Dowel Bar Retrofit – Do’s and Don’ts

WA-RD 576.2

Updated March 2009

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENTS CATALOG NO
WA-RD 576.2		

4. TITLE AND SUBTITLE	5. REPORT DATE
Dowel Bar Retrofit – Do's and Don'ts	March 2009
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Pierce, L.M., Uhlmeyer, J.S and Weston, J.	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Washington State Department of Transportation PO Box 47365 Olympia, Washington, 98504-7365	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. CO-SPONSORING AGENCY NAME AND ADDRESS Washington State Department of Transportation Research Office Olympia, Washington 98504-7372 Research Manager: Kim Willoughby 360.705.7978	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

This report documents construction and inspection guidelines for the successful construction of a dowel bar retrofit project.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Dowel bar retrofit, concrete rehabilitation, construction techniques	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None		

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The following describes and illustrates the dowel bar retrofit construction process. Much of the information contained in this appendix has been adopted, and significantly enhanced from *Dowel Bar Retrofit – Do's and Don'ts*[1]. In addition, descriptions of critical details for ensuring pavement performance are also included.

In general, the dowel bar retrofit process includes the following steps:

1. Using diamond saw blades, sawcut dowel bar slots (three to four per wheelpath).
2. Remove existing concrete within dowel bar slot.
3. Remove diamond blade slurry and other debris from dowel bar slot.
4. Seal existing joint or crack within the dowel bar slot with caulking material.
5. Place dowel bar retrofit assembly (dowel bar, chairs, foam core board and end caps) into the dowel bar slot, centered over the joint or crack.
6. Place, consolidate and cure patching material.
7. Diamond grind surface.

Since dowel bar retrofit performance is highly dependent on construction practices, it is advised that prior to project startup the project inspector consider the following:

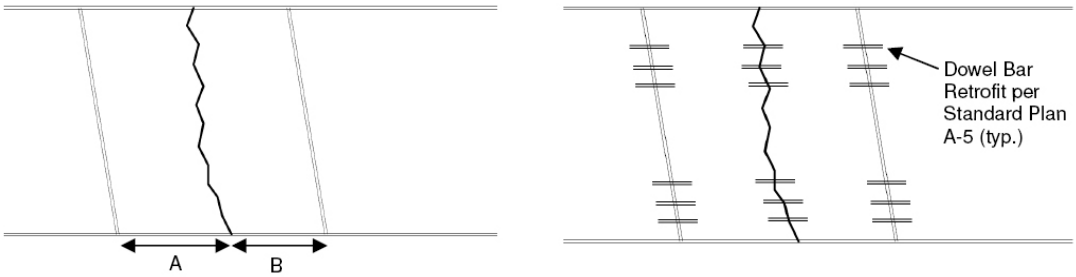
- Become familiar with Construction Plans, Specifications and Special Provisions
- Consider having a preconstruction workshop to ensure contractor and agency understand project requirements
- Consider including experienced personnel during the preconstruction meeting and potentially on the job-site during construction.
- Remember that bridge approach slabs should not be retrofitted.

Dowel Bar Retrofit and Panel Replacement Guidelines

The following images (courtesy Z. Martin) illustrate general guidelines for dowel bar retrofit and panel replacements.

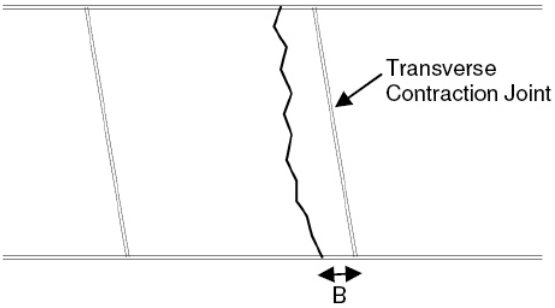
[1] Pierce, L.M., Uhlmeyer, J.S. and J. Weston (2003). *Dowel Bar Retrofit Do's and Don'ts,* Research Report WA-RD 576.1, Washington State Department of Transportation.

Transverse Crack

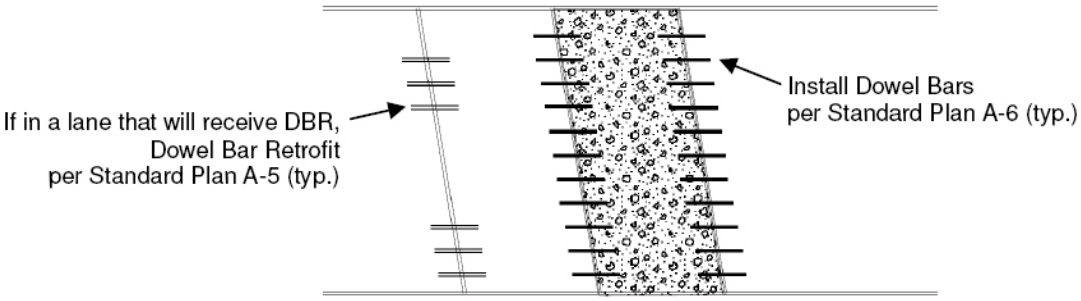


(a) Existing (b) Solution

Figure 1 Mid panel transverse crack (A and B greater than three feet).



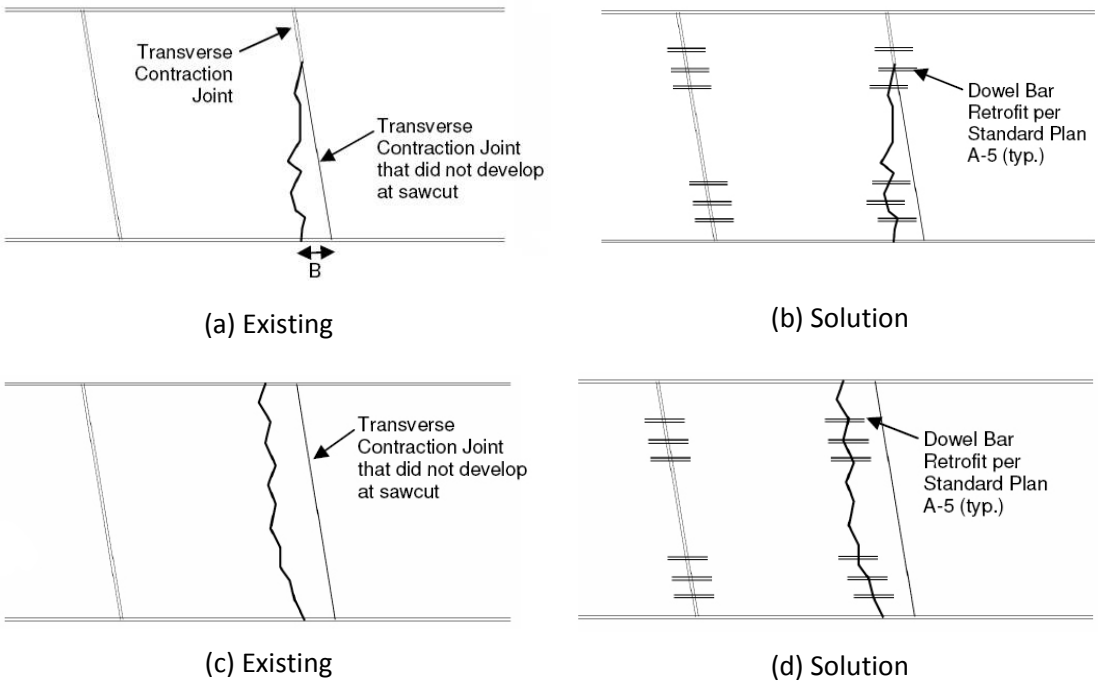
(a) Existing



(b) Solution

Figure 2 Existing transverse crack (B < three feet).

Transverse Working Crack

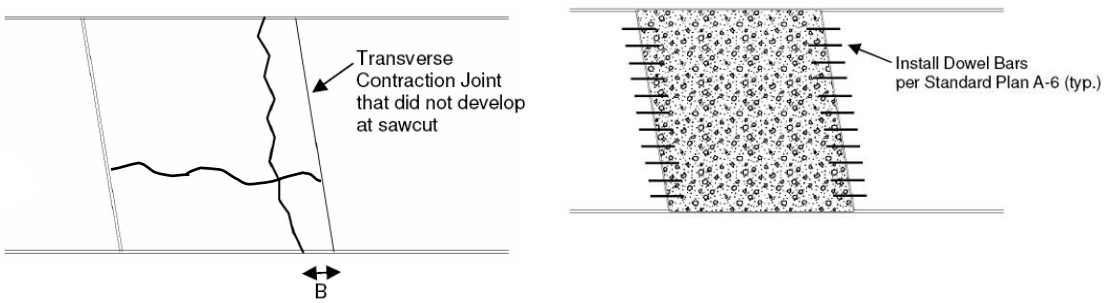


(a) Existing (b) Solution

(c) Existing (d) Solution

Figure 3 Working transverse crack.

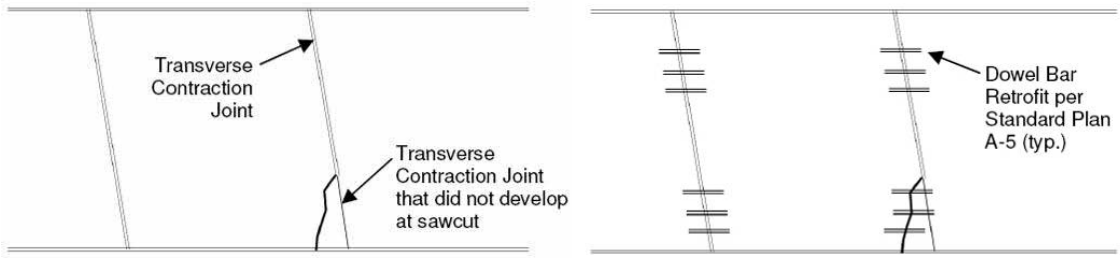
Multi-Cracked and Settled Slabs



(a) Existing (b) Solution

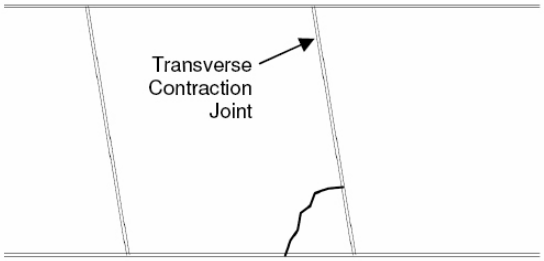
Figure 4 Multi cracked (two or more) and settled (> ½ inch) slab.

Corner Crack

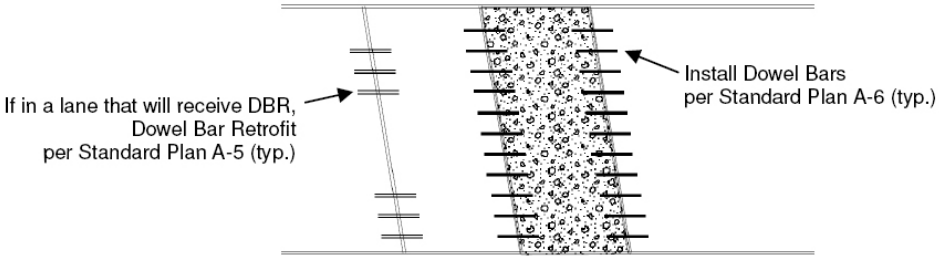


(a) Existing (b) Solution

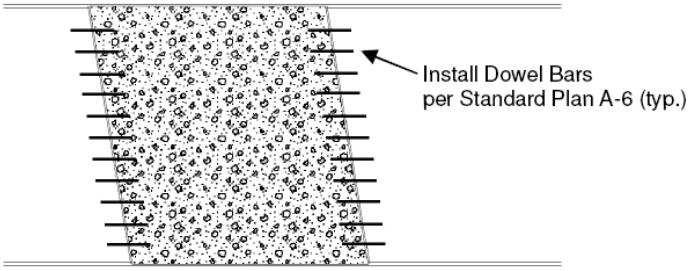
Figure 5 Working corner crack.



(a) Existing



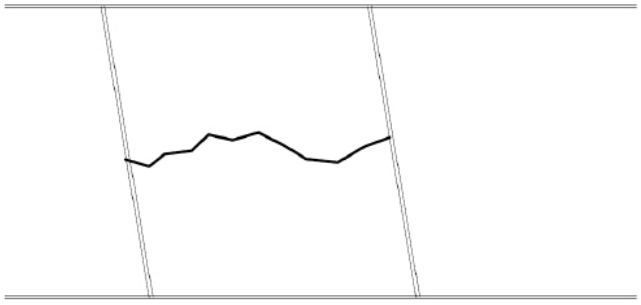
(b) Maximum longitudinal length between crack and transverse joint < six feet



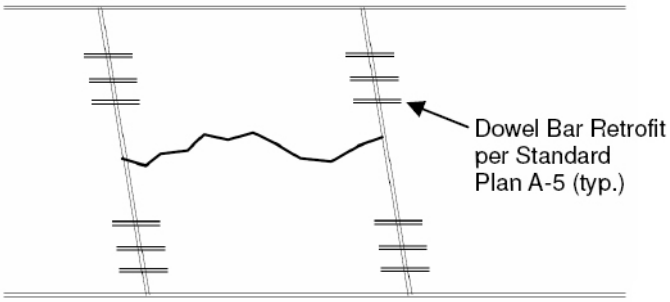
(c) Maximum longitudinal length between crack and transverse joint > six feet

Figure 6 Corner crack.

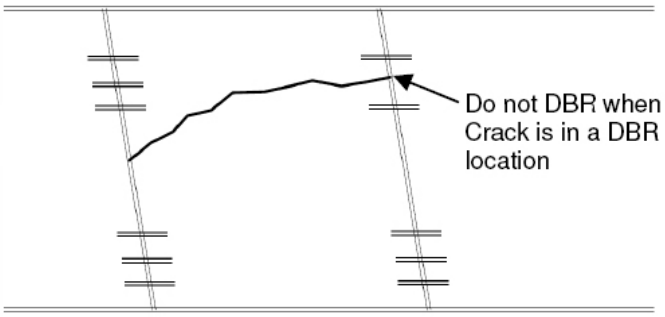
Longitudinal Cracking



(a) Existing



(b) Solution



(c) Solution

Figure 7 Longitudinal crack.

Cutting Dowel Bar Slots

Figure 8 illustrates equipment that can saw cut six dowel bar slots in one pass. This device is very effective in cutting both non skewed and skewed transverse joints. This device is also effective in cutting dowel bar slots on transverse cracks, depending on angle of crack skew.

Figure 8 Cutting equipment for six dowel bar slots per joint.

Figure 9 and Figure 10 shows the equipment for cutting three dowel bar slots per wheelpath. This equipment is effective on non-skewed and skewed joints and transverse cracks.

Figure 9 Cutting equipment for three dowel bar slots per wheelpath.

Figure 10 Diamond blades and spacing for three dowel bar slots per wheelpath.

Figure 11 illustrates equipment to saw cut a single dowel bar slot.

Figure 11 Cutting equipment for one dowel bar slot at a time.

Figure 12 illustrates the completed product from the sawcutting operation.

Figure 12 Cut dowel bar slots on non-skewed transverse joint.

For skewed joints, when using sawcutting equipment that is capable of cutting three or more dowel bar slots per wheelpath or six dowel bar slots per joint (in one pass), dowel bar slots should be cut with sufficient length (Figure 13) to allow the dowel bar retrofit assembly to be centered over the joint (equal length of dowel bar on either side of the joint).

Proper alignment of the dowel bar slot is essential for minimizing the potential for dowel bar lockup. Lockup is the inability of the dowel bar to move freely as the slab expands and contracts due to curling and warping. If the dowel bar movement is restricted, stresses can be induced within the dowel bar slot and eventual cracking and spalling of patching material may occur. Stresses may also be significant to cause cracking within the concrete panel.

Figure 14 illustrates dowel bar slots that have not been correctly sawcut on a skewed joint. In this case, the dowel bar slots were cut perpendicular to the skewed joint (as is necessary for non-skewed joints) rather than parallel to centerline.

Figure 13 Dowel bar slots on a skewed transverse joint.

Figure 14 Dowel bar slots incorrectly cut on skewed joints.

Slots cut deeper than necessary can contribute to corner cracking (Figure 15). Patching material failure and the potential of the jackhammer punching through the bottom of the dowel bar slot may also occur. The Contractor/Inspector should physically measure the dowel bar retrofit assembly height (including chairs) to ensure proper sawcut depth.

Figure 15 Distress due to dowel bar slot cut and/or chipped too deep.

Figure 16 Check depth of dowel bar slot.

Dowel bar slot width should also be confirmed to ensure that the dowel bar chairs and foam core board fit snugly against the sides of the dowel bar slot. This will assist in holding the dowel bar retrofit assembly securely in the dowel bar slot during placement of the patching material.

Dowel bar slots should be aligned to miss (**Error! Reference source not found.**) any existing longitudinal crack. Depending on the wander of the longitudinal crack, dowel bar slots could also be eliminated (**Error! Reference source not found.**). If the longitudinal crack was located in the right wheelpath, completely eliminating all dowel bar slots would not be recommended. In this instance, it may be best to place as many dowel bar slots as possible without intersecting the longitudinal crack.

Figure 17 Dowel bar slots aligned to miss an existing longitudinal crack.

Figure 18 Left wheelpath dowel bar slots not installed to avoid existing longitudinal crack.

Figure 19 and Figure 20 illustrate instances where the dowel bar slot was not placed to miss the existing longitudinal crack resulting in failure of the patching material. Dowel bar slots placed over a longitudinal crack will fail within a very short period of time (< 12 months). The failure mechanism is typically debonding, cracking and spalling of the concrete patching material. Shifting dowel bar slots, three to four inches, will prevent this distress while still providing the required load transfer. If a gang saw is used, dowel bar slots may be sawed but not retrofitted, any non-retrofitted sawcuts should be cleaned and sealed with an epoxy resin.

Figure 19 Failure of dowel bar slot placed over existing longitudinal crack.

Figure 20 Severe failure of dowel bar slot placed over existing longitudinal crack.

All existing transverse joints and cracks should be dowel bar retrofitted. Figure 21 shows a non-working joint (narrow joint opening and excellent joint sealant condition after being in-

service for more than 20 years with no maintenance) and a transverse crack that is functioning as the working joint. In this case, the crack should be dowel bar retrofitted and not the joint.

Figure 21 Transverse crack is functioning as the working joint.

Removing Existing Concrete from Dowel Bar Slots

The existing concrete should be removed from the dowel bar slot using jackhammers weighing 30 pounds or less. Jackhammers should be operated at a 45 degree angle or less (Figure 22 through Figure 24). Jackhammers operated in a vertical position can punch through the bottom of the dowel bar slot.

Figure 22 Maintain jackhammer at no more than a 45-degree angle.

Figure 23 Jackhammer operation.

Figure 24 Removing concrete within dowel bar slot.

Leveling of the dowel bar slot bottom (Figure 25) helps ensure that the dowel bar will meet alignment tolerances. This work should be conducted with a 15-pound or lighter jackhammer.

Figure 25 Leveling the bottom of the dowel bar slot.

A breaker bar Figure 26 and Figure 27 may be used to expedite the jackhammer removal operation of the concrete within the dowel bar slot.

Figure 26 Breaker bar.

Figure 27 Close-up of breaker bar.

Figure 28 illustrates insufficient removal of the existing concrete from the bottom of the dowel bar slot. This high point may result in a skew in the horizontal position of the dowel bar beyond that which is allowed by specification tolerances. If this skew is severe, dowel bar lockup and eventual failure of the patching material may occur. Slot bottom should be leveled using a lightweight (< 15 pound) jackhammer.

Figure 29 illustrates insufficient removal of the existing concrete at the end of the dowel bar slot. Improper concrete removal could result in insufficient length for the dowel bar to sit level in the dowel bar slot and may not allow for sufficient patching material around the dowel bar. Though this may not be extreme in this case, spalling at the end of the dowel bar slot may occur due to difficulty in obtaining patching material consolidation.

Figure 30 illustrates a situation where the jackhammer operation caused failure of the bottom of the dowel bar slot. This may have occurred due to operating the jackhammer at an angle greater than 45 degrees, the dowel bar slot was sawcut to deep leaving an insufficient depth of concrete between the dowel bar slot bottom and the bottom of the concrete slab, which was easily broken during the jackhammering process or the use of jackhammers weighing more than 30 pounds.

Figure 28 Concrete not fully removed from the bottom of the dowel bar slot.

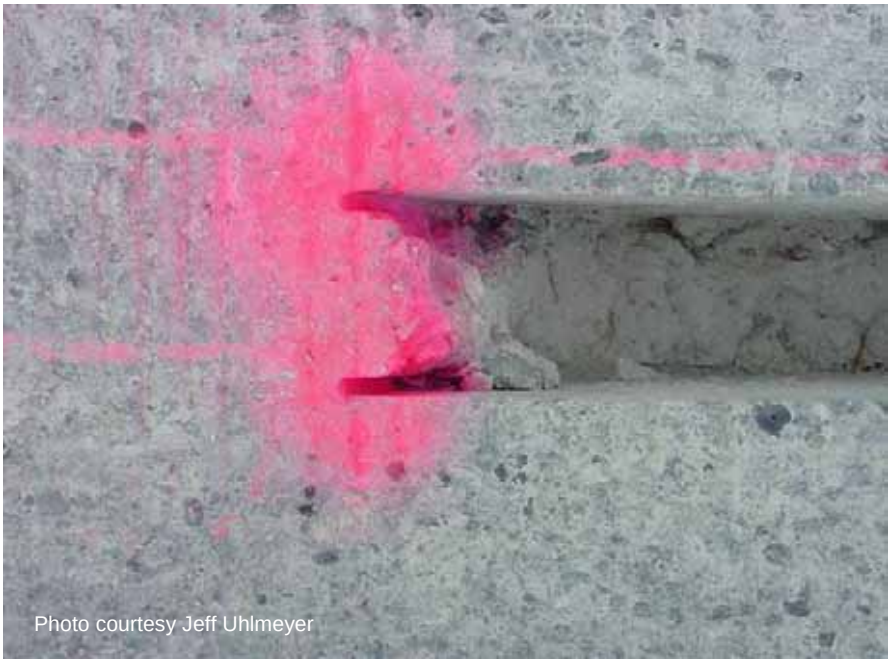


Figure 29 Concrete not sufficiently removed from the end of the dowel bar slot.

Figure 30 Jackhammer punching through the bottom of the dowel bar slot.

Removal of the dowel bar slot debris can be quite laborious. The use of a small loader can aid in the clean-up operation (Figure 31 through Figure 33).

Figure 31 Debris from the jackhammering process.

Figure 32 Debris removal.

Figure 33 Loading debris into dump truck.

Figure 34 Sweeping debris from roadway.

Cleaning Dowel Bar Slots

After completion of the sawcutting and concrete removal process, debris and saw blade slurry exists in the dowel bar slot (**Error! Reference source not found.**). This material must be removed prior to installation of the dowel bar retrofit assembly. Insufficient cleaning of the dowel bar slot will prohibit adherence of the patching material to the existing concrete, which will result in a bonding failure between the patching material and the existing concrete.

Figure 35 Sawcut blade residue on slot walls.

All exposed surfaces and cracks in the dowel bar slot should be sand blasted (**Error! Reference source not found.** and **Error! Reference source not found.**) and cleaned to bare concrete to remove any diamond saw blade slurry or other debris. The dowel bar slot is considered to be clean when all debris and standing water has been removed from the dowel bar slot sides and bottom. The side of the dowel bar slot is considered clean when wiping the sides of the dowel bar slot, with a clean towel or hand, produces no residue.

Figure 36 Cleaning dowel bar slot by shot blasting.

Figure 37 Dowel bar slot after shot blasting.

Compressed air (Figure 38 through Figure 40) may also be used to remove debris, water and slurry from the sides and the bottom of the dowel bar slots.

Figure 38 Cleaning shot blasting debris from roadway.

Figure 39 Removing water and other debris with compressed air.

Figure 40 Cleaning dowel bar slots with compressed air.

Figure 41 shows a properly cleaned dowel bar slot.

Figure 41 Cleaned dowel bar slot.

Removal of debris and slurry residue can be challenging if water is present in the dowel bar slot. If water is present (Figure 42), slurry residue is redistributed to the bottom or sides of the dowel bar slots and should be removed by sandblasting or compressed air. More than one attempt at cleaning the dowel bar slot may be required to obtain the desired cleanliness.

Figure 42 Water must be removed prior to placement of patching material.

Figure 43 and Figure 44 shows debonding of the patching material from the dowel bar slot. This distress is typically related to inadequate cleaning of the dowel bar slot. Repair of this distress requires removal and replacement of the patching material.

Figure 43 Patching material bond failure.

Figure 44 Severe patching material bond failure.

Figure 45 illustrates spalling of the patching material. Potential causes of this distress can be related to consolidation, lack of sufficient aggregate or opening too early to traffic. Figure 46

illustrates insufficient consolidation in the patching material. Repair, for both instances would include removal and replacement of two to three inches of the patching material.

Figure 45 Spalling of patching material.

Figure 46 Insufficient consolidation of patching material.

Figure 47 illustrates shrinkage cracking of the patching material. This type of cracking is repaired by removal and replacement of distressed patching material.

Figure 47 Shrinkage cracks of pour back material.

Debris should be removed a minimum of four feet from the dowel bar slots. This material can be reintroduced (Figure 48) into the dowel bar slot and may result in bonding issues.

Figure 48 Debris should be cleared to a sufficient distance to prevent intrusion.

Sealing Joint or Crack within the Dowel Bar Slot

Transverse joints and cracks must be caulked (Figure 49 and Figure 50) within the dowel bar slot. Caulking material should not extend more than ½ inch beyond either side of the joint or crack. The caulking material will prevent patching material from entering the joint/crack.

Figure 49 Caulking dowel bar slot sides and bottom.

Figure 50 Caulked dowel bar slot.

Placement of Dowel Bar Retrofit Assembly

Prior to assembly and placement into the dowel bar slot, dowel bars should be lightly coated with a parting compound. Parting compound that is applied after the dowel bar retrofit assembly has been placed in the dowel bar slot will result in debonding of the patching material. Once the parting compound has been applied, foam core board, chairs and end caps should be installed onto the dowel bar.

The chair design should hold the dowel bar tightly and fit snugly against the dowel bar slot such that movement is minimized during placement of the patching material. Chairs should be strong enough to allow full support of the dowel bar. Chairs should allow at least a ½ inch clearance between the bottom of the dowel and the bottom of the dowel bar slot.

End caps shall be tight fitting, placed on each end of the dowel bar, each allowing at least ¼ inch of movement. Loose fitting end caps will allow movement of the dowel bar within the dowel bar slot, which could lead to failure of the patching material. The dowel bar must be allowed to move within the end cap to allow for expansion and contraction due to curling and warping.

The ⅜ inch thick foam core board (closed cell foam with plastic or poster board faced material) should be of sufficient quality to allow a tight fit around the dowel bar and to all edges of the dowel bar slot during placement of the patching material. Care should be given to ensure the foam core board extends beneath the dowel bar to the bottom of the dowel bar slot. The foam core board should be placed at the transverse joint or transverse crack and at the middle of the dowel bar. The foam core board reestablishes the transverse joint or crack and allows for the expansion of the patching material.

Dowel bar retrofit assemblies must be centered over the existing transverse joint or transverse crack and parallel to the concrete surface.

Figure 51 shows the assembled dowel bars, chairs, end caps and foam core boards on a flat bed trailer. Dowel bar retrofit assemblies are taken from the flat bed trailer, placed adjacent to the dowel bar slot locations (Figure 52 and Figure 53) and inserted into the dowel bar slot (Figure 54). Figure 55 shows the dowel bar retrofit assembly at a transverse joint location and Figure 56 and Figure 57 shows the dowel bar retrofit assembly at transverse cracks.

Figure 51 Dowel bar retrofit assemblies.

Figure 52 Dowel bar retrofit assemblies ready for installation.

Figure 53 Close-up of dowel bar retrofit assemblies.

Figure 54 Inserting dowel bar retrofit assemblies into dowel bar slots.

Figure 55 Dowel bar retrofit assembly at a transverse joint.

Figure 56 Dowel bar retrofit assembly at a transverse crack.

Figure 57 Close-up of dowel bar retrofit assembly at a transverse crack.

The dowel bar epoxy coating should be inspected and if any discrepancies are present the dowel bar should be rejected. On one particular project, dowel bar corrosion (Figure 58 and Figure 59) was determined to be the cause of the dowel bar slot failure.

Figure 58 Corroded epoxy coated dowel bars.

Figure 59 Close-up of corroded epoxy coated dowel bars.

Placement of Patching Material

Patching material can be batched using a mobile mixer (Figure 60 and Figure 61) or in individual batches. If a mobile mixer is used, batching of the individual components must be closely monitored to ensure proper proportioning.

Figure 60 Mobile mixer.

Figure 61 Delivery of materials to mobile mixer.

Patching material should not be dumped directly into the dowel bar slot; the impact of the patching material falling directly into the dowel bar slot will cause movement of the dowel bar retrofit assembly. The patching material should be placed adjacent (Figure 62 and Figure 63) to and spread with shovel (Figure 64) toward and into the dowel bar slot.

Figure 62 Placement of patching material.

Figure 63 Placing patching material adjacent to dowel bar slots.

Figure 64 Moving patching material into dowel bar slots.

Placement of patching material that causes movement (Figure 65 and Figure 66) of the dowel bar retrofit assembly should be rejected and replaced.

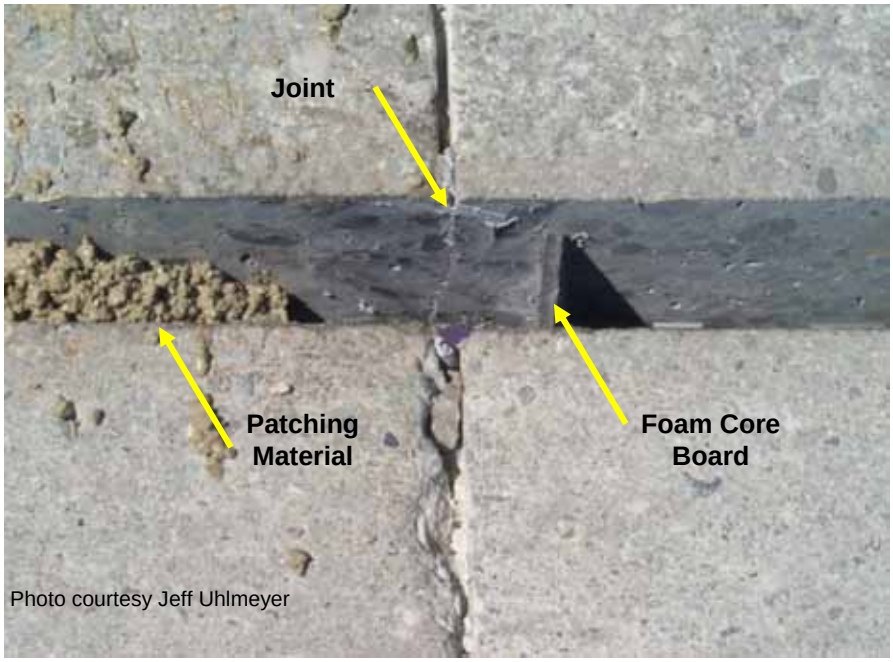


Figure 65 Movement of bar during placement of patching material.

Figure 66 Misaligned foam core board.

Patching material consolidation should be conducted with a pencil (or similar) vibrator (Figure 67). Care must be taken to not relocate the dowel bar retrofit assembly during consolidation.

Figure 67 Consolidating patching material.

Figure 68 and Figure 69 illustrate patching material voids in the vicinity of the dowel bar. The core shown in Figure 68 was taken from the first dowel bar retrofit project and illustrates lack of consolidation beneath the dowel bar, which could be due to aggregate size and the inability to move the aggregate around the dowel bar or lack of consolidation. Figure 69, on the other hand, was taken from a more recent project (2006) and shows lack of consolidation around and above the bar. In this case, it was determined that the aggregate gradation was too large to adequately fit around the bar and WSDOT modified specifications to allow only AASHTO Grading No. 8 (prior to this project, either AASHTO Grading No. 7 or 8 was allowed).

Figure 68 Poor consolidation beneath bar.

Figure 69 Poor consolidation around bar.

During the finishing process, care should be taken to not overwork the patching material (Figure 70 and Figure 71). Overworking can lead to segregation and floating of the fine material to the surface of the dowel bar slot. The fine material is susceptible to wear, especially when subjected to studded tires. Patching material should be left ⅛ inch to ¼ inch high (Figure 72 and Figure 73), which will be removed during the diamond grinding process.

Figure 70 Finishing patching material.

Figure 71 Finishing patching material.

Figure 72 Patching material should be left high to prevent overworking

Figure 73 Patching material left high to minimize segregation.

Curing compound should be applied (Figure 74) to the patching material as soon as possible after the finishing operation.

Figure 74 Applying curing compound.

Establishing the transverse joint within the dowel bar slots (Figure 75) should be conducted within 24 hours after placement. If the transverse joints were originally constructed with a tape joint and the joint is uneven (Figure 76), the transverse joint should not be sawcut. In this situation, sawcutting a straight line would be challenging without creating slivers that would eventually spall.

Figure 77 illustrates damage caused by mechanically sweeping the roadway prior to the patching material reaching the required strength. As before, the methodology for repairing this distress is to saw cut, remove and replace two to three inches of the distressed material.

Figure 75 Establishing joint in patching material.

Figure 76 Transverse tape joint (original construction).

Figure 77 Mechanical sweeping prior to patching material reaching strength.

Studded tire wear is one of the more predominant distresses affecting pavement (both HMA and concrete) performance in Washington State. For dowel bar retrofit, the largest impact of studded tires is wear in the dowel bar slot (Figure 78 and Figure 79).

Figure 78 Wear due to studded tires.

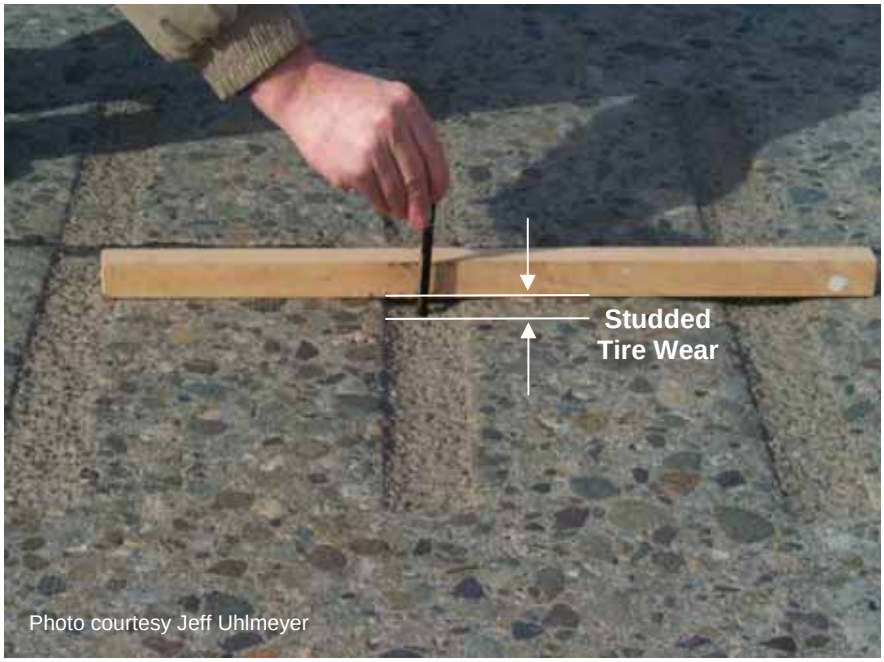


Figure 79 Wear due to studded tires.

Diamond Grinding

Diamond grinding (Figure 80 through Figure 82) should begin within 10 working days of placing dowel bar retrofit patching materials. The primary reason for this specification is to minimize traveler complaints related to intentionally leaving dowel bar patching material high.

Figure 80 Diamond grinding equipment.

Figure 81 Diamond grinding equipment.

Figure 82 Diamond grinding equipment.

Slurry Removal

Removal of the grinding residue from the roadway surface should occur immediately after grinding. Slurry should not be allowed to drain across open traffic lanes and shoulders. Slurry should not be allowed to drain into any waterway, placed on the roadway slope within 200 feet of any waterway, or other areas as designated by the Engineer.

The agencies environmental section should be consulted during the dowel bar retrofit design regarding concrete slurry removal. Some projects will allow slurry to be placed on the roadway slopes while some areas, depending on environmental requirements, will require that the slurry be deposited (and treated as necessary) off site.

Reseal Joints and Cracks

Research studies have been conducted for determining the benefits of resealing concrete joints. There will be no attempt to determine the economic benefits of joint resealing in this document, however, it is recommended that all joints and cracks be cleaned and sealed following the diamond grinding process. The primary reasons are to remove any debris and diamond grinding slurry from joints and cracks and to minimize the amount of water and incompressibles from entering the pavement structure through the joints and cracks.

Completed Product

Figure 83 and Figure 84 illustrate successful completion of the dowel bar retrofit process.

Figure 83 Completed roadway.

Figure 84 Close-up of completed dowel bar retrofit.