Maintenance Resealing of Rigid Pavement Joints

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Transverse joints in an existing portland cement concrete pavement were resealed to evaluate a number of sealers and sealing methods. Six liquids were installed, including asphalt cement, field-mixed rubber asphalt, two premixed rubber asphalts, polyvinyl chloride coal tar, and tar-modified polyurethane, as well as three preformed neoprenes. Liquid sealers were placed 50.8 to 63.5 mm (2 to 2½ in) deep in some joints and restricted to 12.7 mm (½ in) deep in others. Some joints were sandblasted to determine the effect of clean joint faces on sealer performance. Three types of joints were resealed: (a) 25.4-mm (1-in) expansion joints spaced at 30.48 m (100 ft); (b) 6.3-mm (¼-in) sawed contraction joints spaced at 18.54 m (60 ft, 10 in); and (c) 9.5-mm (⅜ in) formed contraction joints spaced at 18.54 m (60 ft, 10 in). Sealer performance has been evaluated over 3 winters, and pavement cores and sealer samples have been taken to observe sealer condition. All the neoprene sealers effectively seal the joints except along spalls. Some compression set has occurred in one brand but has not yet affected performance. The polyvinyl chloride sealer has generally performed best of the liquids, and the asphalt and field-mixed rubber-asphalt sealers generally performed poorly. Loss of adhesion between sealer and joint face is the most common failure mode for liquid sealers; entrapment of incompressible debris is a serious problem for asphalt and field-mixed rubber-asphalt sealers. Thorough joint cleaning was essential for some tested materials, but had no apparent effect on others. Generally, sealers placed 12.7 mm (½ in) deep did not perform as well as those placed 50.8 to 63.5 mm (2 to 2½ in) deep.

Transverse and longitudinal joints in rigid pavements are constructed to control expansion and contraction forces resulting from temperature and moisture changes. They are sealed to prevent intrusion of foreign materials that prevent them from functioning. Transverse joints are the more difficult to seal because they are subject to greater movements and are also very susceptible to damage if not properly sealed.

Keeping transverse joints in rigid pavements effectively sealed is a long-standing problem, and in New York it is aggravated by two factors. Joint spacings are very long [18.28 m (60 ft) or more], and the annual pavement temperature differential approaches 83.3°C (150°F). In combination, these factors cause large width changes in transverse joints between summer and winter, as great as 12.7 mm (½ in) in some cases.

New York currently specifies 31.7-mm (1¼-in) neoprene sealers in 15.9-mm (⅝-in) contraction joints, and they are giving good service. Before 1968, narrower neoprene sealers were used in contraction joints; asphalt sealers were used as well in both contraction and expansion joints. Because of the short life provided by these earlier sealers and the realization that the current sealer system will not last indefinitely, an effective resealing program is needed to ensure that transverse joints are sealed throughout the life of a pavement.

The standard maintenance sealer in New York has been 50-60 penetration grade asphalt, but its performance has been poor for a number of reasons. For the past several years, ground reclaimed rubber has been added to the asphalt during melting on a trial basis in an attempt to obtain better performance. The effectiveness of this additive had not been clearly demonstrated.

In 1972, the study reported here was initiated to identify transverse joint sealers and sealing procedures that might provide better performance than the standard asphalt sealer at reasonable cost. Six liquid and three preformed sealers were installed in nearly 300 transverse joints, and their performance has been evaluated over 3 winters.

INVESTIGATION

Selection of Test Sealers

Fifty-one sealer manufacturers were contacted to select sealers for the study. The sealers had to meet three general requirements: (a) they had to be easy to handle, prepare, and install without expensive equipment; (b) they had to be stable and nontoxic; and (c) they had to have a short cure time. Sixteen companies submitted data on 21 sealers, which were screened according to the following criteria:

1. Cost of the sealer (and primer, if required);
2. Ease of handling, mixing, and placing;
3. Stability and nontoxic qualities;

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4. Shelf life, pot life, and cure time;
5. Equipment required for mixing and installation;
6. Solvents and equipment required for cleanup;
7. Compatibility with asphalt (because most joints to be resealed had previously been sealed with asphalt, which is extremely difficult to remove completely from joint faces); and
8. Previous experience with the sealer in earlier studies.

In all, six liquid and three preformed sealers were selected (including two liquids then used by the department); sealer details are given in Table 1. (Names of the manufacturers of the products tested may be obtained from the authors.)

Test Joints and Their Preparation

Sealer test sections were installed in three areas of I-87 north of Albany, a six-lane divided portland cement concrete pavement. Three types of joints were sealed: (a) 25.4-mm (1-in) expansion joints spaced at 30.48-m (100-ft) centers; (b) 6.3-mm (¼-in) sawed contraction joints spaced at 18.54 m (60 ft, 10 in); and (c) 9.5-mm (⅜-in) formed contraction joints spaced at 18.54 m (60 ft, 10 in). All three types of joints are shown in Figure 1, and the highway sections are described in Table 2.

Sealers were placed in only one lane to simplify traffic control during installation and evaluation (the northbound median lane for the expansion joint section and the northbound driving lane for the two contraction types of joint). The joints for resealing were carefully screened to eliminate variable sealer performance caused by spalled and damaged joints or by midslab cracks that would influence joint movement. Brass pins were installed at each joint to monitor joint width changes during the test.

The old sealers were removed by several methods, including pickaxes, powered wire brushes, screwdrivers, and concrete saws. However, none was very efficient (an effective means of removing old sealers is needed). The expansion joints were cleaned to a minimum depth of 38.1 mm (1½ in), and the contraction joints were cleaned for the entire reservoir depth, which was approximately 63.5 mm (2½ in). All joints were blown out with compressed air after removal of the old sealers, and half were sandblasted to determine whether this extra cleaning would improve sealer performance. Half the contraction joints were filled full depth [63.5 mm (2½ in)] with the liquid sealers. In the other half, a filler material was used to restrict sealer depth to 12.7 mm (½ in).

Nine sealers, three types of joints, two joint preparation methods, and two sealer depths were included in the test. Not all combinations of variables were included, however. In addition to the reasons already mentioned, poor weather, equipment failure, and scheduling problems prevented completion of some planned installations. Preformed compression sealers were not placed in the 25.4-mm (1-in) expansion joints because the joints had spalls in which compression seals would have been ineffective and they would have required a sealer about 50.8 mm (2 in) wide, which would have been too expensive. The number of joints to be sealed for each combination of variables was set at five. This limited the total to be sealed and evaluated to a workable number, slightly less than 300. At the same time, five would provide a representative picture of sealer performance. Some variation in performance could be tolerated, and sealer capabilities could still be assessed validly.

Sealer Installation

In general, no serious problems were encountered while the hot-poured liquids were installed, but some had to be heated as long as 3 h before they reached pouring consistency. Minor difficulties were experienced with automatic joint-sealing equipment used with the premixed rubber asphalts and the polyvinyl chloride (PVC) coal tar sealers, but they were isolated instances and would not be expected to occur if these sealers were installed on a production basis. Rapid set times, all less than 30 min, were experienced for all the hot-poured sealers, making it possible to reopen the pavement to traffic soon after resealing was completed. Some problems were experienced with the cold-poured polyurethane sealer because of its long set time; it tended to run out of the low end of the joint groove and through the crack beneath it, making it difficult to fill the joint to the desired level. Because of its slow curing rate, tracking from vehicle tires was also experienced when the pavement was reopened. The preformed neoprene sealers were installed with hand rollers, but, in some very narrow joints, particular care was necessary to hold longitudinal stretch below the specified 5 percent limit, which in some cases was slightly exceeded.

Field Surveys

The joints were surveyed monthly for 2 years and quarterly for a third year. All changes in the sealers were noted, including oxidation or discoloration of the surface, surface cracking or crazing, air bubbles, sealer extrusion and tracking by traffic, depth of sealers in the joints, compression set and web sticking in the preformed sealers, and embedment or entrapment of foreign materials in the sealer or the joint. Total length of adhesion failure between the joint face and sealer and cohesion failure within the sealer were measured at each joint. Many types of failure are apparent from the surface, and their extent can be measured or estimated. Adhesion and cohesion failures, however, are difficult to assess unless in an advanced stage. These were counted when a thin-bladed putty knife could be inserted by applying only slight pressure between the sealer and joint face or in the separation in the sealer. More pressure could not be exerted because of the danger of creating failures where none had existed. Because both types of failure are related to joint width, the rates of failure were greatest in cold weather when joints were widest and varied greatly from survey to survey. Sealer failures from loss of adhesion and cohesion were defined as occurring when the total full-depth failure present exceeded 10 percent of the joint length, or 0.73 m (28.8 in) for two 3.66-m (12-ft) joint faces. Failures not extending the full depth of the sealer were noted but generally had little adverse effect on sealer performance and did not enter into the failure criterion. Because some variability in performance was observed, all five joints in a test group were rated together. In most cases, the 10 percent failure criterion was first exceeded in cold weather, and most sealers appeared to recover with warm weather. However, because intrusion had occurred, the sealer was still considered to have failed.

For liquid sealers, entrapment of incompressible materials was another common failure mode. This was estimated from surface observations supplemented by sampling of the sealers as will be explained later. Consequences of the other failure modes were small compared with the full-depth bond and cohesion failures or entrapment and had no practical influence on determining when failure occurred.

Full-depth core samples were obtained at the end of the second winter and again during the third winter from each joint group to check intrusion of foreign material. They also made it possible to assess the entrapment of foreign material in the liquid sealers and compression set and web sticking in the preformed sealers. Some cores were taken in areas of typical performance for a joint group and others were taken in areas that appeared to be in particularly good condition to determine whether sealers were actually performing as well as they appeared to be from the surface.

Some variation in joint movement was expected and must be accommodated by an effective sealer. Test joint widths were measured periodically to detect abnormal changes that might have pronounced effects on a particular joint or group of joints. As expected, expansion joints moved more because of their greater spacing, and substantial variation was apparent between joints. This variation, however, does not appear to be abnormal and no differences in sealer performance can be related to it.

SEALER PERFORMANCE

Asphalt Control Sealer

Asphalt cement, the department's standard sealer, performed poorly in all three test areas. Of 10 test sections, 3 failed during the first winter and 4 more failed during the second. Three remaining sections approached 10 percent full-depth failure during the third winter. Table 3 gives a summary of the performance of this and the other sealers. It is very temperature-susceptible; it becomes hard and brittle in winter and soft and sticky in warm weather. Massive adhesion failures in cold weather have been one failure mode—one expansion section failed during the first winter and the other failed during the second. The restricted-depth sealers in 6.3-mm (¼-in) contraction joints failed from massive adhesion failure during the first winter. Several more sections failed the same way during the second winter; by the third winter, three sections were still providing marginal service although each had exhibited considerable adhesion failure during cold weather as well as severe embedment and infiltration.

Chunks of this material also were lost during cold weather, and the surface became very irregular. Figure 2a shows the appearance of this sealer during the first winter with infiltration of foreign material into surface voids. With warmer weather and contraction joint closure, it appeared to recover (Figure 2b), but, when a section was removed (Figure 2c), extensive embedment and intrusion of foreign material were apparent. This embedment, accompanied by the joint closure, resulted in sealer extrusion (Figure 2d). Such material is worn away by traffic, and the following winter its capacity to seal is reduced even further.

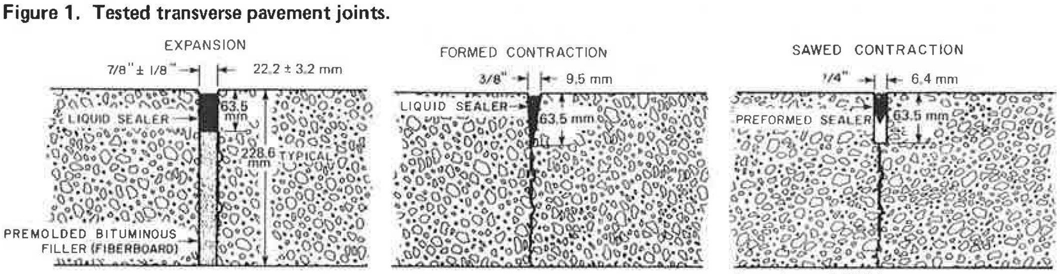
For the three test sections that failed during the first winter through adhesion or cohesion failure, embedment was not a factor. In all other sections, it was found during the first summer; at the end of the second winter, all displayed serious embedment and infiltration of foreign material. These sealers thus cannot be considered to be performing satisfactorily even though they have not

Table 1. Tested sealers.

Sealer	Description	Specification
Liquid	50-60 penetration grade asphalt cement	NYS item 702-50
	Field-mixed rubber asphalt	—
	Premixed rubber asphalt	ASTM D 1190-64 Federal specification SS-S-164(4)
	Premixed rubber asphalt	Federal specification SS-S-1401A
	PVC coal tar	ASTM D 3406-75T
	Tar-modified polyurethane	Federal specification SS-S-00200C
Preformed	Neoprene extrusion	ASTM D 2628-67T NYS item 705-12

Note: Neoprene extrusions made by three different manufacturers were tested.

Figure 1. Tested transverse pavement joints.



Note: 1 mm = 0.0394 in.

Table 2. Test areas.

Test Area	Location	Slab Length (m)	Type of Joint	Joint Dimensions (mm) Width	Depth	Previous Seal
1	Mohawk River to Clifton Park	30.45	Hand-formed expansion	25.4	Full	Asphalt
2	Malta to Saratoga	18.54	Sawed contraction	6.3	63.5	14.4-mm neoprene seal
3	Glens Falls to Lake George	18.54	Insert-formed contraction	9.5	63.5	Asphalt

Note: 1 m = 3.28 ft. 1 mm = 0.0394 in.

reached 10 percent full-depth failure.

Other Liquid Sealers

In terms of full-depth failure, the field-mixed rubber asphalt material performed slightly better than the control asphalt sealer. Only one section, sealed 12.7 mm deep (½ in) in 6.3-mm (¼-in) contraction joints, failed during the first winter. Four more failed during the second winter, and all experienced considerable full-depth failures although five did not reach 10 percent.

By the end of the third winter, three more sections had experienced complete failure and only two had less than 10 percent failure. The material exhibited slightly less embrittlement in cold weather than did the asphalt control sealer, but it became sticky in warm weather with extensive embedment and infiltration. When sampled after the second winter, all test sections displayed foreign material in and below the sealer. The same extrusion problems mentioned for the control sealer were experienced here. In winter, it was less susceptible to tearing out of large chunks than the more brittle control,

Table 3. Summary of sealer performance.

Sealer	Test Area	Joint Numbers	Sealer Depth (mm)	Sealer Width (mm)	Joint Preparation	Maximum Full-Depth Failure[a] Length (mm)	Date	Months in Service at Failure
Asphalt cement (control)	1	1 to 5	Full	–	Cleaned	3 937.0	11/73	13
	1	6 to 10	Full	–	Sandblasted	5 486.4[b]	4/73	6
	2	91 to 95	Full	–	Cleaned	2 463.8	2/74	30+[c]
	2	96 to 100	Full	–	Sandblasted	5 054.6	2/74	14
	2	101 to 105	12.7	–	Cleaned	10 668.0	2/73	3
	2	106 to 110	12.7	–	Sandblasted	7 315.2	2/73	3
	3	86 to 90	Full	–	Cleaned	5 232.4	2/74	16
	3	91 to 95	Full	–	Sandblasted	3 378.2	2/74	30+[c]
	3	96 to 100	12.7	–	Cleaned	4 622.8	2/74	16
	3	101 to 105	12.7	–	Sandblasted	1 701.8	2/74	30+[c]
Field-mixed rubber asphalt	1	11 to 15	Full	–	Cleaned	3 149.6	4/73	30+[c]
	1	16 to 20	Full	–	Sandblasted	4 064.0	2/74	16
	2	111 to 115	Full	–	Cleaned	8 712.2	2/74	16
	2	116 to 120	Full	–	Sandblasted	5 613.4	2/74	16
	2	126 to 130	12.7	–	Cleaned	4 749.8	2/74	4
	2	131 to 135	12.7	–	Sandblasted	3 378.2	2/74	30[d]
	3	111 to 115	Full	–	Cleaned	5 410.2	2/74	16
	3	116 to 120	Full	–	Sandblasted	2 159.0	2/74	30+[c]
	3	121 to 125	12.7	–	Cleaned	1 346.2	2/75	30[d]
	3	126 to 130	12.7	–	Sandblasted	2 032.0	2/75	30[d]
Premixed rubber asphalt 1	1	21 to 25	Full	–	Cleaned	914.4	2/74	30+
	1	26 to 30	Full	–	Sandblasted	2 463.8	2/74	30+
	2	51 to 55	Full	–	Cleaned	5 232.4	2/74	14
	2	56 to 60	Full	–	Sandblasted	4 368.8	2/74	15
	2	61 to 65	12.7	–	Cleaned	3 500.6	2/74	30+
	2	66 to 70	12.7	–	Sandblasted	3 683.0	2/74	14
Premixed rubber asphalt 2	1	31 to 34	Full	–	Cleaned	1 219.2	1/75	30+
PVC coal tar	1	41 to 45	Full	–	Cleaned	7 696.2	6/74	19
	1	46 to 50	Full	–	Sandblasted	1 219.2	1/75	30+
	2	141 to 145	Full	–	Sandblasted	3 479.8	2/75	30+
	2	146 to 150	12.7	–	Cleaned	5 689.6	2/74	15
	2	151 to 155	12.7	–	Sandblasted	2 006.6	2/74	30+
	3	11 to 15	Full	–	Cleaned	1 117.6	2/75	30+
	3	16 to 20	Full	–	Sandblasted	None	–	30+
	3	21 to 25	12.7	–	Cleaned	5 537.2	2/75	26
	3	26 to 30	12.7	–	Sandblasted	304.8	2/75	30+
Tar-modified polyurethane	1	51 to 55	Full	–	Cleaned	3 073.4	1/74	30+
	1	56 to 60	Full	–	Sandblasted	6 045.2	1/75	14
	2	1 to 5	Full	–	Cleaned	3 886.2	2/75	27
	2	6 to 10	Full	–	Sandblasted	5 969.0	2/75	27
	2	11 to 15	12.7	–	Cleaned	7 239.0	1/74	14
	2	16 to 20	12.7	–	Sandblasted	4 419.6	2/75	27
	3	131 to 135	Full	–	Cleaned	10 134.6	2/75	27
	3	136 to 140	Full	–	Sandblasted	609.6	2/75	30+
	3	141 to 145	12.7	–	Cleaned	6 375.4	2/75	14
	3	146 to 150	12.7	–	Sandblasted	1 549.4	2/75	30+
Neoprene 1	2	41 to 45[e]	–	13.7	Cleaned	965.2	2/74	30+
	2	46 to 50[e]	–	13.7	Sandblasted	762.0	2/74	30+
	3	51 to 55	–	25.4	Cleaned	457.2	2/74	30+
	3	56 to 60	–	25.4	Sandblasted	660.4	3/74	30+
Neoprene 2	2	31 to 35	–	10.6	Cleaned	1 041.4	2/74	30+
	2	36 to 40	–	10.6	Sandblasted	1 778.0	2/74	30+
	3	161 to 165	–	19.8	Cleaned	863.6	2/74	30+
	3	166 to 170	–		Sandblasted	1 117.6	2/74	30+
Neoprene 3	2	156 to 160	–	10.6	Cleaned	457.2	2/74	30+
	2	161 to 165	–	10.6	Sandblasted	457.2	2/74	30+
	3	1 to 5	–	19.8	Cleaned	406.4	6/73	30+
	3	6 to 10	–	19.8	Sandblasted	762.0	3/74	30+

Note: 1 mm = 0.0394 in.

[a]Total for five joints; criterion for 10 percent failure = 3657.6 mm (5 x 3657.6 x 2 x 0.1) [144 in (5 x 144 x 2 x 0.1)].
[b]3657.6-mm (144-in) bond failure in one joint; other four failed after 13 months.
[c]Failed through embedment.
[d]Failed July 1975.
[e]Joints 45 and 46 had 10.6-mm (7/16-in) sealer.

although some chunking did occur (Figure 3a).

Of the two premixed rubber asphalts, the first survived 3 winters in the 25.4-mm (1-in) expansion joints. Although less temperature sensitive than the control and field-mixed rubber asphalt, it too became brittle in cold weather and lost some sections in chunks. In the summer, although it became soft and extruded from the joints, it did not become sticky and subject to embedment and entrapment of foreign material. Although the 25.4-mm (1-in) expansion joints had not exceeded the 10 percent full-depth failure limit by the end of the third winter, they did not completely prevent infiltration of foreign material between the sealer and joint face (Figure 3b). In the 6.3-mm ($^1/_4$-in) contraction joints, three of four test sections failed during the second winter from massive adhesion failure along the joint face, and the fourth nearly reached the 10 percent failure criterion. In spite of these adhesion failures, infiltration past the sealer (Figure 3c) was much less than for the control asphalt and the field-mixed rubber asphalt. Embedment in the sealer itself was also noticeably abent. Because of poor weather during installation, this sealer was not installed in the 9.5-mm ($^3/_8$-in) contraction joints.

Because of equipment problems, the second premixed rubber-asphalt installation was not completed before winter, and only four 25.4-mm (1-in) expansion joints were sealed. In terms of full-depth failure, it performed very much as the other premixed rubber asphalt and was still below 10 percent failure after 3 winters. Although it remained more pliable in cold weather, it too allowed some infiltration along the joint face. Although extrusion occurred in hot weather when the joints closed, it did not flow out of the joint where it could be worn away by traffic but rather remained intact (Figure 3d). Like the first rubber asphalt, the second succeeded in preventing embedment of foreign material within the sealer. Based on this small installation, the second premixed rubber asphalt appears to possess better material properties than the asphalt control or field-mixed rubber asphalt and is less susceptible to embedment. However, it does not completely seal a joint for a much

Figure 2. New York State standard liquid asphalt control sealer.

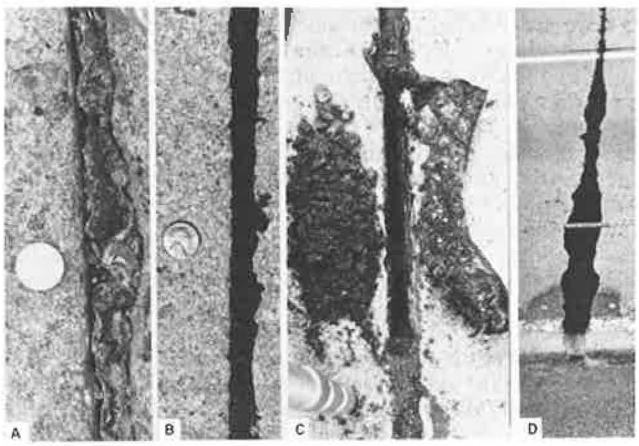


Figure 3. Experimental liquid sealers.

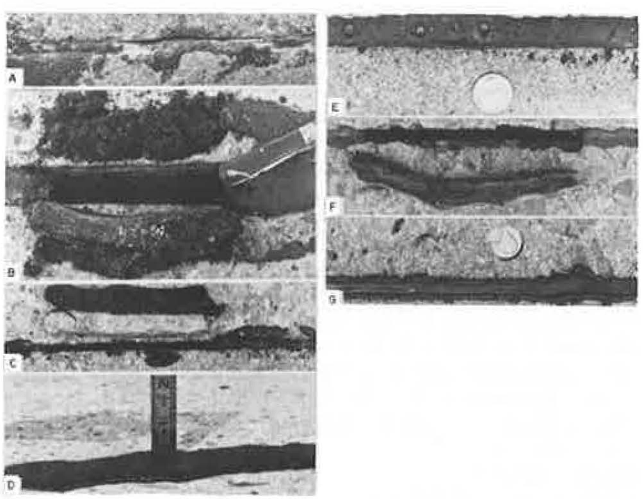


Figure 4. Preformed neoprene sealers.

Table 4. Sealer life expectancy and performance.

Sealer	Description	Expected Years of Service: Contraction	Expected Years of Service: Expansion	Temperature Susceptibility	Embedment Resistance	Failure Mode
Liquid	Asphalt cement	1 or less	1	Poor	Poor	Bond, embedment, extrusion
	Field-mixed rubber asphalt	1	1	Poor	Poor	Bond, embedment, extrusion
	Premixed rubber asphalt	1	3+	Good	Good	Bond
	PVC coal tar	3+	3+	Good	Excellent	Bond
	Tar-modified polyurethane	2 to 3	1 to 3	Excellent	Excellent	Bond, cohesion
Preformed	Neoprene 1	3	–	Excellent	Excellent	Spalls, compression set
	Neoprene 2	3+	–	Excellent	Excellent	Spalls
	Neoprene 3	3+	–	Excellent	Excellent	Spalls

greater period.

Two PVC sealers—both manufactured to the same specification—were intermixed during installation and have been evaluated as one. All test sections survived at least into the second winter, and the sandblasted sections were still in service after 3 winters. All failures took the form of full-depth adhesion failure between the sealer and the joint face. Other than small bubbles in its surface (Figure 3e) and very slight embedment of a few small stones in the surface, it had not deteriorated over 3 winters. The material is very resistant to changes in consistency caused by temperature. It remains pliable to very low temperatures and does not become soft and sticky in hot weather. Extrusion did occur when joints closed in hot weather in areas overfilled during sealing, but the sealer retained its integrity and did not track under traffic. Sandblasting has a pronounced effect on the performance of this sealer. In 25.4-mm (1-in) expansion joints that were not sandblasted, some adhesion failure appeared during the first winter and complete failure occurred during the second, but sandblasted joints were still performing satisfactorily into the third winter. The same is true in 6.3-mm (¼-in) joints; sandblasted joints are still in service after 3 winters, and the others failed during the second. In 9.5-mm (⅜-in) contraction joints, the 12.7-mm-deep (½-in-deep) sealers without sandblasting failed during the second winter, and full-depth joints without sandblasting have experienced some full-depth adhesion failure; considerable adhesion failure occurs along the top of the sealer to a depth of 6.3 to 12.7 mm (¼ to ½ in), but these joints have not reached the 10 percent limit. The sandblasted joints, at both full and restricted depth, are still in excellent condition, and have exhibited little or no failure. Except in areas of full-depth adhesion failure, these joints and sealers remain clean and free of intrusion and embedment (Figure 3f). Based on the excellent condition of some test sections after 3 winters, we anticipate that this sealer will provide several years of service before resealing is required.

Three sections of cold-poured polyurethane failed during the second winter and four more failed during the third. Of three still below the 10 percent criterion, one has nearly reached that limit and the other two have smaller amounts of adhesion failure. In addition to full-depth adhesion failures, others due to the placement problems were encountered. In some cases, multiple layers of material required to fill the joint separated, and chunks were lost. Foam dams used to retard sealer flow during installation were also starting places for failures. Otherwise, the sealer has retained its integrity over 3 winters, and its consistency has not been sensitive to temperature changes; in fact, in hot weather it remains the firmest of all the liquid sealers. When extrusion has occurred in hot weather, it has been similar to that experienced by the PVCs, the entire sealer being extruded above the pavement but remaining intact. In the contraction joints, sandblasting generally resulted in fewer full-depth failures. In the 25.4-mm (1-in) expansion joints, the sandblasted section failed during the second winter, but the nonsandblasted section is still below the 10 percent criterion; the difference in failure between the two sections, however, was not great until the third winter. One other defect noticed with this sealer and attributed to installation problems is its tendency to be low in the joint. In some cases, sealers still in good condition are 12.7 to 19.0 mm (½ to ¾ in) below the pavement surface, and dirt and small stones are trapped above even though the joints are still sealed. In other cases, the sealers remained at the surface of the pavement (Figure 3g). Several cores and sealer samples have been removed. As expected, infiltration was found in joints where failures were observed, but, in areas where sealers were functioning properly, no foreign material was found in the joint or embedded in the sealer.

Preformed Sealers

Their performance having been similar, the three preformed sealers will be discussed together. Through the end of the third winter, the only full-depth adhesion failures observed were in areas of joint spalling (Figure 4a). Nearly all of these spalls were present before resealing; some resulted from efforts to remove old sealers. Because very few full-depth adhesion failures have occurred, the evaluation is based heavily on cores and samples removed from these joints.

Samples of the first brand were obtained after the second winter. In the 6.3-mm (¼-in) joints, sides of the joint and sealer were clean without signs of infiltration past the sealer. Some evidence of compression set was noticed. In the 9.5-mm (⅜-in) joints, no compression set was observed, but silt was found in small quantities on the sides of the sealer. At the end of the second summer, this brand was cored in a 9.5-mm (⅜-in) joint; during the third winter, it was again cored in a 6.3-mm (¼-in) joint. The latter showed dirt penetrating the full depth of the sealer on both sides and considerable compression set. The other core, however, which was in a sandblasted joint, showed satisfactory performance and the lubricant adhesive was still working. In the 9.5-mm (⅜-in) joints, one not sandblasted again showed infiltration starting and compression set in the sealer (Figure 4b), but a sandblasted joint was again in good condition. Close examination after the third winter confirmed that compression set was occurring in several sealers, and dirt was infiltrating the sides of both sandblasted and nonsandblasted joints. The top of the sealer was also folded over in several areas, trapping dirt and small stones in the top of the joint (Figure 4c), but in no case was any appreciable amount of dirt found below the sealer.

The second preformed sealer was also sampled in four joints after the second winter [two 6.3-mm (¼-in) joints and two 9.5-mm (⅜-in) joints]. Although traces of silt were found along the upper portion of the sealer, all were in good condition and no compression set was observed. The following fall, one core was removed from a 9.5-mm (⅜-in) unsandblasted joint and the sealer was again found in good condition with only very slight infiltration on the joint sides. During the third winter, one core was removed from each test section; again, all were in good condition and there were only slight traces of side infiltration (Figure 4d). When surveyed after the third winter, several sealer sections were pulled out of the joints. Aside from some slight infiltration near spalls, they were in good condition and were preventing infiltration of all but fine silt, but debris was also being trapped above the sealer.

The third sealer, when sampled after the second winter, showed slight infiltration on the side of the 9.5-mm (⅜-in) joints, but the 6.3-mm (¼-in) joints were clean. The following fall, a core removed from an unsandblasted 6.3-mm (¼-in) joint revealed slight silt stains starting down one side of the sealer; lubricant adhesive was still adhering on the other side. During the third winter, one core was removed from each test section. In all four cases, only slight silt stains were found on the side of the joints, and most lubricant adhesive was still holding. No compression set was detected at any time. The spring survey following the third winter confirmed that, except for failures in spalled areas and slight silt infiltration along the joint sides,

all of these sealers were in excellent condition. In most cases, the preformed sealers were installed lower in the joints than is normal for new construction in an attempt to get below the spalls for an effective seal, but success was limited because of the depth of most spalls (Figure 4e). In some cases, greater sealer depth added to the problem of accumulation of debris above the sealer.

DISCUSSION OF RESULTS

The four principal variables in this experiment were type of sealer, joint geometry, sealer depth, and method of joint preparation. Of these, type of sealer was shown to have the greatest effect on performance.

The standard asphalt sealer performed poorly in most joints and failed both by loss of adhesion and by entrapment of debris within the sealer. Addition of ground rubber to the asphalt sealer reduced its temperature sensitivity somewhat, but performance was little improved. The premixed rubber asphalts performed substantially better than the control asphalt and field-mixed rubber-asphalt sealers, especially in the 25.4-mm (1-in) expansion joints. The first were less temperature sensitive and quite resistant to embedment. The expansion joints resisted full-depth adhesion failures through three winters, and the contraction joints resisted them at least into the second winter. The PVC performed best of any of the liquid sealers; the sealer itself is in excellent condition after 3 winters. Although most joints that were not sandblasted have failed from full-depth adhesion failure, those that were sandblasted have exhibited very little of such failure. Because this sealer is not susceptible to temperature changes and resists embedment, most sandblasted joints are still in excellent condition. The cold-poured polyurethane performed better than the asphalt and rubber-asphalt sealers, particularly in the sandblased joints, but it did not perform as well as the PVC. This sealer also has little susceptibility to temperature and has remained intact over 3 winters. It, too, is resistant to embedment, but installation problems led to some isolated failures.

Except for failures in spalled areas, all three preformed sealers performed well over 3 winters. One brand is now beginning to display compression set. Although they have not prevented intrusion of all silt and water into the joint, they have been successful in preventing entrance of larger material. They are not suitable for joints with more than slight spalling.

Table 4 gives a summary of the properties of each sealer. Expected life, based on their performance in this test, is given for both expansion and contraction joints. For some sealers, sandblasting or other thorough joint cleaning would be required to achieve that life. The susceptibility of each sealer to temperature change and embedment and the principal failure modes that have been observed are given.

Thorough cleaning of joint faces by sandblasting had a pronounced effect on performance of some sealers, and very little on others. For all asphalt and rubber-asphalt sealers, sandblasted joints performed better in some cases, but not in others. In view of the failures caused by embedment and the extrusion problems mentioned earlier, determining whether sandblasting provided any real advantage is impossible. For the premixed rubber-asphalts, no advantage was obtained by sandblasting. However, for the PVC, in three out of four cases, the sandblasted joints performed better. In the fourth case, both the sandblasted and nonsandblasted test sections are still below the 10 percent limit. Three of the four nonsandblasted sections have failed, and the fourth has displayed some full-depth failure. Here, sandblasting appears to be essential for the sealer to perform as intended. For the polyurethane, sandblasting presented no advantage in the 25.4-mm (1-in) joints, but one extra year of service was achieved for the 12.7-mm (½-in) sealers in the sandblasted 6.3-mm (¼-in) joints. For sandblasted 9.5-mm (⅜-in) joints, this treatment appears to offer a significant advantage because they are still in service and the unsandblasted have failed. For preformed sealers, little difference is apparent to date except that lubricant adhesive seems to adhere better in sandblasted joints. Because few failures have occurred, no real difference can be expected at this time.

Both full-depth and 12.7-mm-deep (½-in-deep) liquid sealers were installed in 6.3 and 9.5-mm (¼ and ⅜-in) joints. In those not sandblasted, full-depth sealers generally performed better. In five of eight comparisons, such sealers performed better. In only two cases did they perform worse. The same is true for the sandblasted joints; in six of nine cases, full-depth materials have done better. In only two cases did restricted depths do better. In both of the latter cases, the joints failed early; therefore, no real advantage was gained. In several of the nine comparisons, both full- and restricted-depth sections are still in service, but, when the total amount of full-depth failure is examined, the advantage of full-depth sealing is apparent.

Joint width also has had a pronounced effect on performance. For liquid sealers, 6.3-mm (¼-in) contraction joints have performed considerably worse than the 9.5 or 25.4-mm (⅜ or 1-in) joints. For preformed sealers, both the 6.3 and 9.5-mm (¼ and ⅜-in) joints are generally sealed satisfactorily, but compression set in one sealer was somewhat more noticeable in the narrower joints.

CONCLUSIONS

From observations and measurements in this study, 14 conclusions appear to be warranted:

1. Removal of old sealers was difficult and slow, especially in narrow contraction joints, and, in some cases, resulted in spalled joint faces. Sandblasting cleaned them thoroughly after the old sealers were removed, but this process was very time consuming.
2. The asphalt and field-mixed rubber-asphalt sealers are the simplest of the hot-poured group to prepare and install although both require long heating to achieve pouring consistency.
3. The premixed rubber-asphalt and PVC sealers were more complicated to prepare and place than the asphalt and field-mixed rubber asphalts. Joint-sealing equipment was provided but did not function properly; installation would proceed rapidly with properly adjusted equipment.
4. The cold-poured polyurethane sealer required very little preparation time and no special equipment. Its very slow curing time makes installation difficult. Because it ran down through the bottoms of the joints and out the ends, most had to be refilled. Because of its slow curing, tracking by traffic was also a problem.
5. The preformed compression sealers were generally quite easy to install, but caution was necessary to avoid stretching them in the narrower joints.
6. The asphalt sealer currently specified by the New York State Department of Transportation provided the poorest service of all sealers tested; most test sections failed during the first or second winter from full-depth adhesion failure. It is very temperature susceptible, becoming hard and brittle in cold weather and soft and sticky in the summer. Those joints not failing from full-depth loss of adhesion had embedded foreign ma-

terial by the end of 2 years.

7. The field-mixed rubber-asphalt sealer performed slightly better in terms of full-depth adhesion failure, but only two test sections had less than 10 percent full-depth failure after 3 winters; the others failed from embedment. The most noticeable difference with this sealer is that it appeared to recover quickly in warm weather even though massive embedment had occurred over the winter. The additional cost and effort of adding ground rubber to the asphalt sealer does not appear to be justified by the minor improvements in performance.

8. The premixed rubber-asphalt sealers were less temperature sensitive and were not subject to massive embedment. Performance was similar to the asphalt and field-mixed rubber asphalt in contraction joints, in terms of full-depth failure. However, since little embedment occurred, the only foreign material to enter the joints was between the sealer and the joint face. The 25.4-mm (1-in) expansion joints are effectively sealed after 3 years. These sealers, therefore, appear satisfactory for wide joints and capable of sealing them through at least three winters.

9. The PVC sealer has little temperature sensitivity and successfully resists embedment of foreign materials. In sandblasted joints, it provided 3 winters of service with very low failure rates. Based on this performance, it appears suitable as a maintenance sealer in joints of the geometries tested here provided they are thoroughly cleaned before sealing.

10. The cold-poured polyurethane sealer is the least temperature sensitive of any of the liquids tested, and is not subject to embedment. This sealer provided good service in the sandblasted 9.5-mm ($^3/_8$-in) contraction joints but was similar in terms of full-depth adhesion failure to the asphalt and rubber-asphalt sealers in other joints. Installation problems also led to some isolated failures and, in spite of good performance in some test sections, made this sealer less suitable than others that provided comparable performance.

11. All three preformed compression sealers performed well over 3 winters although one has now begun to exhibit compression set. They have not been effective in spalled areas in spite of their being installed low to try to seal below the spalls. In such areas, dirt and incompressibles have been able to enter the joint. In spall-free joints, they appear capable of providing several years of good performance, but not in spalled joints.

12. For the PVC and cold-poured polyurethane sealers, sandblasting before sealing appears essential for good performance. For others it does not appear warranted.

13. Joints sealed to full depth generally performed better than those restricted to 12.7 mm ($^1/_2$ in), but some optimum depth between these extremes may provide satisfactory performance for some sealers.

14. An effective method of removing old sealers and cleaning joint faces is needed for an effective joint-resealing program.

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Interested readers may note that an expanded version of this paper is in preparation; further information may be obtained by writing to James E. Bryden in care of the Engineering Research and Development Bureau, New York State Department of Transportation, State Campus, Albany, New York 12232, and inquiring for the first interim report on Research Project 105-1.