Performance and Structural Evaluation of Cracked and Seated Concrete

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The benefits derived from rehabilitating Portland cement concrete (PCC) pavements using asphalt concrete (AC) overlays may be minimized because of reflective cracking in the AC overlay. Reflective cracks can cause early deterioration of the asphalt pavement in the form of raveling and spalling adjacent to the joints. One method that has been successful in reducing reflective cracking is known as "cracking and seating." This method involves cracking the existing PCC pavement into smaller interlocking pieces that have aggregate-to-aggregate contact. This cracked PCC pavement is then seated with a heavy pneumatic-tired roller that prevents rocking or movement of the existing pavement. This procedure reduces the potential for reflective cracking by reducing the amount of movement at the joints due to temperature changes. Cracking the existing PCC pavement into smaller pieces reduces the strength of the rigid pavement, but little information has been published on how much loss is expected. This paper addresses the reduction in pavement strength due to the "cracking and seating" method by evaluating the effective modulus. Effective modulus values for the cracked PCC pavement were determined using measured deflection basins obtained by the Falling-Weight Deflectometer (FWD) and comparing these deflection basins to those predicted by the elastic layer theory. The effective modulus values were obtained for the existing PCC pavement before and after the pavement had been cracked and seated. The effective modulus values of the pavement layers were also determined after placing each intermediate course of asphalt concrete (AC) overlay.

Background

The performance of rehabilitated Portland cement concrete (PCC) pavements with asphalt concrete (AC) overlays is often marginal and only a temporary solution. One of the shortcomings of this rehabilitation technique is the eventual occurrence of reflective cracking, which is the development of a crack pattern in the AC pavement similar to the crack pattern in the underlying PCC pavement. Cracks and joints of the PCC pavement eventually propagate up through the new AC overlay, causing early deterioration of the pavement. Rehabilitation techniques that provide improved performance at lower costs are very important to pavement engineers because of the increasing maintenance requirements of rigid pavements.

Reflective cracks are fractures in the AC overlay that result from movement of cracks and joints in the PCC pavement. These differential movements, either horizontal or vertical, cause high stresses in the asphalt concrete that develop fractures in the overlay. Vertical movements that are caused by traffic loads or rocking slabs, and horizontal movements that are caused by temperature and moisture changes must be reduced in order to retard or prevent early deterioration of an AC overlay.

One method that has been used to reduce the potential for reflective cracks in PCC pavements with AC overlays is cracking and seating of the existing PCC pavement prior to the overlay. Cracking and seating the PCC pavement has been used for more than 25 years as a method to prevent reflective cracking. New improvements in equipment and a better understanding of the method, primarily due to experience, have encouraged the use of this technique. Satisfactory results in pavement overlays using this method have been widespread.

The cracking and seating technique involves the breaking up of the existing PCC into small segments that contain interlocking pieces and then seating those pieces with a heavy pneumatic roller. This procedure prevents rocking or moving of the PCC pavement. Once the existing PCC has been cracked, however, the strength of the PCC has been reduced.

Objective

The objective of this study was to perform a structural evaluation of cracked and seated Portland cement concrete pavement with various thicknesses of AC overlays and to analyze the performance and effectiveness of this rehabilitation technique.

Scope

This study was conducted to evaluate the effectiveness of cracking and seating PCC pavements with AC overlays to retard reflective cracking. An investigation was undertaken to obtain information relating to the performance and structural strength of cracked PCC. Three cracking and seating projects were investigated to determine the effectiveness of this method. Construction projects at Rock Island Arsenal, Illinois, and Fort Wainwright, Alaska, were evaluated to determine the performance of cracking and seating. A structural evaluation using nondestructive testing (NDT) equipment was performed on a cracking and seating project at Aberdeen Proving Ground, Maryland. This analysis evaluated the PCC pavement before and after cracking and after

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placing three layers of asphalt concrete. From these investigations, the performance of cracking and seating PCC pavements to prevent reflective cracks and the reduction of PCC pavement strength were determined.

DESCRIPTION OF CRACKING AND SEATING

Cracking and seating of rigid pavements prior to an AC overlay is an accepted method for rehabilitating rigid pavements. This method involves cracking the existing PCC slab into small segments, which reduces movement of the rigid layer. By inducing small hairline cracks in the PCC pavement, the potential for reflective cracks is decreased. Various types of equipment and construction procedures are used to produce satisfactory results.

Cracking Equipment

Cracking the PCC pavement is the most important step of this rehabilitation technique. The cracking pattern must produce hairline cracks that break the PCC into segments that have aggregate particle interlock. The pavement strength is reduced by cracking, but the cracked PCC still functions as a load-carrying medium. Excessive cracking can be detrimental to the pavement structure and turn the PCC into rubble, which is not desired.

Various types of equipment can be used to produce the desired cracking of a PCC pavement. These hammers include the modified pile driver, impact hammer, guillotine hammer, and the whiphammer. Each device can adjust the impact force applied to the pavement, thus producing the desired cracking pattern.

Construction Procedures

Preparation of the existing PCC pavement is essential for the success of the rehabilitation method. The existing joint and crack sealant is removed prior to cracking the slabs. The joint and crack sealing material is removed to prevent any slippage or bleeding of the sealant through the AC overlay. Proper drainage of the pavement is also required prior to cracking the PCC. Drains can prevent water from accumulating under the pavement and can prevent a loss of structural support due to a saturated base.

As previously mentioned, cracking of the PCC pavement is extremely important to the success of cracking and seating. A proper cracking pattern that produces small segments that have aggregate particle interlock is required. Several factors that influence the cracking pattern are (1) type and size of hammer, (2) impact force of hammer, (3) strength and thickness of PCC, and (4) condition of subgrade.

The cracking pattern usually preferred in cracking and seating breaks the slabs into pieces that measure from 18 in. to 36 in. Because of the variables listed in the previous paragraph, a test section is cracked to determine the impact force and spacing of the hammer that will produce the recommended crack pattern. Because of various field conditions, the crack pattern developed in the test section may have to be adjusted. Segments that are cracked into pieces smaller than 12 in. may result in spalling and loss of structural strength.

After the PCC pavement has been cracked as specified, the cracked concrete is seated or embedded into the base with a heavy pneumatic roller. This process ensures that the rigid pavement does not rock or move under traffic loads. The seating of the cracked PCC is accomplished by using a 30- to 50-ton, rubber-tired roller. Generally, three to five coverages of a heavy pneumatic roller are adequate to seat the cracked PCC.

During the cracking and seating operation, areas that are not structurally sound will be evident. Punch-throughs in the PCC and rocking of the PCC slabs indicate that the pavement needs repair. In these weak areas, the affected pavement is removed and replaced. Full-depth asphalt or crushed-base course of adequate strength should be used as a patch prior to the AC overlay.

To complete the rehabilitation of the rigid pavement, an AC overlay is placed. The cracked and seated pavement is prepared by removing all debris and applying a tack coat. To correct the uneven surface caused by cracking and seating, a leveling course is placed prior to the surface course material. The thickness of AC depends on the structural capacity of the existing pavement and the amount of anticipated traffic. The minimum recommended thickness of asphalt concrete for cracking and seating is 4 in. (*1–3*).

PERFORMANCE OF CRACKING AND SEATING

The Waterways Experiment Station (WES) has been actively involved in evaluating the construction procedures and the effectiveness of cracking and seating as a rehabilitation method to prevent reflective cracks of PCC pavements through an AC overlay. Two projects that have been evaluated were located at Rock Island Arsenal, Illinois, and Fort Wainwright, Alaska. The project description, construction, and performance are discussed for each site.

Rock Island Arsenal

The cracking and seating method was used to rehabilitate a PCC parking lot at Rock Island Arsenal, Illinois. This project was conducted as a demonstration under the Facilities Technology Application Test (FTAT) program. This nonreinforced rigid pavement was rough and uneven and presented a constant maintenance problem. Several slabs were excessively cracked and needed replacing. Water accumulation under the slabs also caused support problems throughout the pavement. Rehabilitation using the cracking and seating method was the best alternative for this repair. Prior to cracking the PCC, all existing joint and crack sealing material was removed to a minimal depth of 1 in. below the surface. Slabs that were excessively cracked and structurally unsound were removed and replaced with high-quality base material. Drainage of the subgrade under the parking lot was also corrected by constructing a French drain system along the outside edge of the pavement.

The cracking of the PCC parking lot was accomplished using an impact hammer shown in Figure 1. A cracking pattern was

FIGURE 1 Impact hammer used at Rock Island Arsenal.

FIGURE 2 Fifty-ton pneumatic-tired roller used to seat cracked PCC pavement.

selected to break the existing PCC slabs into pieces with a minimum size of 18 in. and a maximum size of 24 in. After cracking, the PCC pavement was seated using a 50-ton roller shown in Figure 2. A minimum of two passes was required to seat the cracked PCC. After the cracking and seating procedures were completed, a minimum of 4 in. of asphalt concrete was placed.

The rehabilitation project was completed in 1984. Figure 3 shows the finished AC pavement surface. The pavement was inspected in August 1988, and no reflective cracks were observed. The performance to date has been very satisfactory. The cracking and seating method has been successful in preventing reflective cracking for 4 years. The cracking and seating method has been an effective and economical method to reduce reflective cracking of PCC pavement through an AC overlay (*4*).

FIGURE 3 Completed asphalt concrete pavement.

Fort Wainwright

The cracking and seating technique was used to rehabilitate the 6-in. reinforced PCC runway pavement at Fort Wainwright, Alaska. Some of the existing PCC slabs had become severely cracked, and the pavement surface had become so rough and uneven that an asphalt overlay was required. The pavement distress was due primarily to the extreme weather conditions.

There were several objectives in using the crack and seat method to repair the PCC runway. One objective was to locate voids and areas that were structurally unsound and replace them prior to overlaying. Another was to provide a smooth pavement surface at the desired grade. The main objective in using this method was to reduce the amount and degree of reflective cracks that would propagate through the AC overlay.

The specified cracking pattern required the breaking of the PCC pavement into 2-ft squares. An impact hammer was used to produce hairline cracks that penetrated the full thickness of the pavement. A section of PCC was removed to evaluate the total cracking of the pavement. Typical scenes of the construction are shown in Figures 4 through 6.

The cracked concrete was seated with thirty coverages of a 50-ton pneumatic roller. During the proofrolling, areas with

FIGURE 4 Hydraulic impact hammer for cracking PCC slabs.

FIGURE 5 Overall view of cracking pattern.

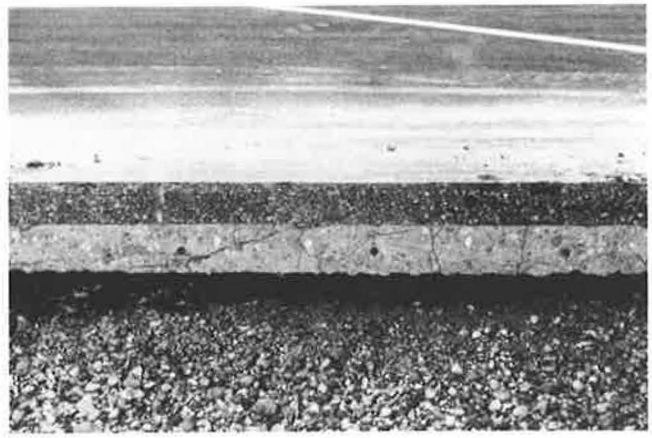

FIGURE 7 Cut-away section of asphalt overlay of cracked and seated pavement.

voids and weak spots were located and repaired prior to the asphalt overlay. After cracking and seating procedures, the pavement was overlaid with 4 to 5 in. of asphalt concrete.

The rehabilitation of this pavement was completed during the summer of 1982. The pavement was evaluated in July 1984 and was in excellent condition. The pavement surface did contain transverse cracks that occurred at 100-ft intervals. These cracks appeared to be caused by thermal stress and not by reflection. In 1983 and 1984, sections of the pavement were removed to inspect its full depth. Several photos were taken to show the effectiveness of the crack and seat method. Figure 7 shows the cracked PCC pavement under the AC pavement with no reflective cracks. Figure 8 shows the AC overlay over a joint in the PCC pavement. Figure 9 shows a typical transverse crack and indicates that the crack is caused by temperature changes and not movement in the cracked PCC.

The runway at Fort Wainwright was inspected again in July 1988, and the pavement was still in good condition. The pavement did have transverse cracks at 60-ft intervals, but these cracks were caused by thermal stresses. These transverse cracks continued across the entire width of the runway into the shoulders, which indicated that these wide cracks (1–2 in.) were caused by earth movement and were not reflecting up from the cracked PCC. The performance to date using cracking and seating has been satisfactory, and no deterioration has occurred adjacent to any cracks (*5*).

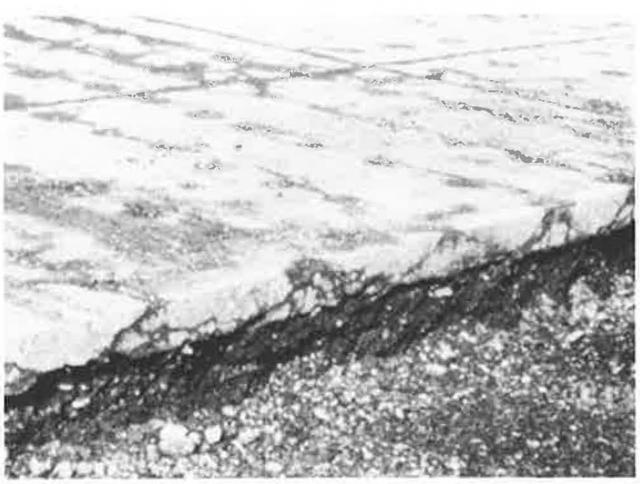

FIGURE 6 Close-up view of cut-out section demonstrating full-depth cracking.

STRUCTURAL EVALUATION OF CRACKED AND SEATED PCC

Description

Aberdeen Proving Ground (APG), Maryland, contracted a project to rehabilitate Maryland Boulevard, which is a primary access road to the installation. The existing 40-year-old PCC pavement contained slabs that were structurally sound but had excessive movements over the years, causing a very rough ride. The joints were a tremendous maintenance problem. Medium to severe joint spalling had occurred on a large portion of the roadway. The PCC around many of the joints

FIGURE 8 Cut-away section of asphalt overlay over a PCC pavement joint (ballpoint pen shows scale).

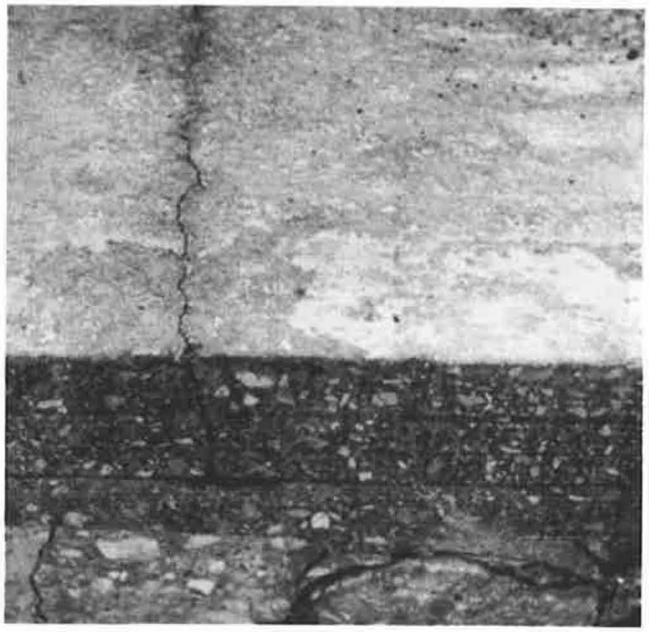

FIGURE 9 Cut-away section of typical transverse crack.

had been removed and replaced with asphalt concrete. Because of the importance of this pavement and the high volume of traffic it served, it was determined that the maintenance procedures being used would not slow the deterioration of the pavement and that some form of resurfacing should be implemented.

The initial plans for reconstruction of Maryland Boulevard included removing and replacing faulty slabs and resurfacing with asphalt concrete. The pavement section designed for this rehabilitation included a 3.5-in. crack relief layer and 4.5 in. of AC overlay. Before construction began, the contractor submitted a comprehensive Value Engineering Change Proposal that included the cracking and seating method. Owing to the uncertainties of this method, APG requested that Waterways Experiment Station (WES) evaluate the proposal and provide technical assistance in all phases of the project.

The proposal generated a cost savings of approximately 30 percent, which is substantial since the total project was bid at more than $3 million. The new proposal deleted any removal and repair of existing PCC slabs and implemented the cracking and seating procedures. The AC overlay thickness was determined using the National Asphalt Pavement Association (NAPA) guidelines. The total overlay thickness recommended was 8 in. This thickness was checked using Corps of Engineers (COE) thickness design AC overlays and was considered adequate.

Construction

The construction of this rehabilitation project began in late September 1986. Several areas of the roadway had to be prepared prior to cracking and seating the PCC pavement. Excessive crack and joint sealing material was removed using a small grinder. Extensive grading was done to improve water runoff and drainage along the roadway. Edge drains were also installed in some areas of Maryland Boulevard to improve subsurface drainage.

The 8-in. nonreinforced PCC slabs were broken using a whiphammer (Figure 10). It was recommended that the slabs be broken into segments approximately 2 ft square. To break up the 12 ft by 15 ft slabs in the desired cracking pattern, the whiphammer had to impact the slabs at 2-ft intervals in the transverse direction. The trial section was dampened to show the hairline cracks that were produced by the cracking operation (Figure 11). Cores were also taken to ensure the cracks penetrated the full depth of the pavement.

Immediately after cracking the PCC slabs, the cracked pavement was seated with a heavy pneumatic roller. The 50-ton roller made three passes over the pavement to ensure the slabs were embedded in the subgrade to prevent any rocking of the slabs. No excessive movement was noticed during any of the seating operations.

The project was separated into three segments for ease in construction and traffic control. Once all four lanes of a segment were cracked and seated, a leveling course using a surface mixture was placed over the cracked PCC and the asphalt shoulders. This produced a good riding surface until the remaining lifts could be placed and also protected the base from harsh weather conditions. Two intermediate courses, each 2.75 in. thick, were placed on Maryland Boulevard, making the total AC thickness approximately 6.0 in. The final surface course was placed in October 1987.

FIGURE 10 Whiphammer used at Aberdeen Proving Ground.

FIGURE 11 Close-up view of cracked PCC pavement.

Nondestructive Testing

As previously mentioned, cracking and seating PCC pavements reduces the structural strength of the pavement. To determine the extent of this reduction in pavement strength, the layered elastic model using nondestructive test data was used to evaluate the effective modulus for the cracked concrete and the remaining pavement layers. This project evaluated the structural strength of the pavement before and after cracking and after placing 4- and 6-in. asphalt concrete.

The effective modulus values for the cracked PCC pavement were determined using measured deflection basins obtained by the Falling Weight Deflectometer (FWD) shown in Figure 12. This FWD uses a weight dropped on a steel plate to produce an impulse load to the pavement that causes the pavement to deflect. Four drop heights were available to vary the impact load, which ranges between 8,000 and 26,000 lb. For these deflection readings, the maximum load was used for each slab. The actual load applied to the slab was measured by a load cell. Velocity transducers that are spaced at 0, 12, 24, 36, 48, 60, and 72 in. from the center of the plate were used to measure surface deflections (Figure 13).

The deflection basins measured by the FWD were used to determine modulus values for the pavement layers, subgrade, concrete, and asphalt concrete. The effective modulus values were determined by matching the measured deflection basin with the calculated deflection basin. The calculated deflections were determined using the layered elastic model solved with the BISAR computer code. To match the measured and calculated deflection basins as closely as possible, several iterations were done using the computer programs BISDEF and COMDEF.

FIGURE 12 Dynatest Falling Weight Deflectometer.

FIGURE 13 Close-up view of velocity transducers.

Deflection basins were measured at the center of fifty slabs on Maryland Boulevard. It is general practice to measure deflections in the center of the slab so that conditions of continuous, homogeneous, linearly elastic layers assumed in the analytical model are as valid as possible. For each case, before and after cracking and after placing each intermediate course of asphalt concrete, deflection basins were measured to be used to determine modulus values for each pavement layer. The average predicted effective modulus values for each case are shown in Table 1.

ANALYSIS OF DATA

Although the cracking and seating rehabilitation technique has been accepted and had widespread use, the effect of its use on the pavement structure has not been quantified. Evaluation of each pavement layer with the FWD during each phase of construction was considered the best method of assessing the technique. A comparison of each pavement layer was made for each phase of construction, before cracking, after cracking, and after placing asphalt concrete overlays.

With the data from the nondestructive testing and the use of the computer programs BISAR, BISDEF, and COMDEF, the effective modulus values for the subgrade, concrete, and asphalt concrete were predicted. The average predicted modulus values for each case are shown in Table 1. The computer modeling of these field data was excellent; the computed deflection values matched the deflection value measured by the FWD. Because of low percent errors in matching the deflection basins, the confidence level of the predicted modulus was high.

The predicted modulus values computed using the measured deflection basins showed that the effective subgrade modulus was stress-dependent. The average predicted subgrade modulus was 22,618 psi for the existing PCC pavement. After cracking and seating the PCC, the average predicted subgrade modulus decreased to 12,106 psi. This indicated that the subgrade after cracking and seating was carrying an additional load and a higher stress was being applied to the top of the subgrade because of the reduced strength of PCC. The subgrade modulus then increased with each additional asphalt overlay, which corresponds to a lower stress on the subgrade. The

TABLE 1 PREDICTED MODULUS VALUES

Case	Subgrade (PSI)	Concrete (PSI)	Asphalt Concrete (PSI)
Before cracking	21,618	5,896,165	–
After cracking	12,106	1,143,948	–
4-in. AC	15,642	1,276,666	271,885
6-in. AC	17,598	1,541,334	361,063

TABLE 2 SUMMARY OF STRESS ANALYSIS

Case	Maximum Vertical Stress (PSI)
Before cracking	2.02
After cracking	3.77
4-in. AC	2.97
6-in. AC	2.33

subgrade modulus for 4 to 6 in. of asphalt concrete was 15,642 psi and 17,598 psi, respectively.

The measurement of the reduction in PCC pavement strength was a primary objective of this investigation. The predicted modulus values for the PCC before and after cracking were used to evaluate the reduction in strength. The modulus value for the PCC prior to cracking and seating was 5,896,165 psi, which is a reasonable value for a 40-year-old PCC pavement. Once the PCC was cracked and seated, the predicted modulus value decreased to 1,143,948 psi, an 80 percent decrease. The modulus value did not vary much with the addition of asphalt overlays. The approximate modulus value of the cracked concrete after the AC overlays was 1,500,000 psi. Although there was a significant reduction in PCC stiffness, the modulus values predicted for the cracked concrete are much higher than typical modulus values for base courses. Typical modulus values for base courses range from 30,000 psi to 100,000 psi.

An additional stress analysis was computed on the pavement layers using the computed modulus values. For each phase of construction, the maximum vertical stress was computed in the top of the subgrade. The standard 18,000-lb, single-axle dual wheel (SADW) loading was used in all calculations. Table 2 lists the value for stress calculated by the BISAR computer programs.

The computed stress values in the top of the subgrade indicated that the subgrade modulus value is stress-dependent; as stress decreases, the effective modulus value increases. The computed stress on the top of the subgrade for the existing pavement was 2.02 psi. After cracking and seating the PCC, the stress increased by 86 percent to 3.77 psi. The stress on the subgrade decreased with each additional asphalt overlay. Approximately 6 to 7 in. of asphalt concrete was needed after the concrete was cracked and seated to result in the same stress on top of the subgrade as in the PCC pavement prior to cracking and seating.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Cracking and seating of jointed PCC pavements is a viable rehabilitation alternative. This rehabilitation technique can reduce and retard cracks and joints from reflecting upward when the existing pavement is properly cracked and seated and when an adequate thickness of asphalt concrete is used. The pavement strength is reduced by the cracking and seating, but the cracked PCC layer still functions as a load-carrying medium.

Based on the data obtained in this investigation, the following conclusions can be made concerning the cracking and seating rehabilitation technique:

1. Cracking and seating of PCC pavements does significantly reduce the stiffness of the PCC.
2. Joints and cracks reflecting through the asphalt concrete overlay are reduced.
3. Flexural fatigue of asphalt concrete should not be a problem if slabs are broken into pieces 2 ft by 2 ft.
4. Approximately 6–7 in. of asphalt concrete was needed after the concrete was cracked and seated to result in the same stress on top of the subgrade as in the PCC pavement prior to cracking and seating.

Recommendations

1. Sealer material should be removed from cracks and joints prior to cracking and seating to prevent bleeding and slippage of the asphalt concrete overlay.
2. Proofrolling is required to seat the cracked PCC pavement but can damage the subgrade if there is excessive proofrolling.

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