R) of the overlay was measured on November 13 at an age of 13 days and found to be 260 lb/in^2 (7). The overlay was opened to traffic at an age of approximately 4 weeks. On April 26, 1990 the travel lane of the same structure was shotblasted at the rate of 11.5 yd^2/min and overlaid with a latex modified slag slurry (see Figure 4). The slurry was placed between 10:00 and 11:30 a.m. The temperature was 86°F at noon. The slurry was opened to traffic after 48 hours of cure.

The 300-ft pavement application and the two 204-ft bridge deck plus approach slab applications illustrate that a latex modified slag slurry can be placed on decks to provide adequate surface texture. The surface was shotblasted prior to placing the slurry to remove dirt, oil, weak surface mortar and materials that can interfere with the bonding or curing of the slurry. The slurry was batched with a concrete mobile and brooms were used to brush the binder into the surface. Gage rakes set at 3/16 to 1/4 in were used to strikeoff the slurry placed on the bridge deck. Gage rakes were not used on the 300-ft pavement application and the surface was very uneven and not pleasing to the eye. Slag having a gradation similar to an ASTM C33 concrete sand (see Table 1) was used in the slurry mixture. However, the slag used on the bridge deck was first passed through a No. 8 sieve. Material that passed the sieve was used in the mixture (see Table 2) and material that was retained was broadcast onto the freshly placed slurry at the rate of 5 lb/yd^2 to provide additional microtexture and macrotexture. A liquid membrane curing material was applied to prevent water from evaporating from the slurry. The slag was obtained from Ducan Slag Products Company in Pittsburgh, Pennsylvania.

The slurry must cure for about 48 hours to obtain adequate strength for traffic (1,500 psi compressive strength) (See Table 3). Advantages of the slag slurry include increased cover over the top mat of rebar, high micro-texture and adequate macrotexture at a very low cost compared to 2-in thick portland cement concrete overlays, 1.25-in thick latex modified concrete overlays and 0.25-in thick polymer overlays. A slag slurry mixture made with a high early strength special blended cement should be evaluated for use when a short lane closure time is required.

Multiple Layer Polymer Overlays

Multiple layer polymer concrete overlays have been installed on portland cement concrete bridge decks in Virginia and several other states to increase the skid resistance of the surface and to protect the concrete from the infiltration of chloride ion (5). The overlay consists of two layers of epoxy, polyester with a methacrylate prime coat, or epoxy urethane and clean, dry, angular-grained, silica or basalt aggregate applied to the top of a portland cement concrete deck to provide a 0.25-in thick wearing surface. Typically, the polymer is applied with brooms or squeegees uniformly over the surface of the deck and before it gels is covered to excess with broadcasted fine aggregate (see Figure 5). Usually, within the first hour, a layer cures sufficiently to permit vacuuming the excess aggregate preparatory to placing a subsequent layer. The polymer concrete overlay has an advantage over other deck protective systems in that it can be constructed in stages during off-peak traffic periods. The first layer of resin and aggregate can be applied to a lane that has been closed and shotblasted, and after a minimum of three hours of cure, the lane can be opened to traffic. The second layer can be placed on the next day or night off-peak traffic period.

An additional advantage of overlays such as latex modified slag slurry and polymer is that new decks can be constructed with polishing aggregates, thereby extending our diminishing supplies of aggregates, and the thin overlays can be applied to provide adequate skid resistance.

RESULTS

Skid Numbers at 40 mph

Table 4 shows the results of skid tests conducted at 40 mph using a smooth tire (ASTM E524-88) (8). The minimum acceptable number in Virginia is 20. New surfaces should have numbers much higher than 20 because the numbers decline as the cumulative traffic over the surfaces increases (*5*).

As can be seen from Table 4 the bridge deck and pavement constructed with polishing limestone aggregate and a screeded surface in the sixties were in need of corrective action. Table 4 shows that the highest numbers were obtained with the latex slag slurry pavement application and the polymer overlays and the lowest numbers were obtained with shotblasting and sealing and the latex slag slurry bridge deck application. The numbers shown in Table 4 were measured within several months after the techniques were applied. All the techniques provide adequate skid numbers.

With the exception of the polymer overlays, skid numbers at later ages are not available because the experimental techniques were first applied in Virginia in 1989. Polymer overlays have been shown to exhibit skid numbers of 35 after 7 years in service (*5*). The skid numbers should be measured at later ages to allow the service life to be estimated.

Permeability to Chloride Ion

A rapid permeability test (AASHTO T277) was used to measure the permeability to chloride ion of the top 2 in of 4–in diameter cores taken from selected bridge decks and the pavement on I–81. The cores were taken within several weeks after the textures were applied with the exception that the cores taken to represent the sawcutting of grooves were textured in the laboratory several days prior to testing. The results are reported in Table 5 in coulombs where <100 = negligible; 100–1,000 = very low; 1,000 – 2,000 = low; and 2,000 – 4,000 = moderate permeability. It can be seen from Table 5 that all the techniques with the exception of the polymer overlay increase the permeability of the top 2 in of the concrete. However, the application of the penetrating sealers to the shotblasted surface brings the permeability back in line with that of the unblasted surface. The application of the latex modified slag slurry also increases the cover over the rebar and should provide additional protection. The protection is not apparent from the test results because the test requires a 2–in thick specimen. In new construction additional cover can be added to account for the cover that will be lost by tining, sawcutting grooves or shotblasting.

The permeability of portland cement concrete surfaces usually decreases with age as the surfaces are sealed by road dirt, oil and carbonation as the portland cement concrete ages. The permeability of the polymer overlays increases with age (*5*). The permeability to chloride ion can be a significant factor when selecting the texturing technique for bridge decks with less than 2 in of cover over the rebar and rebar that is not epoxy coated.

Cost

Table 6 shows the initial cost of the texturing techniques. It is obvious that tining is the most economical technique and the polymer overlay is the most expensive. The other techniques cost about $6/yd^2 with the exception that shotblasting with no sealing costs about $2.50/yd^2. The life cycle cost of the techniques cannot be computed because the life of the surfaces is not known.

Subjective Rating of Techniques

Any one of the five techniques can be used to increase the skid resistance of a deck and the most effective technique is the one that best meets the needs of the deck. A subjective rating as shown in Table 7 can be used to select the optimum alternative in a given situation. The analysis in Table 7 shows that tining is the optimum technique when all factors are given equal weight. However, tining is not an option on old decks and some high quality concretes do not lend themselves to tining. When lane closure time is important sawcutting grooves, shotblasting and polymer overlays can be used. When decks are constructed with polishing aggregates, overlays such as the latex modified slag slurry or the polymer can be used.

CONCLUSIONS

1. At least five techniques can be used to increase the skid resistance of bridge decks and the most effective technique is the one that best meets the needs of the deck.
2. Tining the plastic concrete is the most economical technique for increasing macrotexture but its use is limited to new decks or overlays that are constructed with nonpolishing aggregates and with mixtures and construction procedures that provide for good surface workability at the time the texture is applied.
3. Sawcutting grooves and shotblasting and sealing are economical techniques for increasing the macrotexture of hardened concrete surfaces constructed with nonpolishing aggregates. Both techniques reduce the cover over the rebar and the protection provided by the concrete. Traffic can be applied to the sawcut surface immediately and to sealed surfaces after about 1 hour of cure time.
4. Decks constructed with polishing aggregates would have to be shotblasted on a regular basis, depending on the volume of traffic, to maintain an adequate microtexture.
5. The application of a latex modified portland cement slag slurry is an economical technique for increasing the microtexture and macrotexture of hardened concrete surfaces constructed with polishing or nonpolishing aggregates. The technique also increases the cover over the rebar but is limited to decks that can be closed for two days to allow for proper cure. A slag slurry mixture made with a high early strength special blended cement should be evaluated for use when a short lane closure time is necessary.
6. The application of a multiple layer polymer overlay is a more expensive technique for increasing the microtexture and macrotexture of hardened concrete surfaces constructed with polishing or nonpolishing aggregates. The higher cost can be justified when additional protection against the infiltration of chloride ion is needed and a short lane closure time is necessary.

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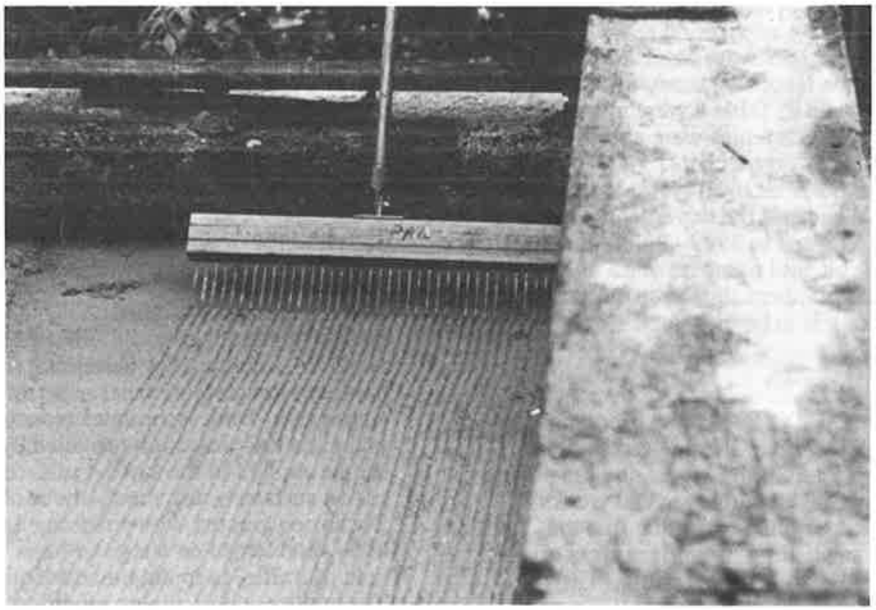

FIGURE 1 A tining device should be pulled across the surface as soon as possible after the finishing operation is complete to produce grooves that are approximately 1/8 in wide and 1/8 in deep and 3/4 in on center to produce a surface with a high skid resistance.

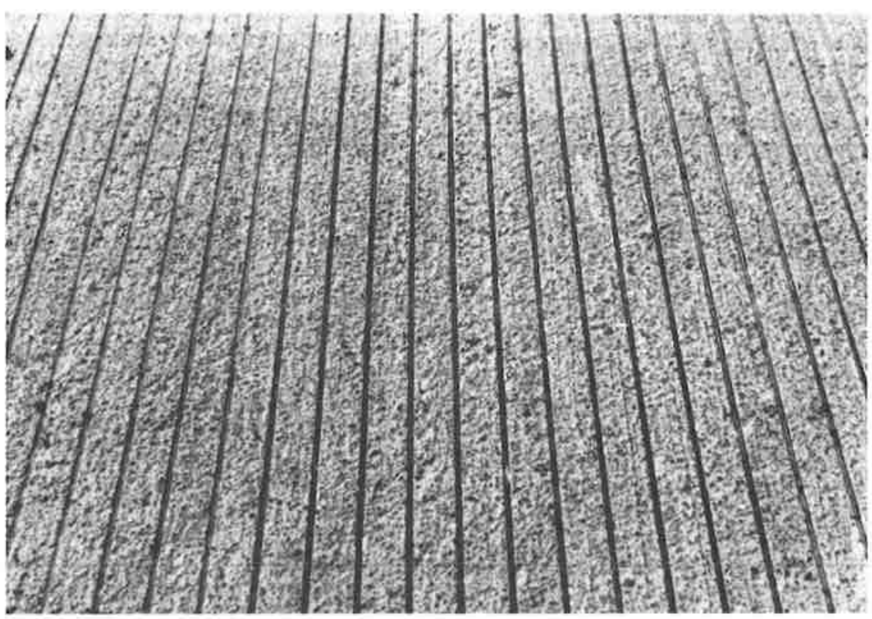

FIGURE 2 The hardened concrete may be sawed to produce grooves approximately 1/8 in wide by 3/16 in deep and 3/4 to 1 1/2 in on centers. The grooves shown here are spaced 1 1/4 in on centers.

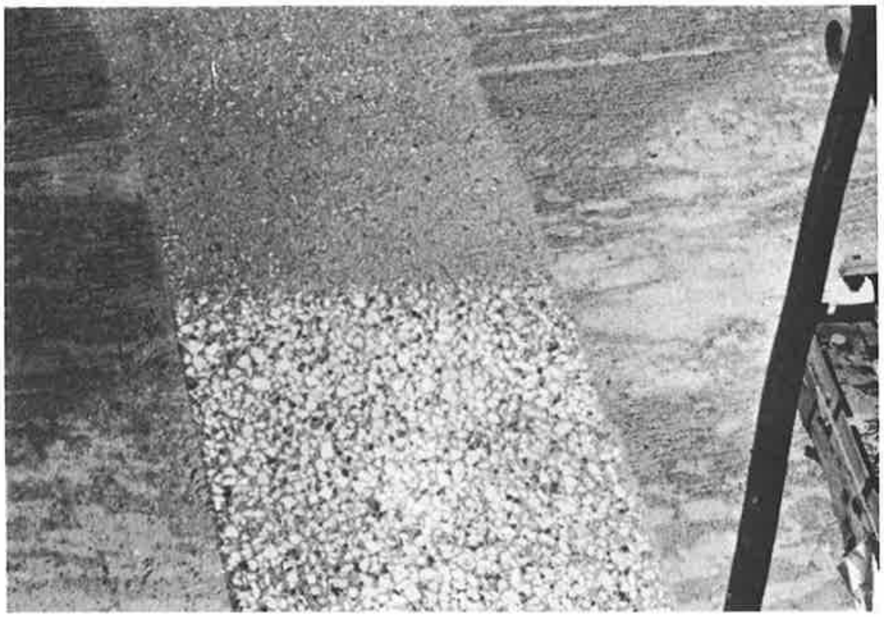

FIGURE 3 The degree of cleaning obtained with shotblast equipment is a function of the forward speed, the number of passes, the size of the shot, and the gate opening. Once the proper setting is identified, the entire surface should be cleaned at that setting. A slow speed or multiple passes are required to obtain the exposed aggregate surface shown above. The lighter cleaning (top of figure) was obtained by increasing the forward speed of the blaster. It is usually necessary to expose the coarse aggregate to obtain adequate bond strength and to provide good skid resistance.

FIGURE 4 A latex modified slag slurry overlay is here applied to a bridge deck to increase the skid resistance. Brooms should be used to brush the slurry into the shotblasted surface and the slurry should be struck off and pulled forward with gage rakes set to provide a 3/16 in to 1/4 in thick slurry. For increased skid resistance slag should be broadcast onto the struck off surface, and a liquid curing material should be applied to prevent the evaporation of water. The slurry can be opened to traffic in two to three days.

FIGURE 5 An epoxy urethane mixture is here spread over the deck with notched squeegees. Basalt aggregate is here broadcast to excess from the back of a dump truck. Polymer overlays constructed with epoxy, polyester, methacrylate, and epoxy urethane can be used to increase the skid resistance of bridge decks.

TABLE 1 Sieve Analysis of Slag, % Passing Indicated Sieve

Sieve	Slag	ASTM C33
-3/8	100	100
—4	95	95–100
—8	63	80–100
−16	39	50–85
−30	24	25–60
−50	16	10–30
-100	9	2–10
-200	4	

TABLE 2 Mixture Proportions for Latex Modified Portland Cement Slag Slurry, lb/yd^3

	Design	Actual**
Cement*	911	874
Slag	2,375	2,279
Latex emulsion	368	353
Water	213	272
W/C	0.44	0.52

* Type III portland

** The slag was assumed to have an 8% moisture content, but was found to have an 11% moisture content.

TABLE 3 Compressive Strength, lb/in^2, Vs Age*

Technique Test section	Latex Modified Slag Slurry I-81 NBTL pavement	 I-81 NBTL bridge deck	Polymer Overlay Typical for modified epoxy
3 hr	—	—	2,800
18 hr	370	—	—
24 hr	—	1,050	8,100
40 hr	1,970	—	—
48 hr	—	1,590	8,500
28 day	4,100	2,680	—

* Results based on average of three tests on 2-in field cured mortar cube specimens.

TABLE 4 Smooth Tire Skid Numbers at 40 mph

Technique	Test Section	Skid Numbers
None (12.8 in dia. sand patch)	I–81 SBTL bridge deck	17
None (10.1 in dia. sand patch)	I–81 NBTL pavement	27
Tining plastic concrete	Latex modified concrete overlay Rte. 340 over Hawksbill Creek	41
Tining plastic concrete	Bridge deck Rte. 161 over North Run	42
Sawcutting grooves 3/4 in on center	International Blvd. pavement (2)	47
Sawcutting grooves 1 1/2 in on center	International Blvd. pavement (2)	41
Shotblast (5.5 in dia. sand patch)	I–81 NBTL pavement	45
Shotblast (7.4 in dia. sand patch)	I–81 SBTL bridge deck	37
Shotblast and seal with gum resin (7.2 in dia. sand patch)	I–81 SBTL bridge deck	36
Shotblast and seal with siloxane (7.5 in dia. sand patch)	I–81 SBTL bridge deck	40
Latex modified slag slurry	I–81 NBTL pavement	65
Latex modified slag slurry	I–81 NBTL bridge deck	39
Polymer overlay	I–64 EBTL bridge deck	63

TABLE 5 Permeability to Chloride Ion, Coulombs

Technique	Test Section	Permeability
None	I–81 SBPL bridge deck	1,866
None	I–81 NBTL pavement	2,100
Tining plastic concrete	Latex modified concrete overlay Rte. 340 over Hawksbill Creek	1,464
Tining plastic concrete	Bridge deck Rte. 161 over North Run	3,385
Sawcutting grooves 3/4 in on center	Latex modified portland cement concrete overlay (16 yr old)	146*
Sawcuttings grooves 3/4 in on center	Portland cement cencrete concrete overlay (16 yr old)	2,147**
Shotblast (8.0 in dia. sand patch)	I–81 NBTL pavement	2.925
Shotblast (7.4 in dia. sand patch)	I–81 SBTL bridge deck	2,731
Shotblast and seal with gum resin (7.2 in dia. sand patch)	I–81 SBTL bridge deck	1,480
Shotblast and seal with siloxane (7.5 in dia. sand patch)	I–81 SBTL bridge deck	1,975
Latex modified slag slurry	I–81 NBTL pavement	2,879
Polymer overlay	I–64 EBTL bridge deck	12

* 102 before saw cuts made.
** 1,305 before saw cuts made.

TABLE 6 Cost, $/yd^2$

Technique	Test Section	Cost
Tining plastic conrete	Typical	0
Sawcutting grooves 3/4 in on center	Average for nine bridge decks in Staunton District in 1989 (10,450 yd^2)	6.15
Shotblast (5.5 in dia. sand patch)	I–81 NBTL pavement	2.50
Shotblast and seal with gum resin (7.2 in dia. sand patch)	I–81 SBTL bridge deck	5.25
Shotblast and seal with siloxane (7.5 in dia. sand patch)	I–81 SBTL bridge deck	5.85
Latex modified slag slurry	I–81 NBTL pavement	5.90
Polymer overlay	Typical cost in 1989	30.00

TABLE 7 Subjective Rating of Techniques.

Technique	Tining	Sawcut Grooves	Shotblast and Seal	Latex Modifited Slag Slurry	Polymer Overlay
Cost	5	3	3	3	1
Lane closure time	5	3	3	1	3
Wear	3	3	2	3	3
Surface appearance	3	3	3	2	4
Chloride ion protection	2	2	2	3	5
Total	18	14	13	12	16

1 = low rating for disadvantage.
5 = high rating for advantage.