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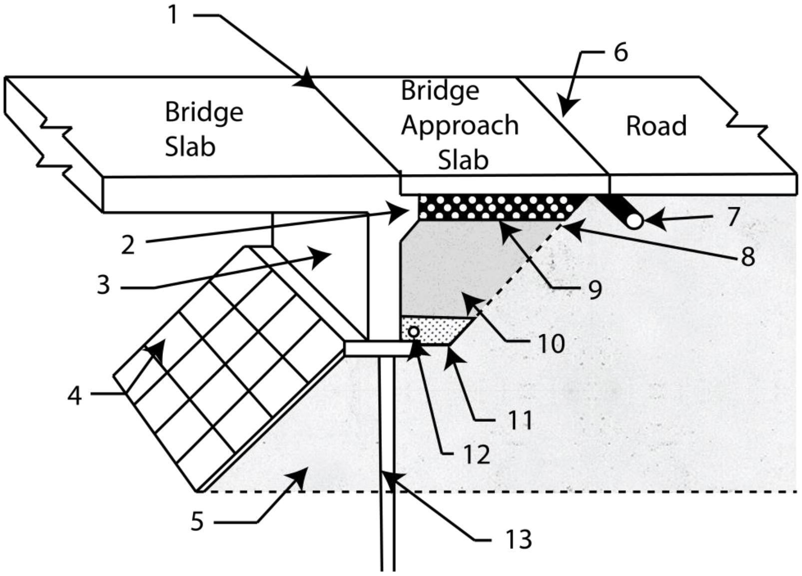
Chapter 6 - Approach Slabs and Approach Roadway

6.1 Approach Slab Function and Potential Issues

What To Look For

- Cracks in Slab
- Uniform/differential settlement of slab
- Degradation/failure of joints with bridge or pavement
- Ponding on slab
- Faulting of slab
- Erosion
- Voids
- “Bumps”

Roadway embankments, which provide support for bridge approach slabs, are continually subjected to traffic-induced compression and settlement throughout the life cycle of the roadway. Embankments are constructed on existing soil subgrades or compacted fill. Figure 6.1 shows the elements of a typical approach slab built on granular backfill.



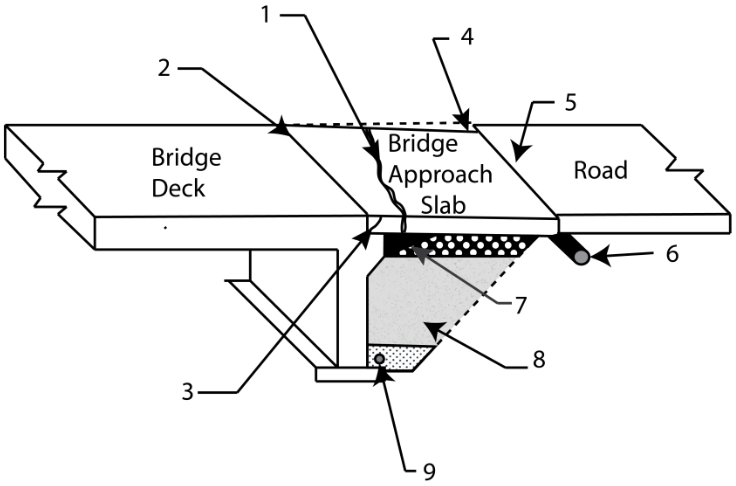
1. Expansion Joint
2. Paving Notch
3. Abutment
4. Slope Protection
5. Bridge Embankment
6. Joint
7. End Drain
8. Backfill Excavation Limit
9. Special Backfill
10. Granular Backfill
11. Porous Fill
12. Subdrain
13. Pile

Figure 6.1 Elements of an Approach Slab

Bridges, by their nature of often having deeper foundations on compact soils, piles or rock, experience less settlement over time. The difference in settlement leads to noticeable bumps, which vehicles feel as they travel across bridges. Approach slabs have often been used to shift the settlement difference from the bridge to further along the roadway, providing a transition zone to minimize noticeable changes in roadway grade.

Some of the potential issues that occur with approach slabs are listed below; some are also shown schematically in Figure 6.2:

- Granular backfills compacting further over time, most often a result of poor compaction during construction (see Figure 6.3)
    - Creates voids
    - Creates faulting of the slab
    - Can lead to cracking of the slab concrete
    - Degradation of joints at both the bridge-slab and the slab-pavement interfaces
- Temperature cycling of deck and approach slabs throughout the years
    - Causes expansion joints to fail
    - Creates voids in winter due to soil compaction during summer bridge expansion
    - Allows water under the slab to erode backfill
    - Longitudinal joints along face of U-wall fail, causing water to erode backfill along edge of slabs
- Short approach slabs (length less than 40 feet)
    - Magnifies settlement issues causing more noticeable bumps
- Approach slabs not built curb-to-curb
    - Leads to differential settlement, especially on sidewalks or at-grade wide shoulders
- Corbels used on abutment stems
    - Prevents proper compaction behind the abutment stem walls
    - Creates pivot point for slabs to rotate on during soil settlement on the other end
    - Leads to expansion joint failure at the back face of the abutment stem
- Cracks appearing through the slab or ponding after precipitation
    - Often indicates settlement of one end, corner, or side of approach slab
    - Usually will continue to grow or spread on the slab if not corrected



1. Faulting
2. Expansion Joint
3. Shearing of End of Approach Slab
4. Settlement of Approach Slab
5. Joint
6. Plugged End Drain
7. Void
8. Poorly Compacted Granular Backfill
9. Plugged Subdrain

Figure 6.2 Potential Issues with Approach Slabs

Figure 6.3 Non-Compacted Granular Backfill Behind a Bridge Abutment (Courtesy of Iowa DOT)

6.2 Assessing Problems

6.2.1 Ride Quality and Settlement Problems

The settlement of the bridge approach pavement has been a continuing problem for many bridge maintenance engineers, leading to bumps and driver discomfort on roadways. Pavement settlement results in poor ride quality on the approach and may pose a safety problem in severe cases of uneven settlement. In cases where bridge approach settlement has created a bump at the end of a bridge, impact loads may be created that can damage the structure. An example of approach settlement is presented in Figure 6.4.

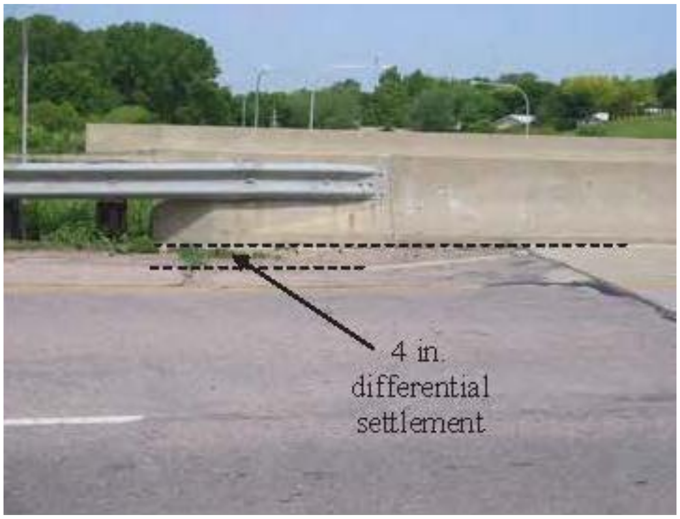


Figure 6.4 Differential Settlement Between the Bridge Deck and the Approach Slab (Courtesy of Iowa DOT)

When concrete approach slabs are attached to the bridge, the settlement is less noticeable. The settlement usually results in cracked pavement that can become severe if it is allowed to continue. Pavement settlement can be a recurring problem. It is often necessary to periodically repeat the repair procedure.

Common causes of fill and approach settlement are provided below. Evidence of these conditions should be investigated when assessing settlement problems at bridge approaches.

- Poorly compacted fill material adjacent to the abutment that continues to consolidate over time.
- Voids behind the abutment resulting from scour caused by the waterway or erosion from surface drainage (see Figure 6.5). Spill through or column abutments are particularly prone to this problem. A small rock drill or ground-penetrating radar can be used to locate and determine the size of voids under the pavement (see Figure 6.6).
- A slight tilting of the abutment from uneven settlement or from scour caused by the waterway that creates a small void near the pavement seat. The pressure of the pavement pushing against the abutment, producing additional movement can further aggravate this situation.

Figure 6.5 Void under Approach Slab (Courtesy of Missouri DOT)

Figure 6.6 Drilling through the Approach Slab (left). Measuring the Depth of the Void (right). (Courtesy of Iowa DOT)

If settlement is occurring, it is very important that the cause of the problem be determined. If scour is creating a void, the condition could become unsafe. Additional layers of blacktop will only temporarily hide the problem and contribute to the unsafe condition because of the increased dead load over the void.

6.2.2 Drainage Problems

Inadequate drainage of abutment backfill is a common problem. Abutment subdrains and weep holes often do not function as intended, or have failed completely, due to being blocked by soil deposits or debris; an example of this is provided in Figure 6.7. Subdrain failure is often a result of non-porous backfill being placed around them. Abutment subdrain failure can lead to erosion of slopes and collapses of armoring.

Figure 6.7 Weepholes Filled with Backfill Material (Courtesy of Iowa DOT)

Surface drainage deficiencies on approach slabs can lead to voids beneath the slabs and eventual settlement. Some items to look out for while performing maintenance activities are provided below.

What To Look For

- Surface gutters and catch basin inlet grates that are clogged by debris
- Sand accumulations along guiderail posts and at inlets or outlets to drain pipes
- Areas where water is or has the ability to pond on top of the approach slab, on the embankments around the abutments, or has previously eroded slopes
- Cracked or damaged expansion joints at the end of the approach slab, where it meets either the deck directly or the rear face of the abutment backwall
- Clogged drainage outlets
- Large separation between bridge railing and return wall

6.3 Preventive and Basic Maintenance of Approach Slabs and Approach Roadway

Proper maintenance of bridge approaches is often as important as proper maintenance of the bridge itself. Problems on the approach may be greater than those of the bridge and can ultimately affect the condition of the bridge, especially in situations where bridge approach settlement has created a bump at the end of a bridge.

6.3.1 Approach Slab Maintenance

To address ride quality issues, maintenance crews may perform the following activities related to approach slabs:

- Patching of spalls (potholes) in the approach slab with asphalt, typically performed on an annual basis
- Placing a temporary asphalt ramp at the end of the bridge when an approach made of poor soils heaves or settles, resulting in a rise or drop of the approach slab in relation to the bridge deck elevation (see Figure 6.8)

Figure 6.8 Asphalt Ramp Placed at the Approach Slab

Preventive maintenance strategies for concrete approach slabs are similar to those employed for concrete bridge decks, and are often performed in conjunction with bridge deck maintenance. Some of the more common preventive maintenance activities are listed below, along with references to the relevant sections in Chapter 7 where these activities are discussed in greater detail.

- Approach slab washing – refer to Sections 7.2.2.1 and 7.2.4.1
- Waterproofing and sealing – refer to Sections 7.2.2.3 and 7.2.4.3
- Overlays – refer to Section 7.2.3, 7.2.4.6, 7.2.4.7 and 7.2.4.8

6.3.2 Maintenance of the Approach Roadway

Maintenance of safety appurtenances in bridge approach areas should also be performed on a regular basis. Such activities include:

- Maintaining all traffic signs
- Prompt replacement of missing or vandalized load limit signs
- Resetting sign posts to a vertical position
- Removing brush, grass, and weeds that obscure signs and reduce visibility
- Repairing deficiencies in guardrails

Other common approach roadway maintenance activities include:

- Grading and shaping of the shoulders adjacent to approach slabs, so that they are at the same (or lower) elevation of the bridge deck
- Removing vegetation under guardrails to facilitate drainage
- Cleaning drainage structures and outletting pipes

6.4 Repair and Rehabilitation of Approach Slabs

6.4.1 Concrete Repair

Typical forms of concrete deterioration in approach slabs, such as cracks, spalls and delamination, are repaired in much the same way as these repairs are performed on concrete deck slabs. Some of the more common concrete repairs are listed below, along with references to the relevant sections in Chapter 7 where these activities are discussed in greater detail.

- Crack injection and epoxy sealing – refer to Sections 7.2.2.6 and 7.2.4.2
- Full and partial depth concrete spall (pothole) repairs – refer to Section 7.2.4.4
- Concrete delamination repair – refer to Section 7.2.4.5

6.4.2 Settlement Repair

There are various methods that can be used to address slab settlement. Installing an asphalt pavement ramp on the approach pavement to compensate for the settlement is a common temporary repair that was mentioned in Section 6.3.1. Alternatively, approach slab overlays, such as those discussed earlier in this chapter, can be applied with varying thicknesses to compensate for the settlement.

Asphalt ramps and approach slab overlays are not appropriate treatments if it is suspected that there are voids beneath the approach slab, as these treatments will simply obscure the underlying problem rather than address it, possibly allowing worsening conditions to go undetected. A few of the methods used by bridge owners to fill voids beneath approach slabs are presented in the following sections.

6.4.2.1 Mudjacking

Mudjacking, also known as Slabjacking, is a process that raises sunken concrete back to its original elevation. The process involves filling any voids and lifting the pavement by pushing it from below with “mud.” The process can cost a fraction of the cost of approach slab replacement, and is relatively fast and clean. The leveling process can be completed and ready for use in a matter of hours. However, if the approach slab contains large areas of deterioration, replacement of the slab may still be a better option.

The mudjacking process requires special equipment and experienced operators. The procedure consists of drilling holes in the pavement and pressure pumping a fine soil slurry containing a hardening agent into the holes. The pressure pumping causes the pavement to rise as the slurry fills any voids as it flows between the pavement and the fill, as shown in Figure 6.9 .

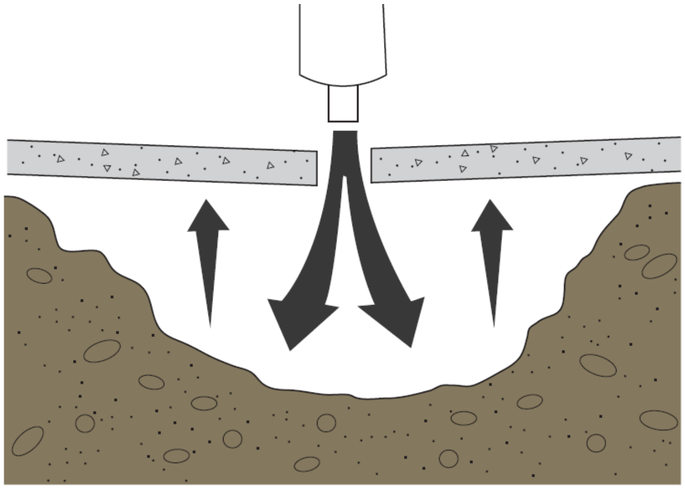


Figure 6.9 Mudjacking Concept

Mudjacking is sometimes also used to fill voids under the approach pavement where settlement has not taken place. The procedures to be followed are basically the same except that the pressure on the slurry should be held to a minimum because lifting of the slab is not required and the probability of blowout is reduced.

There are many materials that can be pumped. Some research is required on the part of the user to find the appropriate material or combination of materials. Some of the most common materials are cement, agricultural lime, pond sand, fly ash, or combinations of these materials. Sufficient water is added to make slurry workable. The characteristics that the material should have are that it is inexpensive, readily available, and is a material that will pump under pressure without having the carrier water separate from the material.

Coarser materials or sand allow separation to happen and can cause many problems. Usually when this separation occurs, it is easily corrected by adding a lubricating material to the mix. The proportion of cement can vary from 1 percent to 20 percent depending on the application or the base material being used. Also, for a mudjacking operation to be successful, it is important that the mix does not shrink as it hardens. Table 6.1 lists the components of typical mixes that have proved satisfactory for mudjacking operations.

Table 6.1 Mudjacking Mixes

	Mix 1	Mix 2	Mix 3
Components	6 parts sand 2 parts commercial (hydrated) lime 1 part Portland Cement*	4 parts sand 8 parts sugarbeet lime (or 12 parts marl) 1 part Portland Cement* Cut-back asphalt RC-1, or asphalt emulsion AE-2, or AE-1 M at a rate of 6.2 liters/cubic meter (1.5 gallons per cubic yard) of slurry	2 parts sand 4 parts commercial (hydrated) lime 1 part Portland Cement* Cut-back asphalt RC-1 , or asphalt emulsion AE-2, or AE-1 M at a rate of 6.2 liters/cubic meter (1.5 gallons per cubic yard) of slurry

* In place of Portland cement, an expansive type cement can be substituted to counteract mix shrinkage.

The fine sand used may be any type having well-rounded particles. Sufficient water must be added to each of the above mixes to make the slurry workable. Mix 2 may also be used without the asphalt materials.

Suggested Procedure

Mudjacking

1. A grid pattern of holes are drilled through the pavement. The diameter of the hole should fit the nozzle on the mudpump. Spacing of the holes depends on the condition of the concrete pavement and the amount of lifting to be accomplished. One typical pattern consists of two rows of holes, each 3 feet from the edge of a 12 foot traffic lane with the holes 6 feet apart along the lane and equally staggered from the holes in the other row. When adjacent lanes are drilled, the holes are staggered from those in the nearest row of the other lane.
2. Once drilled, flush all holes with water under pressure to develop a void under the slab for the slurry to enter.
3. Seal all except two adjacent holes with wooden plugs or stakes.
4. Pump the slurry into one of the two open holes, awaiting the slurry to appear at the other hole, as shown in Figure 6.10.
5. Cover one of the current open holes and remove the seal from a different hole.
6. Fill the new hole with the slurry until it is escaping from the now second open hole and repeat the process until all holes have been pumped into and the approach slab has been raised to the intended elevations. Be sure not to place too much in one hole as that has led to additional cracking of the approach slabs. Smaller placements of slurry will result in better lifting and less slab cracking.
7. Once mudjacking is complete, fill all holes with high-early strength concrete.

An example of mudjacking slurry being pumped under an approach slab is shown in Figure 6.10.

Figure 6.10 Mudjacking Slurry Pumped Under Approach Slab (Courtesy of Missouri DOT)

If slurry appears through the shoulder, as shown in Figure 6.11, an old grader blade can be wedged along and below the pavement edge. Shoulder material can then be added and compacted to seal off the blowout. A wide plank, with the dual wheels of the mudjacking equipment placed upon it, is also effective in keeping the shoulder material from blowing out.

Figure 6.11 Mudjacking Slurry Blowing Out at Barrier (Courtesy of Missouri DOT)

Where the settled pavement areas to be raised are adjacent to structures, extreme caution should be exercised to prevent the concrete pavement approach slab from rising above the bridge deck. The following method has proven effective in preventing over-raising the slab:

Suggested Procedure

Preventing Over-Raising of Slab During Mudjacking

1. Drill 7/8-inch holes diagonally through the approach slab and into the bridge deck slab.
2. Insert 3/4-inch "L" shaped pins into the holes to pin down the approach slab and prevent over-raising of the bridge deck joint. Usually only two or three pins are needed on a 24-foot pavement.
3. After raising the approach slab, remove the "L" shaped pins and refill the holes with mortar.

6.4.2.2 Injecting Expansive Polyurethane

A contractor has developed a method that involves injecting expansive polyurethane under the approach slab to lift the pavement back to its original profile; this method is depicted in Figure 6.12. Grout holes are drilled through the existing approach slab, and then injected by a pumping truck with expansive polyurethane foam that, as it expands, will lift the approach slab and provide an underseal to the slab. Within 15 minutes, 90 percent of its maximum compressive strength is reached. The holes are then filled with non-expansion grout to prevent water and debris from infiltrating the slab. Tests in Oklahoma, Michigan, and Texas found this method to be effective for at least 10 years when properly conducted.

Figure 6.12 Injecting Expansive Polyurethane under Approach Slab (Courtesy of Iowa DOT)

Tests have shown that, prior to injection of expansive polyurethane, the size of the voids should be determined using techniques such as ground-penetrating radar, so that the estimate of expansive polyurethane is more accurate. Fine cracks were also noticed in the slabs, similar to those shown in Figure 6.13, and were likely induced by stresses formed during the slab lifting process.

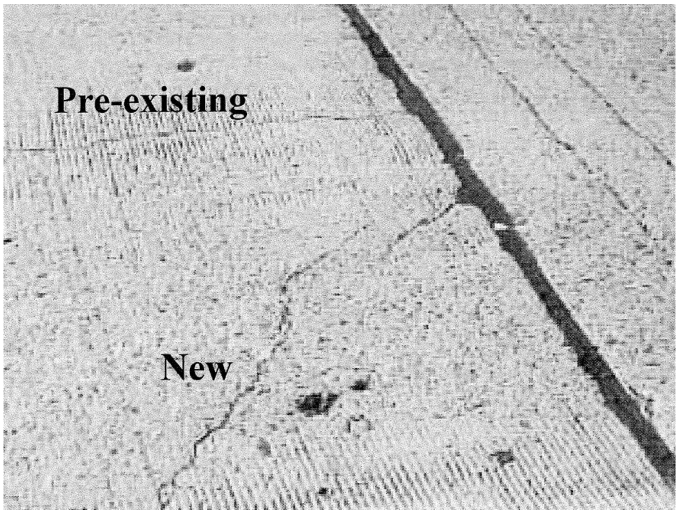


Figure 6.13 Surface Cracks Following Injection of Expansive Polyurethane (Courtesy of Oregon DOT)

6.4.2.3 Pressure Grouting under Slab

Pressure grouting to fill in the voids within the first year of new approach slabs or approach pavement reconstruction has been shown to be effective in settlement prevention. Grouting is done twice, once within the first 2-to-6 months, and then again within 6 months of the first grouting, to fill voids created by settlement and temperature-induced expansion. Grout mix often used was one part Type 1 Portland Cement and three parts Class C fly ash, with water added for workability and fluidity for pumping into holes drilled through the existing slab in-place. However, while used as a mitigation method, this solution is more a short-term fix than a long-term method as soils will continue to settle below the grouted zone.

6.4.2.4 Compaction or High-Pressure Grouting under Slab

High-Pressure Grouting under the slab involves utilizing and often increasing the voids by compacting the soil and fill layers beneath by a sand-cement grout that is placed under high pressures. Once the soil is fully compacted, additional grouting can be used to lift approach slabs and abutting roadways. This method uses a grid pattern of holes drilled through the existing approach slab, and works well with gravel, sand, or coarse silt subgrades.

6.5 Approach Pavement Expansion and Its Effect on Structures

Considerable damage to bridge components has been caused by pressure from encroaching pavements due to the expansion of concrete roadways, also known as “pavement growth.” This expensive and irreversible damage may be reduced if bridge engineers, inspectors, and maintenance workers identify the signs of pavement growth early, and initiate corrective action through the installation of a pressure relief joint in a timely manner.

There are common signs that pavement growth may be occurring at a structure. Several examples are provided below.

What To Look For

- Closed expansion joints (see Figure 6.14)
- Damaged or crushed concrete barriers (see Figure 6.15)
- Railing tube separation at joints between two sections of steel or aluminum railing (see Figure 6.16)
- Diagonal deck cracking at ends of bridge (see Figure 6.17)
- Closed pin and hangers, especially if during cold weather
- Severely tilted rocker bearings, especially if during cold weather
- Beam end contact with backwall, or a backwall that is not vertically plumb

Figure 6.14 Expansion Joint Permanently Closed due to Approach Pavement Growth (Courtesy of MDOT)

Figure 6.15 Crushed Barrier due to Approach Pavement Growth (Courtesy of MDOT)

Figure 6.16 Aluminum Tube Rail Separation, a Possible Sign of Approach Pavement Growth (Courtesy of MDOT)

Figure 6.17 Diagonal Deck Cracking May be a Sign of Approach Pavement Growth (Courtesy of MDOT)

6.5.1 Sources of Pavement Growth

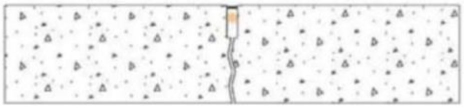
There are many contributing factors that can lead to pavement growth, and also determine the rate and extent of pavement growth. These factors include:

- Length of concrete pavement and joint spacing adjacent to the bridge
- Pavement age
- Average daily traffic
- Joint seal maintenance
- Temperature fluctuations
- Use of sand during winter maintenance operations

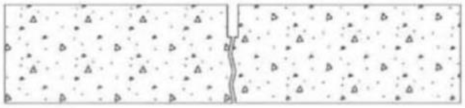
Often these factors are interconnected and work to complement one another. The average daily traffic a roadway experiences and joint seal maintenance are one such example. It is often difficult to justify lane closures for joint sealing in a metropolitan area, but joint seals wear and deteriorate faster where there is more traffic. Open contraction joints allow debris buildup and thus reduce the amount pavement can expand during increasing temperatures.

In various combinations these sources of pavement growth can cause pressures in excess of 1,000 psi at bridges. Joint sealant maintenance and short longitudinal spacing between contraction joints extends the amount of time before bridge damage occurs. Understanding the pressure generation cycles, as illustrated Figure 6.18, and the process used to alleviate these pressures, will reduce the need for expensive rehabilitation projects.

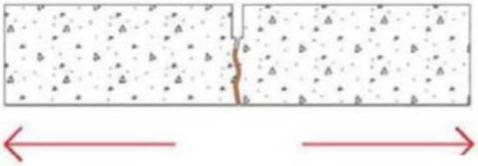
1. Saw cut and sealed new concrete pavement



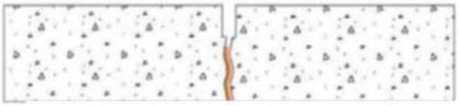
2. Shrinkage crack forms at contraction joint



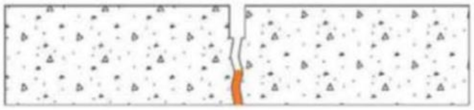
3. Joint seal lost



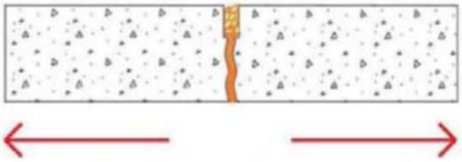
4. Fine particles infiltrate joint and expansion occurs



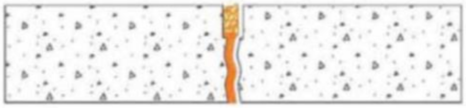
5. Concrete contracts



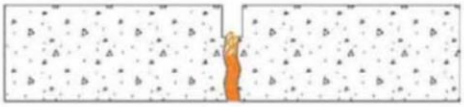
6. Incompressible particles settle



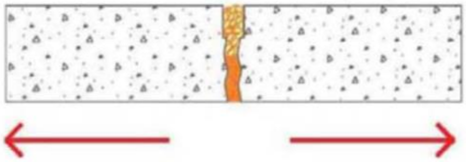
7. Coarse particles begin to infiltrate joint and expansion occurs



8. Concrete contracts



9. Incompressible particles settle



10. Coarse particles infiltrate joint and expansion occurs

Figure 6.18 Concrete Pavement Pressure Generation Cycles (Courtesy of MDOT)

6.5.2 Installing Pressure Relief Joints

Pressure relief joints should be located approximately 50 feet away from the structure, but not placed at an existing joint or load transfer device. When installing pressure relief joints, a section of the concrete pavement is saw cut and then removed across the entire width of the roadway. After saw cutting, the concrete and any mesh reinforcement should be removed completely and the aggregate base must be visible. This may be accomplished using either 60 pound jackhammers or a skid steer with mounted hydraulic hammer attachment.

All additional sources of pressure also need to be relieved; these sources could be located within shoulders, curbs, sidewalks and barriers. When cutting concrete barriers, be mindful of the possible presence of electrical conduits, especially if light standards are mounted on the barrier.

6.5.2.1 Bituminous Pressure Relief Joints

For bituminous pressure relief joints, the opening is normally 12 inches wide (minimum) and filled with bituminous material, like the example shown in Figure 6.19.

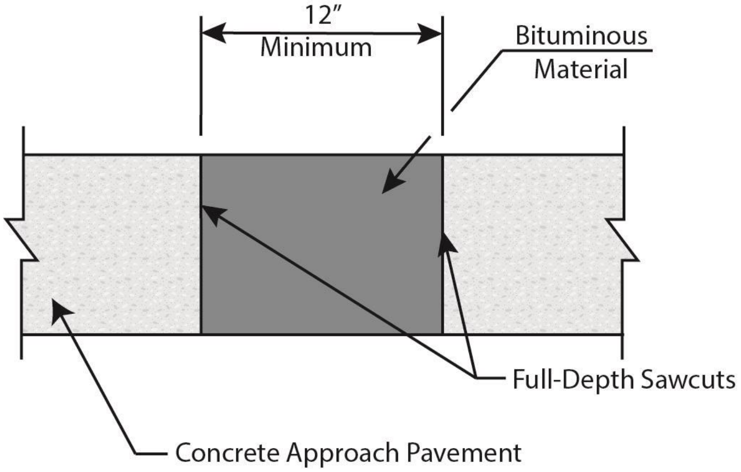


Figure 6.19 Example Detail of a Bituminous Pressure Relief Joint

Bituminous pavement relief joints may bump up over time as pavement growth continues, requiring periodic milling to maintain satisfactory ride quality.

6.5.2.2 Closed Cell Joint Seal Pressure Relief Joints

Narrower pressure relief joints, say 4 inches, can be filled with bridge deck joint seals, as illustrated in Figure 6.20. The joint seal material used should be tested and capable of compressing down to 1 inch without failing or popping out. For this type of pressure relief joint, it is extremely important that the two saw cuts are parallel. Also, installations should only be scheduled prior to peak seasonal temperatures, as placing the material during the summer or fall often results in loss of the material.

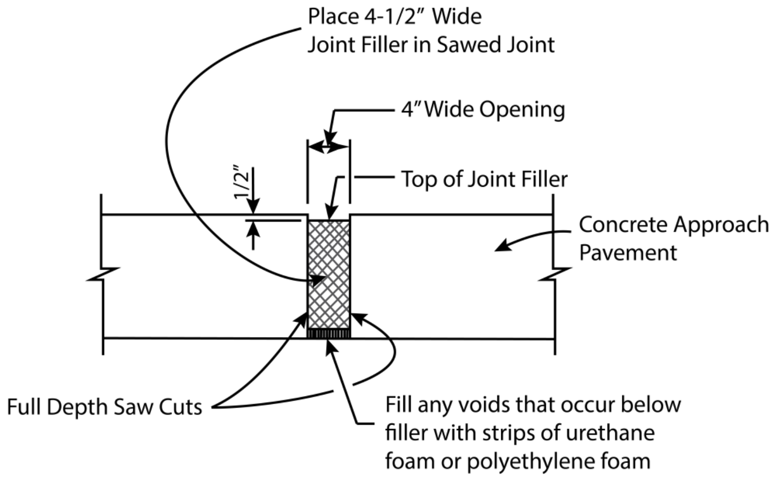


Figure 6.20 Example Detail of a Closed Cell Joint Seal Pressure Relief Joint

Suggested Procedure

Closed Cell Joint Seal Pressure Relief Joint Installation

1. Make two parallel full-depth saw cuts to create a 4-inch-wide joint opening. The joint must be continuous extending across the entire road, and any adjoined curb and gutter or concrete barrier wall must be cut as well.
2. After saw cutting, completely remove the concrete and any mesh reinforcement until the underlying aggregate base is visible. This may be accomplished using either 60 pound jackhammers or a skid steer with mounted hydraulic hammer attachment. A vacuum truck is helpful to remove slurry located in the bottom of the joint that is generated during saw cutting.
3. After concrete removal, dry the vertical surfaces with air and sandblast the vertical surfaces to aid the bonding ability of the lubricant adhesive (see Figure 6.21).
4. Coat each contacting edge of closed cell relief joint material with lubricant adhesive. Inexpensive disposable rollers or steel trowels may be used to spread the material conservatively.
5. Once the sides are coated, press the material in place by hand working from one end to the other without stretching it. Press the foam into the void so it is recessed approximately one half inch. Tools may be cleaned with xylol or acetone to remove any lubricant adhesive residue.
6. The use of spacers is required in areas where irregular saw cuts have resulted in areas where the opening is wider than 4 inches. Spacers are simply pieces of the same material and act as wedges to hold the material in place until it is in a state of compression. Provide spacers a maximum of every 6 inches or as needed to maintain the joint elevation.
7. Allow any excess lubricant adhesive lying on the road surface to cure or place blasting sand on it to prevent tracking. Do not reopen lanes to traffic if the material will be picked up by vehicular traffic.

Figure 6.21 Sandblasting the Vertical Surfaces of the Joint Opening (Courtesy of MDOT)

6.5.3 Monitoring Pressure Relief Joints

Pressure relief joints should be measured regularly and additional joints constructed as the pavement continues to grow. If a joint measures less than 2 inches, a replacement should be added to the list of annual maintenance recommendations. If a pressure relief joint measuring less than 1 inch is discovered, it should be replaced immediately to eliminate the opportunity for damage.

The amount of time required before performing a replacement will vary for each pressure relief joint. A concrete repair project or bituminous overlay on the concrete roadway will significantly reduce the rate at which pavement stresses form. However, if no changes occur and the factors that cause pavement growth are plentiful, replacements will often occur after only four years of service.

6.6 Chapter 6 Reference List

1. American Mudjacking, LLC. FAQ sheet: http://www.americanmudjacking.com/faq/
2. FHWA. *Bridge Maintenance Training Reference Manual.* NHI Course 134029, Publication No. FHWA-NHI-03-045. Washington D.C.: United States Department of Transportation, March 2003.
3. Georgia Department of Transportation, Office of Bridge and Structural Design, Bridge Maintenance Unit. *Bridge Structure Maintenance and Rehabilitation Repair Manual*. June 2012, http://www.dot.ga.gov/travelingingeorgia/bridges/Documents/BridgeRepairManual.pdf
4. Iowa Department of Transportation. *Identification of the Best Practices for Design, Construction, and Repair of Bridge Approaches*. Project TR-481, CTRE Project 02-118, Final Report. Sponsored by the Iowa Department of Transportation and the Iowa Highway Research Board, January 2005, http://publications.iowa.gov/2945/1/BridgeApproachesReport.pdf
5. Kentucky Transportation Center. *Movements and Settlements of Highway Bridge Approaches*. Report KTC-02-18/SPR-220-00-1F. In cooperation with The U.S. Department of Transportation Federal Highway Administration, June 2002.
6. Michigan Department of Transportation, Region Bridge Support Unit, Bridge Field Services. *Alleviating the Effects of Pavement Growth on Structures.* January 2012.
7. National Highway Institute. *Approach Maintenance, Bridge Maintenance Training Instructor Guide.* NHI Course 134029, Session V-A, pages 213-224.
8. New York State Department of Transportation, Office of Transportation Maintenance. *Bridge Inspection Manual*. 1997.
9. New York State Department of Transportation, Office of Transportation Maintenance. *Fundamentals of Bridge Maintenance and Inspection Manual*. September 2008.
10. Oregon Department of Transportation, Research Group. *Injected Polyurethane Slab Jacking*. Report SPR 306-261. In cooperation with The U.S. Department of Transportation Federal Highway Administration, June 2002, http://www.oregon.gov/ODOT/TD/TP_RES/docs/Reports/InjectSlabJack.pdf
11. The University of Texas at Arlington. *Recommendations for Design, Construction, and Maintenance of Bridge Approach Slabs*. Report FHWA/TX-11/0-6022-2. In cooperation with The U.S. Department of Transportation Federal Highway Administration, http://ntl.bts.gov/lib/45000/45100/45156/0-6022-2.pdf

12. University of New Mexico, Department of Civil Engineering. *Settlement Issues – Bridge Approach Slabs (Final Report Phase I).* Report NM04MNT-02. In cooperation with The U.S. Department of Transportation Federal Highway Administration, December 2006, http://dot.state.nm.us/content/dam/nmdot/Research/NM04MNT02SettlementIssuesBridgeApproachSlabsPhaseI_2006.pdf
13. URETEK USA Whitepaper. *The URETEK Method™ for Roadways and Transportation Assets*, http://www.worldofuretek.com/
14. Virginia Transportation Research Council. *Guidelines for the Use, Design, and Construction of Bridge Approach Slabs*. Report VTRC 00-R4. Prepared for: Virginia Department of Transportation and the University of Virginia, November 1999, http://www.virginiadot.org/vtrc/main/online_reports/pdf/00-r4.pdf
15. Wisconsin Department of Transportation, Division of Transportation Systems Development. *Evaluation of The URETEK Method of Pavement Lifting*. Report WI-02-07. In cooperation with The U.S. Department of Transportation Federal Highway Administration, April 2007, http://wisdotresearch.wi.gov/wp-content/uploads/wi-02-07uretekmethod1.pdf