## RECOMMENDATIONS

1. The maximum specific surface area requirement currently used in the specifications for CRCP should be retained. The performance over a 16-year period indicates the necessity for prohibiting fine-grind cement on a large-scale basis.
2. Consideration should be given to revising the specifications to provide closer control of concrete during hot weather placement.
3. Measuring techniques for deflection and the use of a nuclear road logger should be considered on future projects to help locate problem areas, especially for those in which there is concrete honeycombing or low density.
4. The CRCP for a given project should be designed specifically by taking into account the variables enumerated in the conclusions. The CRCP-1 computer program currently available to SDHPT can be used to design the steel and concrete for a specific project by taking into account the factors that are known to influence the pavement performance.

## ACKNOWLEDGMENTS

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# Effectiveness of Pressure-Relief Joints in Reinforced Concrete Pavements

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**This paper discusses the effectiveness of a 100-mm (4-in) wide compressible material that was installed at 305-m (1000-ft) intervals in a jointed, reinforced concrete pavement to reduce pavement blowups. The studies were made on an Interstate highway that carries some 30 000 vehicles/d, which includes approximately 7000 trucks and buses. This paper compares the behavior of the pavement both before and after the installation of the pressure-relief joints. Brief discussions of the factors that indicate the need for such joints, the problems associated with their use, and the potential for their use under overlays are included.**

The performance of jointed concrete pavements in some areas of Virginia has been seriously impaired by the infiltration of incompressible materials into the joints, which results in blowups. This infiltration can come from below the pavement because of the slab-pumping action related to water trapped below the pavement structure, or it can come from above the pavement because of poorly sealed transverse joints. Water is entrapped when the densely graded subbase materials prohibit drainage through the shoulder (1). Transverse joints are poorly sealed when the long slabs and narrow joints, which have seasonal hydrothermal movements, are in excess of the capabilities of the sealing materials (2). The causes and mechanism of blowups in the state have been discussed in a report by Tyson and McGhee (3).

Corrective action to overcome pumping and blowup problems in Virginia has not been totally successful. Pavement-edge drains are effective in removing entrapped water, but they are costly and time-consuming to install after the fact and are used only in the worst pumping cases. Maintenance contracts to replace or patch damaged joints and to furnish preformed seals have been successful in most cases, but, in several instances, the patches have failed early and at a rapid rate.

One case of early patch failure took place on a maintenance contract executed in 1973 on I-95 in Spotsylvania County. As a result of a study in that area, it was suggested that residual pressures in the pavement were among several factors that caused the premature patch failure. However, joint movement studies were also made in that same area over a period of several years, and these studies showed that the occurrence of a blowup tends to relieve pavement pressures for some 150 m (500 ft) on either side of the blowup. Consequently, it was concluded that, if special stress-relieving joints were provided, pavement pressures might be reduced, and, thus, subsequent failures would also be reduced.

Therefore, in October 1973, a pilot experiment was conducted in which three pressure-relief joints were installed on a segment of I-95 where maintenance operations were under way. The joints were installed approximately 305 m (1000 ft) apart, and they extended the full width of the 7.3-m (24-ft) pavement. Because of the difficulty in sawing dowels and the danger of unstable subbase conditions near the old joints, the relief joints were installed at midlength on the 18.7-m (61.5-ft) long slabs. Two parallel saw cuts that were spaced 100 mm (4 in) apart were made through the full depth of the slabs. After the concrete was removed, two of the joint openings were filled with a patented sponge rubber product, and the third was filled with a styrofoam rubber.

Movement was measured as soon as the pressure-relief joints were installed. During the spring of 1974, which was about 8 months after the joints were in place, the measurements showed that the closures were from 28 to 80 mm (1.1 to 3.2 in). These large movements showed that pavement pressures were significantly relieved by provision of the special joints. In addition, field personnel were pleased with the performance of the relief joints and reported that no blowups occurred in their vicinities and that no difficulties with the performance of the joints themselves were noted. Finally, it was noted that the relief joints themselves are good indicators of pavement pressures. For example, a field engineer might decide that when a relief joint 100 mm (4 in) wide has closed to less than 25 mm (1 in) pavement pressures have reached the point where additional relief joints or restoration of the original 100-mm (4-in) wide joint is justified.

On the basis of the above information, a contract for pavement repair and resealing was let on I-95 in September 1974. As part of this contract, pressure-relief joints were installed in pavements where early distress of previous repairs had been noted. The relief joints were installed at approximately 305-m (1000-ft) intervals in both directions on a 24-km (15-mile) segment of I-95.

The increasing use of the pressure-relief joints in various parts of the state has indicated a need for quantitative data concerning their effectiveness. The development of these data was the objective of the study reported here.

## PURPOSE AND SCOPE

As indicated above, the purpose of the study was to evaluate the effectiveness of pressure-relief joints in protecting jointed concrete pavements from the self-destructive effects of joint infiltration and seasonal hydrothermal movements. The study included approximately 24 km (15 miles) of I-95, which is divided into four lanes. Data were collected on the performance of the 230-mm (9-in) reinforced concrete pavement for periods of 8 months before and 8 months after installation of the pressure-relief joints. Information was also developed as a basis for brief discussions of the factors that led to the need for and use of relief joints under overlays.

## RELIEF JOINT DESIGN

Pressure-relief joints are 100 mm (4 in) wide and are installed full depth [230 mm (9 in)] and full width [7.3 m (24 ft)] of the pavement. The pavement has contraction joints that are nominally 10 to 13 mm (3/8 to 1/2 in) wide and that are spaced on 18.7-m (61.5-ft) centers.

For cases in which major joint repairs, including full-depth joint replacement, were required, the relief joints were installed as shown in Figure 1. Pressure-relief joints installed in conjunction with such full-depth repairs are type A. For reasons given earlier, when no full-depth pavement repairs were necessary, the relief joints were installed at midlength of the 18.7-m (61.5-ft) long slabs. These installations are type B. A total of 142 relief joints were installed in the 24-km (15-mile) long segment of roadway. The relief-joint filler material is preformed, cellular-plastic, pressure-relief joint filler that meets the requirements of American Society of Testing and Materials specification D 3204.

The pressure-relief joints were installed in projects 1, 2, and 3, according to construction completion dates of May 27, 1964; October 22, 1963; and May 3, 1965 respectively.

## PROCEDURES

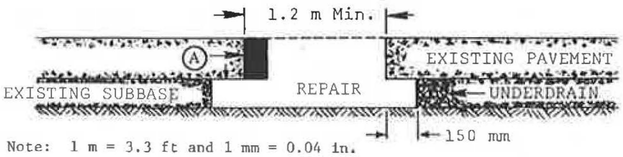
Evaluation procedures included pavement-condition surveys and a study of the pavement movements as reflected in the closure of selected pressure-relief joints. Four condition surveys were conducted as follows:

1. Winter 1973-1974—The first survey was conducted in February 1974 as a part of other studies on the three projects.
2. Fall 1974—The second survey was conducted immediately before repairs were begun on the three study pavements and was completed in September 1974. The results from this survey, during the spring and summer of 1974, were compared with those from the first survey to determine pavement damage that might be related to pavement pressures.
3. Winter 1974-1975—The third survey was conducted after the repairs were completed and the pressure-relief joints were installed. The contractor began work on October 15, 1974, and the survey was completed in April 1975.
4. Fall 1975—The final survey was conducted during the spring and summer of 1975 and completed in October 1975. This survey was made to obtain data for determining the damage subsequent to the repairs.

Each survey included a detailed summary of pavement conditions at the time the survey was made. Every pavement joint was noted on a sketch in which the defects from the other surveys were superimposed on one another. In the survey made immediately after repairs were completed, each pressure-relief joint was noted. Defects that were directly related to pavement pressures such as blowups were especially identified.

Information concerning pavement movements that were influenced by pressure relief was provided by measuring the width of each relief joint shortly after installation and at the time of the last survey. In addition, several sites were chosen for the installation of instrumentation at intermediate joints. This instrumentation, gage points imbedded in the pavement on either side of selected joints, made it possible to study the effect of the relief joints on adjacent joints. The final field work was completed in December 1975, and it involved choosing one section of pavement between the pressure-relief joints for a detailed study of the joint movement associated with the release of pavement pressure. The joint cleaning and resealing work that was done about the same time the relief joints were installed resulted in saw cuts in the bituminous shoulders so that the location of each joint before the pressure was relieved could be established. Each of the above aspects of the overall study is discussed below.

Figure 1. Cross section view of type A pressure-relief material in a full-depth pavement repair.



Note: 1 m = 3.3 ft and 1 mm = 0.04 in.

Table 1. Blowup occurrence with and without pressure-relief joints.

| | | Blowups | | |
|---|---|---|---|---|
| | | Without Joints | | With Joints |
| Project | Lane | To February 1974 | Summer 1974 | Summer 1975 |
| 1 | NB | 25 | 8 | 0 |
| 1 | SB | 29 | 5 | 0 |
| 2 | NB | 18 | 0 | 0 |
| 2 | SB | 18 | 4 | 0 |
| 3 | NB | 3 | 5 | 0 |
| 3 | SB | 2 | 2 | 0 |
| Total | | 95 | 24 | 0 |

Table 2. Total number of distressed joints.

| | | Total Relief Joints | Distressed Joints | | | |
|---|---|---|---|---|---|---|
| Project | Lane | Surveyed | 1/74 | 9/74 | 4/75 | 10/75 |
| 1 | NB | 418 | 249 | 267 | 287 | 293 |
| 1 | SB | 412 | 217 | 248 | 255 | 259 |
| 2 | NB | 395 | 302 | 309 | 316 | 319 |
| 2 | SB | 402 | 258 | 276 | 285 | 294 |
| 3 | NB | 488 | 96 | 111 | 114 | 120 |
| 3 | SB | 493 | 47 | 62 | 67 | 70 |

Table 3. Average widths of pressure-relief joints.

| | | Relief Joints In Each | Joint Width (mm) | | | Total |
|---|---|---|---|---|---|---|
| Project | Lane | Lane | Installed[a] | 5/75 | 10/75 | Closure (mm) |
| 1 | NB | 23 | 104 | – | 70 | 35 |
| 1 | SB | 20 | 109 | 89 | 82 | 27 |
| 2 | NB | 20 | 105 | – | 67 | 38 |
| 2 | SB | 21 | 108 | 81 | 71 | 37 |
| 3 | NB | 30 | 105 | – | 55 | 50 |
| 3 | SB | 26 | 103 | 55 | 38 | 65 |
| Average | | | 106 | 73 | 62 | 43 |

Note: 1 mm = 0.0393 in.

[a] From 10/74 to 3/75.

## EFFECT OF PRESSURE-RELIEF JOINTS

The effectiveness of the pressure-relief joints in halting the occurrence of blowups is given in Table 1. Before installation of the relief joints there were 24 blowups in the 24-km (15-mile) segment during the summer of 1974, whereas after the relief joints were in place, there were no blowups in the summer of 1975. Therefore, it may be concluded that the relief joints were totally effective during their first summer in service. The observations, which are discussed later, made on the current widths of the relief joints suggest that they should be effective for several more years.

The differences in pavement performance indicated by the number of blowups for the three projects before February 1974 are of interest. There is evidence that the differences in performance are related to at least two factors:

1. The lower-strength concrete found in projects 1 and 2 (evidenced by signs of poor consolidation or high water content), and
2. The presence of better draining subbase and shoulder material under project 3.

The relation between blowup frequency and pavement strength is evidenced by the fact that lower-strength concrete will fail at a pressure lower than that for higher-strength concrete. The relation between blowup frequency and subbase type for these projects has been discussed in an earlier report (3). It was pointed out that the pavement pumping associated with poor subbase material may result in the migration of fine, incompressible material into the joints from their outer edges and bottom portions (3). It was also shown in that study that the modified subbase used on project 3 reduced pumping by approximately 75 percent.

The abovementioned factors, along with the metal joint-forming insert used in project 2, contributed to the differences in total joint distress that were experienced by the three projects. Total distress, in terms of the number of joints affected, is given in Table 2. Although there is a greater blowup frequency for the joints in project 1, the total number of distressed joints in project 2 is greater than that in project 1. This difference is due to the presence of the metal joint-forming insert that results in numerous semicircular joint spalls located in the wheel paths. This phenomenon was also discussed in the earlier report (3).

An examination of the new occurrences of joint distress in the summers of 1974 and 1975 suggested that the pressure-relief joints were at least partially effective in reducing the rate of development of distress other than blowups. The northbound lane (NBL) of project 1 had 18 new occurrences of joint distress in the summer of 1974, but only 6 occurrences during the summer of 1975 after the relief joints were installed. Similarly, the southbound lane (SBL) of project 3 had 15 and 3 occurrences for the summers of 1974 and 1975 respectively.

### Pavement Movement

The effectiveness of pressure-relief joints in reducing pavement distress, particularly blowups, was discussed above; however, there are some characteristics of the relief joints themselves that affect pavement movement. These characteristics are (a) the behavior of the relief joints, and (b) the effect of the relief joints on the movement of other joints in the vicinity of and between the relief joints.

### Joint Closure

In sections of the roadway where there is appreciable pressure, the relief joints begin to close almost as soon as they are installed. Pavement pressures of some significance are indicated by the difficulty in making the saw cut because of blade pinching and by the difficulty in removing the sawed segment.

Tests in the Research Council laboratories have shown that a pressure of approximately 165 kPa (24 lbf/in$^2$) is required to compress the 100-mm (4-in) wide, pressure-relief material to 50 percent of its original width. This pressure is negligible even on very weak concrete, but it is sufficient to hold the relief material tightly in place.

The widths of all pressure-relief joints in the three study projects were measured soon after they were installed (October 1974 and March 1975) and at the end of the study period (October 1975). In addition, those in the SBL were measured at an intermediate stage (May 1975). These measurements are given in Table 3.

Several significant observations can be made from the data given in Table 3. First, the average relief-joint closure of 43 mm (1.71 in) during the first year suggests that there were very significant stresses remaining in the pavement, even though numerous blowups had already relieved these stresses in many areas. Second, a careful study of the data shows that about 75 percent of the total closure occurred before the summer months when stresses, if unrelieved, would be the highest. This finding clearly indicates that pavement stresses, even in the winter, were too high to be relieved by the natural tendency of the pavement to shrink in cold weather. Third, project 3, which had the lowest blowup frequency, showed significantly more closure of the relief joints during the summer of 1975 than did the other two projects. Thus, project 3 was observed closely to determine if there was a need for additional relief joints. As indicated earlier, the higher-strength concrete in this project sustained more pressure without failure. However, the relative increase in blowups for this project shortly before the installation of the relief joints, along with the behavior of these joints, indicates that the project would become subject to blowups when the benefits of the relief joints are completely exhausted. The SBL of this project sustained only 4 blowups in its 10-year life, but after only one summer, the relief joints closed an average of 65 mm (2.57 in) or about 65 percent. Such behavior reinforces the previously mentioned possibility that pressure-relief joints can be used to indicate pavement pressures so that corrective action can be taken before pavement damage results.

The relative behaviors of types A and B relief joints are of some interest. The following is the annual relief-joint closure for each project and each type of joint (1 mm = 0.393 in).

| | Annual Average Closure (mm) | | | Annual Average Closure (mm) | |
|---|---|---|---|---|---|
| Project | Type A | Type B | Project | Type A | Type B |
| 1 | 27 | 35 | 3 | 48 | 65 |
| 2 | 37 | 38 | | | |

It should be recalled that type A joints were installed in conjunction with full-depth pavement repairs while type B were installed at midslab length in sound pavement sections. In many cases, the full-depth repairs were made on blowup sections where pavement stresses had been partially relieved because of the blowups. Therefore, it is not surprising to find that the type B joints were somewhat more effective because no natural stress relief had been provided before installation of the joints. This finding suggests that, in future installations, it may be advisable to omit type A joints in lieu of providing more type B joints at strategic locations.

### Movement of Intermediate Joints

The movement of intermediate joints within a typical section that has pressure-relief joints at each end is shown in Figure 2. The section is comprised of 17 slabs, and each slab is 18.8 m (61.5 ft) long. Individual joint movements were measured from the saw marks in the asphalt-concrete shoulder, as previously mentioned. As expected, the movement was maximum at the pressure-relief joints, gradually decreased toward the center of the section, and was negligible at the center. In all cases, joint movement was toward pressure-relief joints with the node point at midsection, which indicated a balance of pavement pressures and movements. The dramatic pavement behavior at a relief joint in service for 1 year is shown in Figure 3.

It is clear from the above data that relief joints were effective for at least the 300 m (1000 ft) contained in the typical section. Careful study of Figure 2 also suggests that the relief joints might have been capable of providing some stress relief for sections longer than 300 m (1000 ft). Theoretically, the joints are effective until there is more than one stationary joint at midsection. The determination of the maximum effectiveness of a section length is not a straightforward procedure. A paradox develops when one considers that the more internal stresses a pavement has, the longer the effectiveness of a section length will be. Conversely, when there are few internal stresses, the relief joints may be immediately effective only over a short distance. In the latter case, the relief joints are probably not needed, but, if used, they will serve for a long period of time. Several examples of this behavior occurred in projects 1 and 2 in which the pressure-relief joints were installed close to the blowups. Because pavement pressures had already been relieved, these relief joints closed less than 13 mm (½ in) during their first year in service.

One type of undesirable behavior of joints between relief joints is shown in Figure 4. An intermediate joint opened so widely that the preformed compression seal was no longer in contact with the walls of the joint. This behavior gives rise to the possibility of initiating a vicious circle in which the provision for too much freedom of joint movement can create conditions in which joint infiltration is aggravated, and, in turn, can require the provision for more pressure relief. Such behavior only occurs at the joints that are located near the relief joints or previous blowups. Since it is not possible to predict when an excessively wide opening might occur, it appears that pavements with preformed seals should be observed for some time after the relief joints are installed. This possibility of an excessively wide, intermediate joint opening is one consideration that should not be overlooked when deciding to use relief joints. There may be instances in which it is advisable to install several relief joints for purposes of observation, possibly 1 year before full-pressure relief is contemplated. Thus, a final determination of the need for the joints could be made.

It is interesting to compare the movement of joints in a pavement that has no stress relief with that of a pavement that has relief joints located at 300-m (1000-ft) intervals. This comparison is shown in Figure 5 for the period of April through September 1975. Although the seasonal movement for the control section was approximately 0.20 mm (0.008 in), the joint located 18.7 m (61.5 ft) from a pressure-relief joint opened a total of 4.5 mm (0.18 in). Similar but less severe movements were recorded for joints located 56.3 m (184.5 ft)

Figure 2. Joint shift between pressure-relief joints.

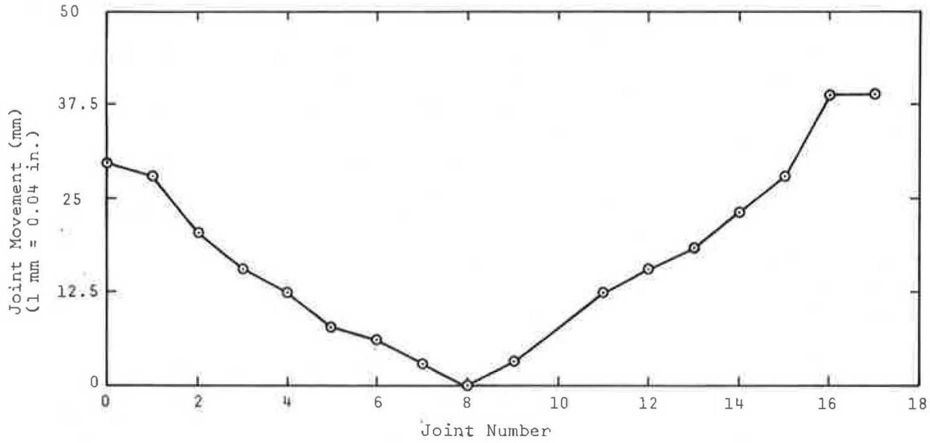


Figure 3. Closure of pressure-relief joint after 1 year in service.

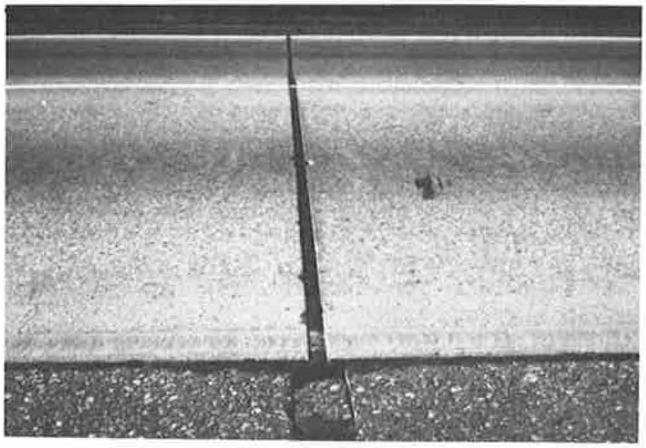


Figure 4. Excessive opening of joint near pressure-relief joint.

and 93.8 m (307.5 ft) from the pressure-relief joints. The pavements contrasted in this figure are also discussed in an earlier report (3) in which the behaviors of pavements that are prone to blowups were compared with those pavements of the control section that had no history of blowups.

Figure 5. Comparison of pavements with and without pressure-relief joints.

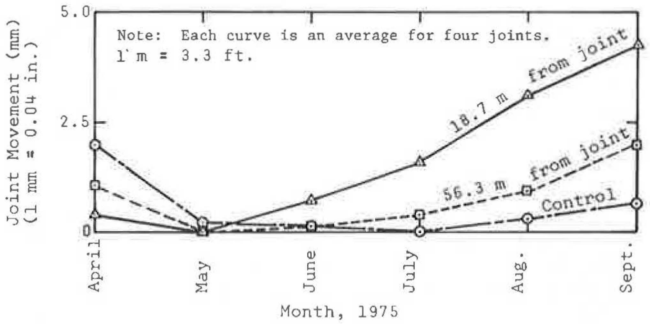
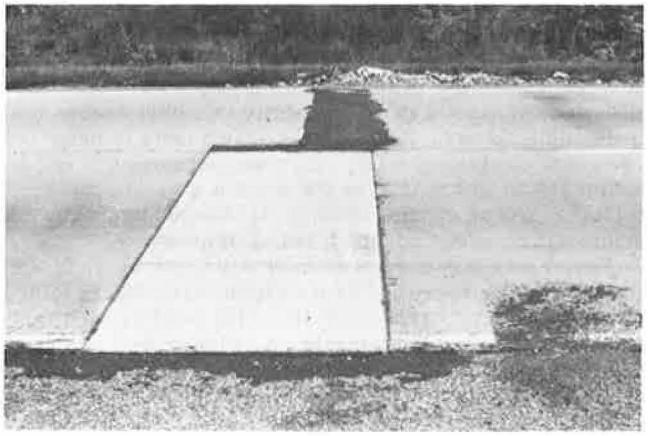


Figure 6. Failure caused by redistribution of stresses between lanes, repairs in near lane, and new blowup in far lane.



## PROBLEMS WITH PRESSURE-RELIEF JOINTS

The use of pressure-relief joints in several locations, including the one discussed earlier, has shown that certain precautions are necessary to achieve their most effective use. Some of these precautions and the related problems are discussed below. Virginia specifications that have been developed for installation of the pressure-relief material have recently covered several of these precautions.

### Multilane Pavements

The pressure-relief material will almost always be used on pavements that have more than one traffic lane; therefore, it is usually impossible to install the material for the full width of the pavement in 1 d. However, the relief of pressure in one lane can substantially increase the pressures in other lanes so that the unrelieved lanes become subject to blowups. Therefore, it is necessary to install relief joints in all adjoining lanes as soon as possible. Figure 6 shows a pavement on which repairs and pressure relief were provided for the near lane, while the sound far lane was left until later. Unfortunately, several weeks of warm weather passed and a blowup occurred in the far lane before the work crew returned to install the pressure relief joint in that lane.

For cases in which the adjoining lane is made of good quality concrete, restraint between the lanes has prevented the pressure-relief joint from functioning, thus, the material is not held tightly in position and can float out during a heavy rain.

Both of these potential problems should be prevented by the new specifications that require installation of the pressure-relief material in adjacent lanes within 24 h. This specification also places restrictions on the width of the material and requires the use of a lubricant-adhesive to install the material, which provides further insurance against floating.

### Hot Weather

The high pressures encountered in the pavement during hot weather make the summer a poor time for installing pressure-relief joints, even though the need might be greatest in this season. Saw-pinching problems and the problem of unequal pressures between lanes are both aggravated during warm weather. Therefore, the new specifications mentioned above provide for the installation of pressure-relief material in a temperature range of from 4 to 20°C (40 to 70°F).

### Too Frequent Installation

In a few instances, pressure-relief joints have been ineffective because of their proximity to other stress-relieving features. Although there is a need to judge the pavement condition, relief joints are not normally needed within 150 to 180 m (500 to 600 ft) of a standard XJ-1 bridge approach expansion joint (4), because such a joint inherently provides adequate relief of pressure.

Pavements that have sustained full-width blowups may not need pressure-relief joints within about 150 m (500 ft) of the blowups, especially if the blowup has been temporarily repaired with bituminous concrete and has remained in that condition for some period of time. This natural relief of pavement pressures will be indicated by unusually wide joints in the vicinity of the blowup.

## PROVISION OF PRESSURE-RELIEF JOINTS

Because the provision of pressure-relief joints is a rather expensive and time-consuming operation, the following discussion is offered. Pavements that have no history of blowups should not have pressure-relief joints installed until the history and condition of the pavement have been carefully considered. Extensive studies of pavements that are prone to blowups in Virginia have shown that blowups will occur or are impending when some or all of the following factors exist.

1. The pavement is more than 5 or 6 years old.
2. The transverse joints are poorly sealed,
3. The pavement is subject to joint or edge pumping because of a poor quality subbase,
4. The pavement is constructed of concrete that contains a siliceous coarse aggregate,
5. Sand or other traction-improving aids are used liberally on the pavement,
6. The pavement is constructed of slabs more than 6 to 9 m (20 to 30 ft) long,
7. The pavement is constructed of poor quality concrete,
8. Dowel bars are misaligned during pavement construction, and
9. Truck traffic volume is high.

Not all of the above factors will be present in every pavement that is prone to blowups, and not all of the factors are given equal weight. For example, when other conditions are equal, pavements with 18.8-m (61.5-ft) long slabs appear to be subject to more blowups than those with shorter slabs. On the other hand, pavements with short slabs have been observed to blowup, but only after many years of service and under adverse conditions. Similarly, pavements can become subject to blowups because of surface infiltration, infiltration from the subbase, or a combination of the two.

Because the relative contributions of each factor noted above are poorly defined, it is necessary to make field inspections so that the probability of blowups can be determined. In general, at least two or three of the following types of visual evidence will be present when blowups are impending.

1. Some transverse joints are tightly closed while others are wide and badly infiltrated.
2. The presence of fines on the shoulder or a depression of the shoulder at the pavement edge show evidence of joint pumping.
3. Joint faulting is evident.
4. Misalignment of the transverse joints is evident, especially at lane additions or drops.
5. Transverse joints show evidence of crushing.

## PROVISION UNDER OVERLAYS

Observations have shown that pavements subject to blowups while in service as a wearing course will often be subject to blowups after they have been overlaid with a bituminous-concrete surface. For this reason, the decision was made to provide pressure-relief joints on I-495 in Northern Virginia when it was widened. The 7.2-m (24-ft) wide existing pavement had suffered a number of blowups in its approximately 10-year life. The primary factors contributing to these blowups were heavy traffic, poor subbase, difficult-to-maintain joints, and long slabs. Since these conditions could not be effectively corrected as a part of reconstruction, the provision of pressure-relief joints was an acceptable effort to reduce future maintenance. Relief joints were also called for in the base so that the old pavement and the 7.2 m (24 ft) of widening base concrete would function together. While the project was still under construction, most of the pavement and widening had been overlaid, and this did not cause any apparent adverse effects other than a slight depression in the overlay at some relief joints. Many of the relief joints closed up to 50 mm (2 in), which is an indication that they were serving their intended purpose.

Based on this experience, it would appear reasonable to continue the use of pressure-relief joints under overlays if an old pavement has a history of blowups or if the causative factors that contribute to blowups are in evidence.

## CONCLUSIONS

1. Pressure-relief joints can contribute substantially to the reduction of blowups and general distress of portland-cement concrete pavements.
2. Pavement containing pressure-relief joints can experience an excessively wide opening of intermediate joints such that the effectiveness of preformed seals is impaired.
3. Rapid, pressure-relief joint closure may be an indication that additional relief is needed.
4. Pressure-relief joints installed at midslab are somewhat more effective than those installed in conjunction with full-depth pavement repairs.
5. Pressure-relief joints are not useful when they are in close proximity to a bridge that has protection expansion joints or when they are near blowups where a full-depth or full-width portion of a pavement has been replaced with bituminous concrete.
6. When making the decision to provide pressure-relief joints, careful consideration should be given to the pavement design and performance history.
7. Pressure-relief joints can be used effectively under bituminous-concrete overlays on portland-cement concrete pavements.

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# Performance Evaluation for Bituminous-Concrete Pavements at the Pennsylvania State Test Track

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**The Pennsylvania State Test Track, which was completed in August 1972, will be used to develop engineering data and criteria for the design and construction of new pavements and for the improvement and maintenance of existing pavements. The test track is composed of sections with various base-course materials and different layer thicknesses. This paper presents the results of performance analyses for sections containing bituminous-concrete base. The analysis was made by using an elastic-layer computer program; only the spring weather condition was considered. Critical responses analyzed were maximum vertical compressive strain at the top of the subgrade, maximum radial tensile strain at the bottom of the base course, and maximum deflection on the pavement surface. Performance data collected included present serviceability index, rut depth, and cracking. Correlations between critical response and pavement performance were established. These correlations permit prediction of pavement performance from pavement response determined in the spring season. A maximum compressive strain of 450 $\mu$m/m (0.000 450 in/in) at the top of the subgrade, a maximum tensile strain of 120 $\mu$m/m (0.000 120 in/in) at the bottom of the base course, and a maximum deflection of 0.51 mm (0.020 in) on the pavement surface were established as the limiting criteria for flexible pavements with bituminous bases to withstand 1 000 000 applications of an 8165-kg (18-kip) axle load without significant fatigue cracking. Based on these limiting criteria, structural coefficients of the bituminous-concrete base and the crushed-limestone subbase were developed. The structural coefficients vary significantly with layer thickness.**

Recognizing the need for an integrated program for pavement research, The Pennsylvania Transportation Institute in cooperation with the Pennsylvania Department of Transportation constructed a one-lane 1.6-km (1-mile) long highway. This facility was completed in August 1972 and is located 9.7 km (6 miles) northeast of State College and 1.1 km (0.7 miles) northeast of University Park Airport in an agricultural area owned by the Pennsylvania State University.

The goal of pavement research at the facility is to develop engineering data and criteria that can be used in the design and construction of new pavements and in the improvement and maintenance of existing pavements. To achieve this goal, two long-range objectives were developed to guide research at the facility. The first is to validate, refine, or, if necessary, regenerate the flexible-pavement design procedure in Pennsylvania. The second is to evaluate the ability of existing pavement-damage models to predict pavement performance.

This paper presents the results of the performance evaluation based on pavement response for the sections that have a bituminous-concrete base course. From field performance data together with pavement response, limiting strain and limiting deflection criteria were de-