CONCRETE PAVEMENT REHABILITATION

Guide for Load Transfer Restoration

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Concrete Pavement Rehabilitation

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1.0 INTRODUCTION

Load transfer is the ability of a joint or crack in a concrete pavement to transfer load from one slab to the next through shear action. Load transfer influences the magnitude of deflections in the slabs under loading and the distribution of stresses in the slabs. Good load transfer improves concrete pavement performance in several ways, including:

- Reducing tensile stresses in concrete, thus reducing potential for cracking and corner breaks;
- Reducing corner deflections, thus reducing pumping and faulting development; and
- Reducing differential deflections, thus reducing reflection crack deterioration in overlays.

Load transfer restoration (LTR) is a rehabilitation technique for increasing the load transfer capability of existing jointed portland cement concrete (PCC) pavement by placement of dowel bars or other mechanical devices across joints and/or cracks that exhibit poor load transfer. The following aspects of load transfer restoration are presented in this document:

- Selection of candidate projects for load transfer restoration,
- Design and material considerations,
- Construction steps,
- Performance, and
- Costs.

2.0 SELECTION OF CANDIDATE PROJECTS

Load transfer restoration is well suited for jointed concrete pavements that have poor load transfer at joints and/or cracks but also have significant remaining structural life and little, if any, joint and crack deterioration related to poor concrete durability. An example is a pavement with a structurally adequate slab thickness but a significant loss of load transfer due to lack of dowels, poor aggregate interlock and/or erosion of base/subbase/subgrade support at the joint. Such pavements exhibit excessive faulting at joints and/or cracks. A second example is a relatively young pavement that, because of insufficient slab thickness, excessive joint spacing, inadequate steel reinforcement at mid-panel cracks, and/or inadequate joint load transfer, is at risk of developing faulting, working cracks, and corner breaks unless the joint or crack load transfer is improved.

Pavements that have little remaining structural life, as evidenced by a substantial amount of slab cracking, are not good candidates for load transfer restoration or other non-overlay restoration techniques. Even if the existing cracking is repaired, additional fatigue cracking will develop relatively soon, and the remaining time before the pavement will require a structural overlay may be so short that restoration is not a cost-effective rehabilitation option.

An exception is a pavement to be overlaid with either bonded PCC or AC. The joints and cracks with medium- or high-severity spalling should be repaired with full-depth concrete. Retrofit load transfer devices could be installed at joints and cracks with poor load transfer but otherwise little or no deterioration. The load transfer retrofit would reduce differential deflections at the joints and cracks and slow the rate of reflection crack propagation and deterioration, extending the performance life of a given thickness of overlay or permitting a thinner overlay for the same design life. Sawing and sealing joints in the AC overlay directly above the joint in the PCC slab has been found to be an effective rehabilitation technique to minimize reflective cracking distress.

Load transfer restoration can also be done at joints or cracks under an existing AC overlay, if the AC is first milled off completely or in the vicinity of the joints and cracks to be repaired. The AC must be milled off for a sufficient length to permit the saw to move forward parallel to the surface of the concrete slab. It may be more efficient to mill off the existing AC overlay entirely prior to retrofitting the load transfer devices, and then diamond grind the surface or replace the overlay, if necessary. Some older concrete pavements that were in good structural condition were overlaid only because they were faulted. Restoring load transfer to a pavement with an existing AC overlay should only be considered if the underlying joints and cracks are known to be in good condition with little or no spalling. This could be investigated by coring through selected joints and cracks.

Pavements exhibiting D-cracking are not good candidates for load transfer restoration because the concrete in the vicinity of the joints and cracks is likely to be weakened and thus retrofit load transfer devices would not have sound concrete on which to bear. For D-cracked pavements with concrete deterioration only in the vicinity of joints and cracks, full-depth repair is more appropriate than load transfer restoration.

Pavements with distress caused by alkali-silica reaction (ASR) or alkali-carbonate reaction (ACR) are not good candidates for load transfer restoration either. Reactive aggregate distress occurs in pavements in which certain types of siliceous or carbonate aggregates react with the alkalies in portland cement, producing a gel product that expands in the presence of water and fractures the cement matrix, eventually producing visible cracking in the slab. As with D-cracking, the concrete in the vicinity of joints and cracks is likely to be weakened and the retrofit load transfer devices would not have sound concrete on which to bear. However, it is unlikely that a pavement with alkali-aggregate reaction would be considered for load transfer restoration. The expansion of the gel causes expansion of the entire slab, causing the joints to close and possibly also resulting in spalling, shattering, or blowing up of the joints due to excessive compressive stress in the slab. Such pavements are not likely to exhibit poor load transfer.

2.1 Measuring and Interpreting Load Transfer

At any given time, the degree of deflection load transfer varies from joint to joint and crack to crack along a project. It also varies over time as the pavement experiences daily temperature and seasonal temperature and moisture fluctuations. Thus, the load transfer should be measured to identify which joints and cracks need load transfer restoration; this measurement should be done under temperature conditions that permit a realistic assessment of the load transfer capability.

Heavy-load deflection testing devices such as the Falling Weight Deflectometer (FWD) are well suited for deflection load transfer measurements. These and other nondestructive deflection testing (NDT) devices are capable of simulating truck wheel loads [e.g., 40 kN] applied in the outer wheelpath on each side of a joint or crack and measuring the resulting deflections on both sides. The loads and deflections are measured by sensors and recorded by a computer in the tow vehicle. Load transfer measurement with an FWD or similar device is a rapid and efficient operation, capable of covering at least a few miles of pavement per day, depending on the joint spacing. The testing machine must be protected by traffic control in the lane being tested.

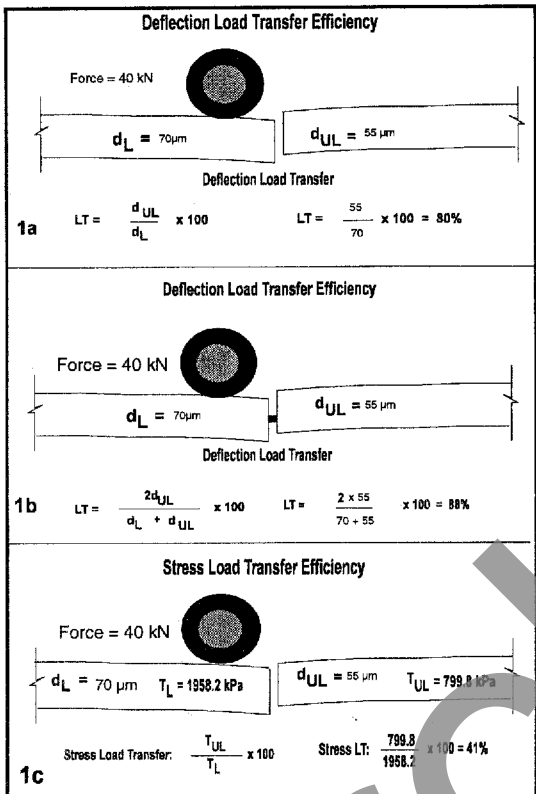


Figure 1. Definition of deflection and stress load transfer efficiency.

If an FWD or similar NDT device is unavailable, deflection load transfer may also be measured using a truck with an 80-kN axle load and two Benkelman beams (or preferably one Benkelman beam with two dial gauges). The Benkelman beam would be positioned on the shoulder with one dial gauge on each side of the joint or crack. The difference in deflections would be read with the load first on the approach side and then the leave side. The lower deflection load transfer ratio would be recorded. This is much less efficient than FWD testing because it requires time to set up the beam and/or gauges at each joint and crack and time to view the dial gauges and manually record the deflections.

One common way in which the load transfer capability of the joint or crack may be expressed is by the ratio of the deflection of the unloaded side of the joint or crack to the deflection of the loaded side, expressed as a percentage (illustrated in figure 1a):

$$\Delta LT = (\Delta_{ul}/\Delta_{l}) \times 100 \text{ where,}$$

ΔLT = deflection load transfer.

Δ_{ul} = unloaded side deflection.

Δ_{l} = loaded side deflection.

Some agencies define deflection load transfer as the unloaded side deflection divided by the sum of the loaded side and unloaded side deflections (see figure 1b). Other agencies may choose to characterize the load transfer capability of the joint or crack by the differential deflection, i.e., the difference between the deflections of the loaded and unloaded sides.

Sometimes a bending correction factor is applied to the Falling Weight Deflectometer deflection load transfer computed as shown in the above equation. The bending correction factor is intended to account for the fact that the ratio of the load plate sensor deflection and the nearest sensor deflection would not be 1.0 even at the interior of the slab. This factor is computed as the ratio of the load plate sensor deflection to the nearest sensor deflection from typical slab interior basin tests, as illustrated in figure 2. Some difference of opinion exists on whether or not the bending correction factor is necessary.

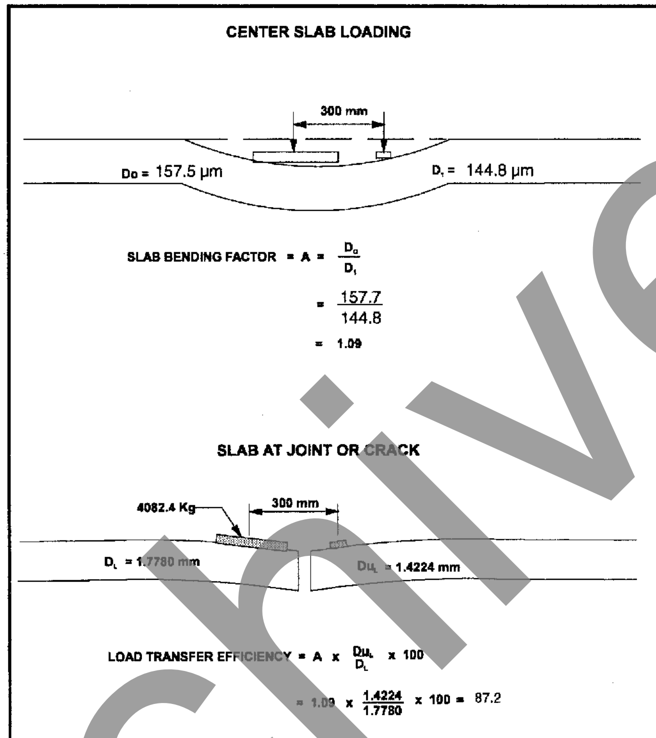


Figure 2. Slab bending factor calculation and LTE adjustment.

The deflection load transfer at any joint or crack varies throughout the day as the slab temperature changes. The relationship of deflection load transfer to temperature is an S-shaped curve approaching 100 percent at high temperatures and approaching a minimum value that theoretically could be 0 but is often about 20 to 40 percent at low temperatures. Deflection load transfer should be measured during times of the day and the year when the joints are not closed completely due to slab expansion. This is generally true at ambient temperatures of about 21°C or less.

In addition, for pavements with stiff treated bases it may be advisable to avoid testing when the slabs are curled up, i.e., at night when the top of the slab is significantly cooler than the bottom. If the slab corners are not in contact with the underlying base, the deflections will be exceptionally high. Therefore, especially during the summer and fall months, the best times to do load transfer testing are usually in early morning and late afternoon, when the slabs are flatter and the temperatures are not too high.

The deflection load transfer computed from NDT measurements is related to the stress load transfer capability of the joint or crack (figure 1c). An approximate illustration of the relationship of deflection load transfer to stress load transfer is shown in figure 3. The actual relationship of deflection load transfer to stress load transfer is a function of the radius of the contact area, the thicknesses and stiffness of the slab and base, and the stiffness of the subgrade. In general, a given deflection load transfer corresponds to a substantially lower stress load transfer. For example, for the FWD load plate radius or

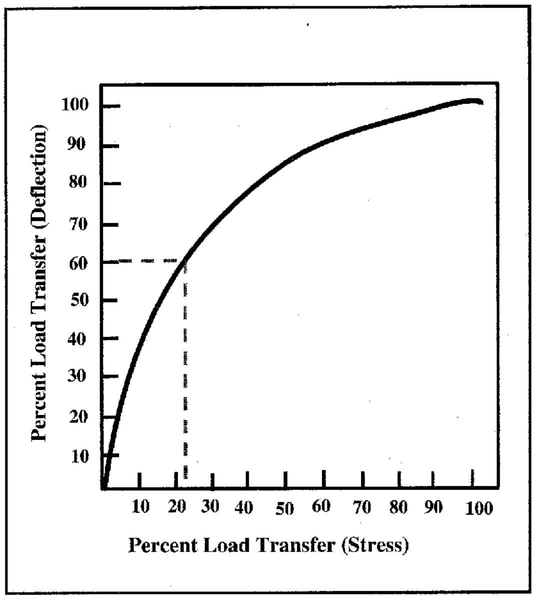


Figure 3. Approximate relationship between deflection and stress load transfer efficiency.

a typical truck wheel contact radius, a deflection load transfer of 60 percent may correspond to a stress load transfer of about 22 percent. This means that the stress induced in the loaded slab by the load is 78 percent or more of the maximum possible free edge stress and only 22 percent or less of the stress is being transmitted to the adjacent slab. For this reason, retrofit load transfer should be considered for joints or cracks having 60 percent or less deflection load transfer.

In some cases the magnitude of corner deflections is high and the computed deflection load transfer is also high. This indicates that support has eroded under the slab at both sides of the joint but shear transfer across the crack face has not diminished significantly. This condition may cause water and fines to pump up through the lane-shoulder joint and may eventually result in corner breaks on both sides of the joint. This is an indication of an inadequate slab thickness and/or excessive erosion of support, but not inadequate joint load transfer. Such a pavement may benefit from both undersealing and load transfer restoration in terms of extended service life.

2.2 Condition Indicators

The following conditions have been identified as indicators that an individual joint or crack would benefit from load transfer restoration:

- Deflection load transfer of 60 percent or less.
- Faulting greater than 2.5 mm.
- Differential deflection of 250 µm [10 mils] or more.

In addition, because the effect of a given magnitude of faulting on ride quality varies with joint spacing, a total faulting level of 500 mm/km or more has been suggested as a project-level indicator of excessive faulting that may warrant load transfer restoration.

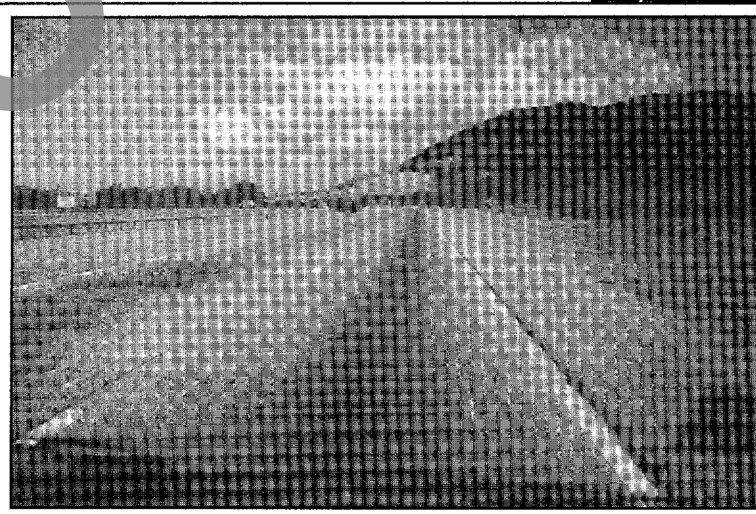


Photo 1. Hundreds of lane kilometers have been restored in Puerto Rico since 1983.

2.3 Applicability of Load Transfer Restoration by Pavement Type

In jointed plain concrete pavement (JPCP), joints constructed without dowels may need load transfer improvement, depending on the volume of heavy truck traffic the pavement carries. Midslab cracks of any severity may need load transfer improvement, because this type of slab does not contain reinforcing steel so the crack may deteriorate quickly as aggregate interlock at the crack face is eroded. However, the presence of a non-erodible base course will reduce the rate of faulting development.

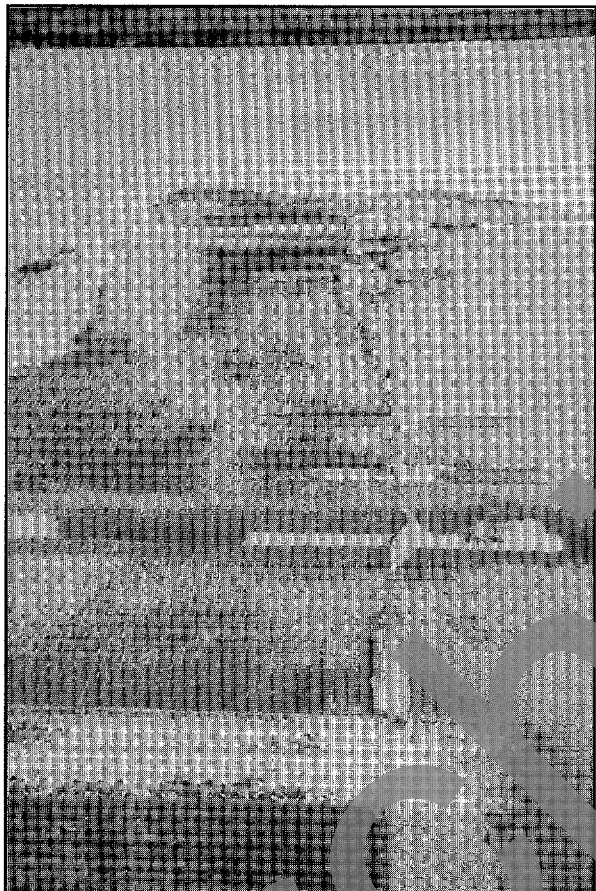


Photo 2. Load transfer restoration of working cracks in JRCP on I-70 near Abilene, Kansas. (1994)

Jointed reinforced concrete pavement (JRCP) is constructed with doweled joints. However, load transfer restoration has been applied successfully to either existing doweled joints or transverse mid-panel cracks due to inadequate slab steel reinforcement. Transverse cracks of low severity (i.e., with no spalling or faulting) do not need load transfer improvement unless that design has a history of developing mid-panel working cracks. Medium- and high-severity cracks, at which the reinforcing steel is probably deformed or ruptured and at which the aggregate interlock at the crack face has eroded to some degree, will need load transfer improvement.

Load transfer restoration has not yet been done on continuously reinforced concrete pavement (CRCP). If considered for CRCP, the same crack severity guidelines as are used for JRCP would also apply. The slots would have to be constructed between existing longitudinal bars with the same amount of concrete cover (not necessarily mid-depth of the slab) over dowel bars as over the existing longitudinal bars provided a minimum cover of at least 50 mm, and preferably 75 mm is available.

2.4 Concurrent Restoration Activities

When load transfer restoration is done as one of several concrete pavement restoration techniques, it should be done after all necessary work such as partial-depth repairs, full-depth repairs, slab replacements, undersealing at joints and cracks, and/or installation of retrofit edgedrains. Work that should be done after load transfer restoration includes diamond grinding, joint resealing, and crack sealing. Normally all of the restoration work on a project is done under a single contract.

3.0 DESIGN AND MATERIAL CONSIDERATIONS

3.1 Load Transfer Restoration Devices

Although several different types of devices have been used to restore load transfer across joints and cracks in existing pavements, smooth round dowel bars are recommended because of their proven long-term performance and cost-effectiveness. Smooth dowel bars provide shear load transfer while also permitting horizontal opening and closing of the joint or crack in response to daily and seasonal temperature and moisture fluctuations. The dowels, including the ends, must be protected from corrosion, usually by an epoxy coating. The dowels must also be coated with an effective bondbreaker such as concrete form oil. The dowel bars should be fitted on both ends with expansion caps that will allow at least 6 mm of horizontal movement at each end (13 mm expansion caps are recommended if only one cap is used). They should be mounted on chairs so that the backfill material can flow around and fully support the dowel. A joint-forming insert is also needed to reestablish the joint through the backfill material and to prevent the backfill material from flowing down into the crack below the joint sawcut or into the sides of the joint or crack. This will also allow for some future expansion room if the joint or crack is not tightly closed and will prevent compression failures or debonding of the patching material during subsequent hot weather. A typical retrofit dowel bar assembly is illustrated in figure 4.

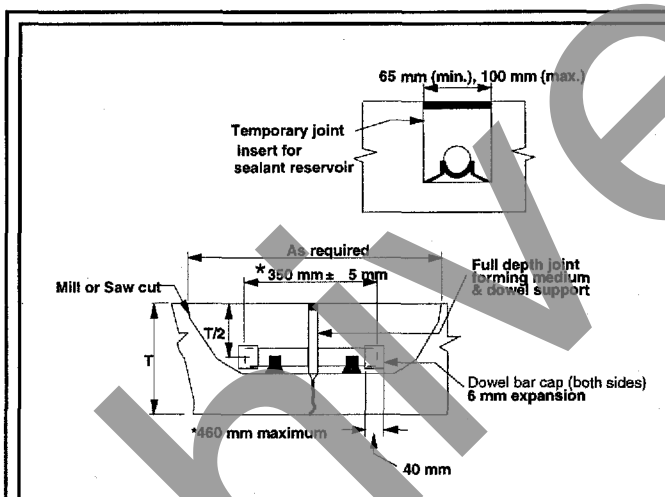


Figure 4. Dowel bar load transfer assembly.

Other devices that have been used for load transfer restoration include double-V shear devices, miniature I-beams, and deformed reinforcing bars. The latter are only appropriate for tying joints and cracks together to prevent horizontal movement, i.e., longitudinal joints and cracks. Smooth, round dowel bars are the most commonly used and reliable retrofit load transfer devices.

3.2 Dowel Diameter and Layout

The design of the retrofit dowel layout includes the number, diameter, and spacing of the dowel bars., Using large-diameter dowel bars, many dowel bars, and/or dowel bars spaced closely together will serve to reduce the bearing stresses of the dowels on the concrete. Lower dowel bearing stress reduces the development of dowel looseness, which reduces the potential for faulting. One study determined that stresses and deflections for a joint with 6 dowels (3 in each wheelpath) were similar to stresses and deflections for a joint with 12 uniformly spaced dowels.[1] It is expected that concentrating retrofitted dowels in the wheelpaths should provide adequate performance for the shorter service life expected from a rehabilitated pavement.

Reference 2 offered the following recommendations for retrofitted dowel bar design:

1. Dowel diameter should be at least 32 mm, although 38-mm-diameter dowels are recommended. Larger-diameter dowels are more effective in reducing faulting and should be used on most high-volume pavements (i.e., 0.5 million or more 80-kN ESALs per year in the outer lane).
2. Dowels should be at least 350 mm long.
3. Three to five dowels spaced 300 mm apart should be used in each wheelpath.
4. The outermost dowel should be no more than 300 mm from the outer lane edge.

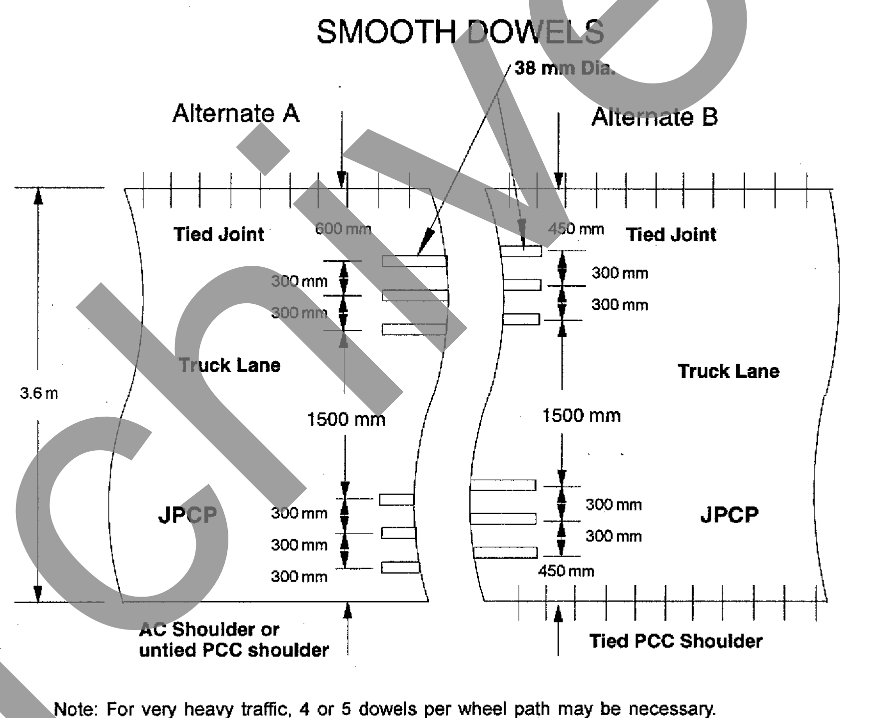


Figure 5. Recommended retrofitted dowel design.

Research indicates that 150-mm dowel embedment on each side of the joint or crack will provide adequate long-term load transfer. Therefore, allowing for the expansion cap(s) and considering some placement tolerance, a minimum length of 350 mm is recommended. For pavements with poor support conditions, slightly longer dowels should be considered to increase reliability due to the relatively small increase in cost.

Recommended layouts for retrofitted dowels with and without tied PCC shoulders is depicted in figure 5. [2] The dowel bars, including the ends, should be epoxy coated for corrosion resistance. The first dowel should be placed no more than 300 mm from the edge of the truck lane when there are asphalt shoulders. If tied concrete shoulders with high deflection load transfer are present, the distance from the first dowel bar to the longitudinal joint can be increased to a maximum of 450 mm. This will also help avoid cutting the existing tie bars.

Retrofitting load transfer across longitudinal joints and cracks has not yet been done. It could be done using dowels or using deformed reinforcing bars if movement is not desired. In the latter case, expansion caps and bondbreaker should not be used . The equipment currently used for sawing slots for retrofit load transfer across transverse joints and cracks may require modification for use on longitudinal joints and cracks. This modification would be needed to minimize encroachment into the adjacent traffic lane on roadways where traffic must be maintained during rehabilitation.

3.3 Backfill Materials

Research indicates that the success or failure of a retrofit load transfer system depends upon the performance of the load transfer device, the preparation of the slot faces to ensure good bonding, and the long-term performance of the backfill material. [3] The backfill material must have little or no shrinkage, must rapidly develop sufficient strength to carry the required traffic loads within a reasonable length of time, and accommodate the thermal stresses caused by daily curling of the slab. The thermal coefficient of expansion of the backfill material should be similar to that of the existing concrete. Good performance of the backfill also depends on its achieving a strong bond with the existing concrete. Several types of backfill materials have been used with retrofit load transfer devices. In general, materials that perform well in partial-depth repairs should also work well for load transfer restoration. [4]

Nonproprietary backfill materials typically use Type III cement for high early strength with calcium chloride to accelerate setting. Where corrosion is a problem, non-chloride accelerators should be used. Minimal backfill shrinkage is essential because excessive shrinkage can cause debonding of the backfill from the existing concrete. A low water-cement ratio, in combination with a water-reducing admixture to allow the material to flow well around the dowel assembly, will help to minimize shrinkage. Proper curing is essential. In some retrofit dowel installations, aluminum powder has been used to counteract shrinkage. However, the reactivity of aluminum powder can be difficult to control in field proportioning, particularly in small batch operations. An alternative is a shrinkage-compensating cement (ASTM C 150, Type K). Note, however, that high-alumina cement is **not** recommended as it is susceptible to a conversion of some of its calcium aluminate hydrate components, which may result in a significant strength loss.

Several proprietary materials are also available for use as a backfill material for retrofit dowels. These materials generally are quick-setting, low-shrinkage,and pre-blended under controlled conditions and tested for quality assurance. These products generally have performed satisfactorily in laboratory testing and field applications. It is strongly recommended that all materials without past satisfactory performance be tested in the laboratory for specification compliance **before being used in the field.**

Among the backfill material properties that should be considered are compressive strength, flexural strength, bond strength, modulus of elasticity, scaling resistance, abrasion resistance, thermal compatibility, shrinkage, and freeze-thaw resistance. References 4, 5, 6, and 7 present laboratory test results from several organizations on a variety of different proprietary products and include suggested specifications. AASHTO is establishing a National Transportation Product Evaluation Program for "Rapid Setting Patching Materials for Portland Cement Concrete," which is also a potential source of information. [12]

The State of Washington tried using mobile batch trucks for mixing the backfill material. Due to the relatively small quantities involved, the concrete was poorly mixed and of inconsistent quality when using this equipment. Washington State is no longer recommending mobile batch mixers for mixing backfill material on their retrofit load transfer projects.

3.3.1 General Requirements for Rapid Set Materials

The following guidelines provide information on those factors considered important for filler (patching) material for retrofit load transfer. [6]

Neat Material

- Compressive Strength, 3 hr, minimum 21 MPa - ASTM C-109
- Compressive Strength, 24 hr, minimum 34 MPa - ASTM C-109
- Abrasion Loss, 24 hr, maximum loss 25 grams - California Test 550
- Final Set Time - minimum 25 minutes
- Shrinkage, 4 days, 0.13 percent maximum - ASTM C-596
- Soluble Chlorides, maximum 0.05 percent - California Test 422
- Soluble Sulfates as SO_4, maximum 0.25 percent - California Test 417

Maximum Extended Material

- Flexural Strength, 3.4 MPa, 24 hr, California Test 551
- Bond to Dry PCC, 2.8 MPa, 24 hr, California Test 551
- Bond to SSD PCC, 2.1 MPa, 24 hr - California Test 551
- Absorption, 10 percent maximum - California Test 551

4.0 CONSTRUCTION STEPS

Dowel bar retrofitting consists of five construction steps:

1. Cutting the slots,
2. Preparing the slots,
3. Placing the dowel bars,
4. Backfilling the slots, and
5. Opening to traffic.

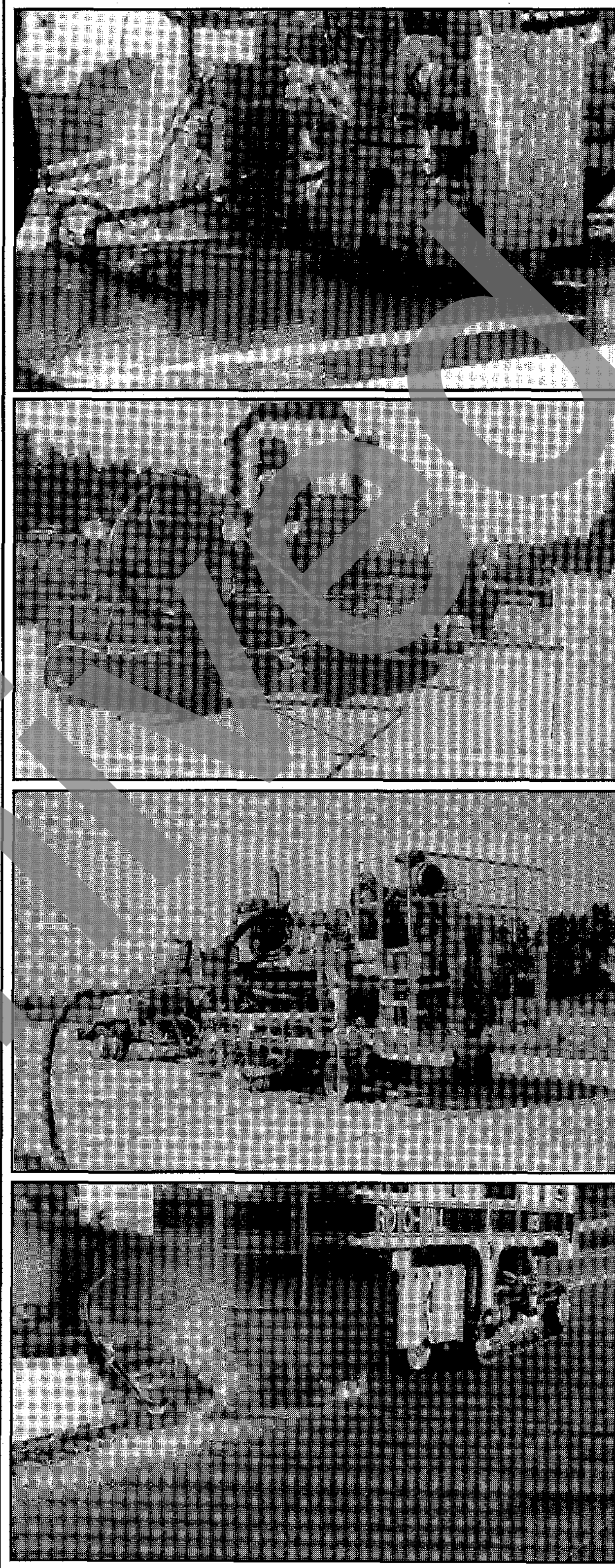
4.1 Cutting Slots

Two types of equipment have been developed to quickly and efficiently cut slots for dowel bar retrofitting: diamond saw slot cutters and modified milling machines. Advancements in the development of slot cutting equipment have greatly improved their efficiency. The diamond saw slot cutter is more commonly used; the modified milling machine has been used less frequently.

Regardless of the type of equipment used, the specifications must require:

1. A positive method of assuring slots are aligned parallel to centerline, and maximum allowable variations.
2. A vacuum system to remove saw slurry or milled concrete, and
3. The maximum amount of spalling allowed on the edges of the slots (this is not critical due to the fine patching material and that retexturing of the surface should also be performed).

Diamond saw slot cutters make two parallel cuts for each dowel slot, leaving a fin of concrete in between that must be broken out after the sawing. Machines exist that can cut either three or six slots (in one or two wheelpaths) at the same time. The saw head is placed before the joint or crack, plunged into the concrete, and advanced across the joint or crack. Typically the saw operator must make more than one pass to get the slot to the required depth. The slot must be long enough that the dowel will lie across the bottom of the slot without the ends hitting the curve of the saw cut.



Photos 3 to 6. Equipment available to construct multiple slots for load transfer restoration.

This typically requires the surface length of the saw cut to be 1 m for a 350-mm-long dowel bar. After the slots are cut, traffic can be permitted on the pavement, but should be limited to 2 to 3 days. After that the fins should be removed, the dowel placed, and the slot backfilled. Sometimes, for constructability reasons, light weight vehicular traffic on pavements with cut slots can be permitted for up to 1 week. No work on the adjacent lane should be allowed while traffic is on lane with cut but unrepaired slots. Cracking of the corners of the sawed but unrepaired slots has been a problem in at least one State.

When the slots are formed by a modified milling machine, the milling head is placed before the joint or crack and plunged into the concrete and moved forward across the repair area. The length should be the same as for sawcut slots. The advantage of milling is that it creates the slot in one pass and does not leave concrete fins to be removed. However, because milling creates open slots, traffic cannot be permitted back on the pavement until the entire dowel retrofitting process is complete. Some agencies have raised concerns about the milling process causing microcracking at the slot edges and fractures at the joint or crack faces, which may decrease the long-term durability of the dowel retrofit. Others believe the rougher milled face provides a better bonding surface than the smoother diamond sawed face even after sandblasting. Additional studies are currently underway to investigate these concerns. Attempts to mill slots in concrete with granitic coarse aggregates in Minnesota in 1996 were unsuccessful. However, this process has been used experimentally in Indiana and on regular construction projects in New Jersey before asphalt overlays, and West Virginia at mid-panel cracks. [14]

It is essential that the slots are cut parallel to the centerline of the pavement. This keeps the dowels in proper alignment and prevents them from locking up and tying the slabs together. The width of the slot is typically between 65 and 100 mm and the depth is slightly greater than half of the slab thickness, so that when dowels placed in slots on chairs will be at approximately the mid-depth of the slab. Additional research is recommended to determine if the dowels can be placed closer to the surface and still perform satisfactorily.

4.2 Preparing Slots

Preparation of slots constructed with diamond saws consists of removing the concrete fins, flattening the bottom, slot cleaning, and caulking the joint or crack in the slot. Small hand-held jackhammers (15 kg or less) should be used to remove the fins. Larger jackhammers may break through the concrete. If the concrete is broken, the joint or crack will require full-depth repair.

One technique for removing concrete fins is to place the jackhammer at the end of the fin and jackhammer down and along the bottom of the saw cuts. Another is to place the jackhammer along the side of the slot and break off the fin. Either way, with some practice, most workers can remove the fin in two or three large pieces. Once the fin is removed, the bottom must be flattened with a small hammerhead on a small jackhammer. This removes the rocks and burrs from the slot bottom and provides clearance for the dowel. Rocks or burrs along the bottom can keep the dowel from lying level and can interfere with proper dowel alignment. They also can prevent the backfill material from completely encasing the dowel bar. Improper dowel alignment and/or incomplete encasement can cause early failure of the retrofit. If the dowels are misaligned, the joint or crack will not be able to open and close in response to temperature changes. Such joint locking may crack or spall the concrete. If the backfill material does not completely support the dowel, the dowel socket may become elongated vertically at the face of the joint, which will contribute to loss of load transfer.

The slot must be clean before the dowel and backfill material are placed. If the slot is not clean, the backfill material will not bond well to the bottom and sides of the slot. Slot cleaning consists of sandblasting to remove sawing slurry and roughen the sides to improve the bond, and then airblasting the slot sides and bottom to remove any loose debris. If touching the slot sides or bottom with your fingers reveals that dust or laitance is still present, the slot must be recleaned.

If a milling machine is used to create the slots, the slot must be cleaned and the joint or crack must be caulked. Additional study is underway to determine if sandblasting is needed for milled slots.

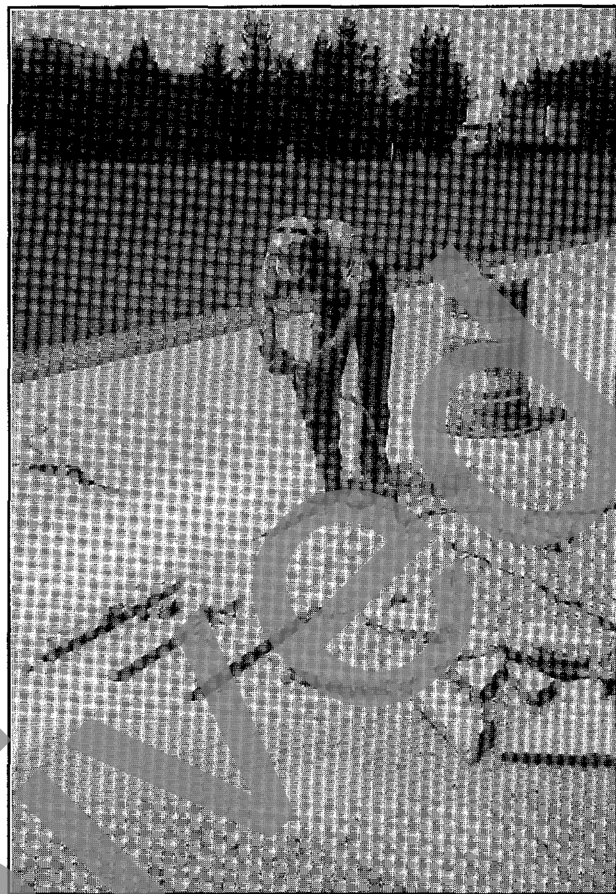


Photo 7. Flattening bottom of slot.

The final step in slot preparation is caulking the joint or crack on the bottom and sides of the slot. This keeps the backfill material from flowing down into the joint or crack. If the backfill material enters the joint or crack, it can later inhibit slab expansion and contribute to joint spalling or blowups or compression failure of the backfill material.

4.3 Placing Dowel Bars

The dowels used for dowel bar retrofit are the same as are used in new concrete pavement construction, with a few modifications. They should be at least 350 mm long to allow for some variation in joint or crack width and provide at least 150 mm of dowel on each side of the joint or crack. The typical dowel length in most retrofit projects has been 450 mm. The dowel diameter is typically 32 or 38 mm, depending on the slab thickness and amount of heavy truck traffic.

Before the dowel is placed in the slot it should be fitted with a 6-mm, non-metallic or epoxy-coated expansion cap on both ends, a Styrofoam or fiberboard joint insert, and chairs that may be either non-metallic or epoxy-coated. The chairs are used to hold the dowel at least 13 mm above the bottom of the dowel slot so that the backfill material may flow completely under the dowel. Non-metallic or epoxy-coated expansion caps and chairs are recommended to minimize the potential for corrosion.

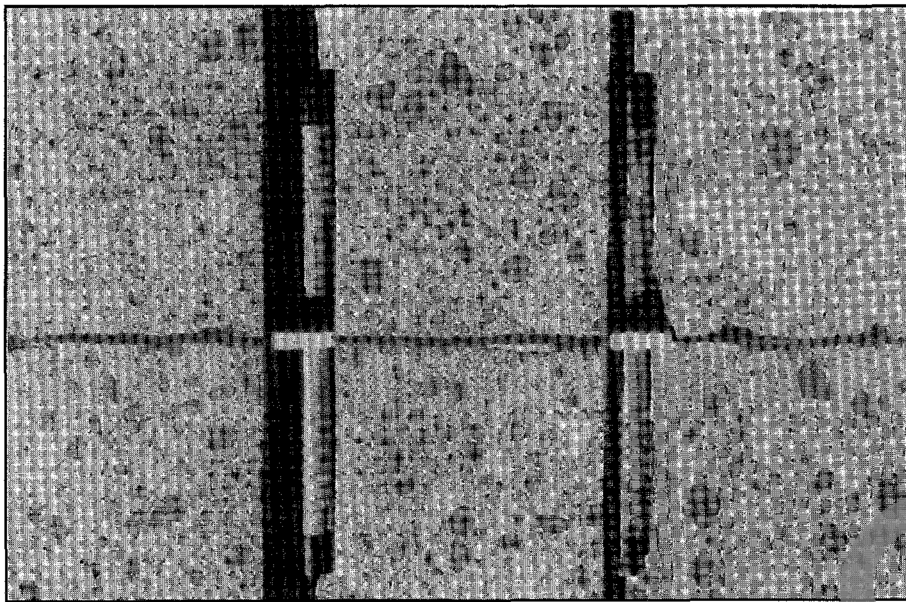


Photo 8. Dowels in place ready for concrete placement.

It is also very important that the dowel is coated with an effective debonding agent such as form oil or light grease so that it can move horizontally after the backfill material has hardened. This must be done before the dowel is in place. Care must be taken to prevent the bondbreaker from falling onto the slot sides or bottom, as this will prevent the backfill material from bonding to the concrete. Some agencies have tried plastic sleeves over the dowels instead of grease or a similar bondbreaker. Sleeves are not recommended because they may build in additional dowel looseness, which diminishes load transfer. For the same reason, the coating of grease on the dowel should not be excessively thick.

The dowel should be inserted so that the chair legs are in the sawcut kerfs or milled edges at the bottom of the slot. This maintains proper dowel alignment by keeping the dowel horizontal and parallel to the pavement centerline and surface. The joint reformer should be over the joint or crack, with half of the dowel length on each side. The legs and sides of the chairs should be snug against the slot wall. This keeps the dowel from moving and becoming misaligned during placement of the backfill material.

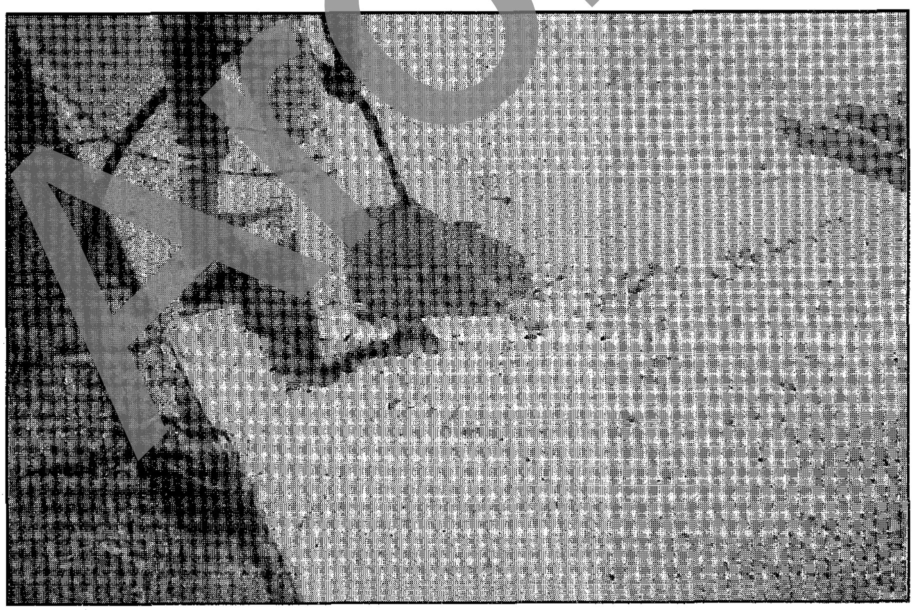


Photo 9. Consolidating the backfill material.

4.4 Backfilling

The backfill material should be placed into the slots and consolidated with a small spud vibrator. Care must be taken not to hit the dowel with the vibrator. After consolidation, a curing compound should be placed on the backfilled slots to reduce shrinkage. The finish of the patch is not critical because the dowel slots make up too small a portion of the surface area to significantly affect surface friction. Furthermore, on most projects, diamond grinding should be performed shortly after the dowel retrofitting is complete. If the pavement is to receive an overlay, this would not be necessary.

4.5 Opening to Traffic

The lane may be opened to traffic when the backfill material has gained adequate strength. Recent studies have shown that the minimum compressive strength required to open a repair to traffic is about 13.8 MPa for slabs 200 mm or thicker. Most fast-track concrete mixes and proprietary mixes can achieve this strength within 2 to 6 hours after placement. A recent dowel retrofit job in the State of Washington used a backfill material that was able to obtain 27.6 MPa compressive strength in about 2 hours. South Dakota requires a compressive strength of 27.6 MPa in 6 hours. [13]

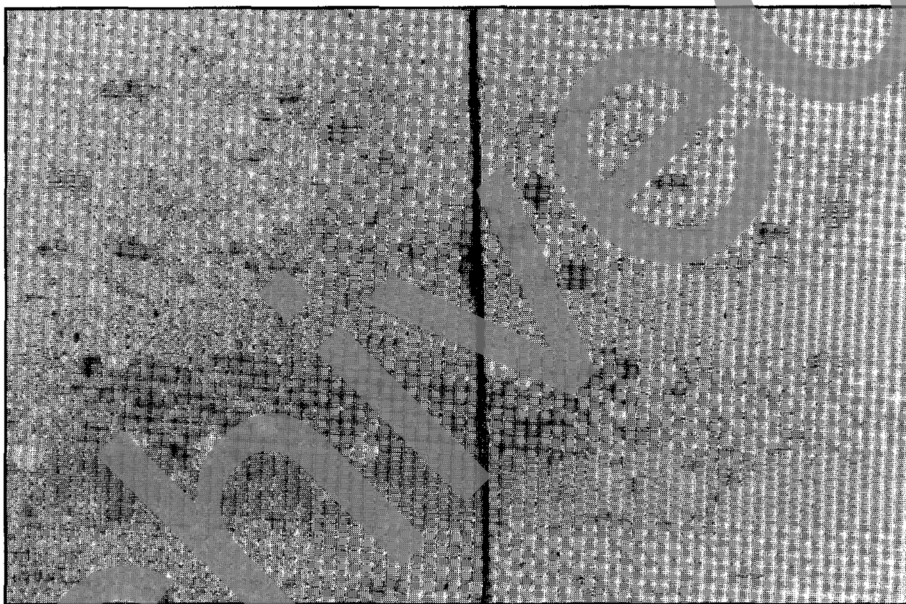


Photo 10. Completed joint.

Dowel retrofitting should be followed by diamond grinding. This removes the existing joint faulting and improves the ride quality of the roadway. Any surface imperfections of the backfilled slots are also removed by diamond grinding. It is very important to restore a smooth riding surface for road users.

5.0 PERFORMANCE

Retrofitted dowel bars generally have performed well. [2, 8] Results have shown that the dowels perform very well after up to 15 years of traffic. The effectiveness of the backfill material is not as critical as with other types of shear devices. [2, 9]

The Puerto Rico DOT has retrofitted many kilometers of roadways with dowel bars as part of their concrete pavement restoration program. A recent review of over 7000 dowel bars indicated that less than 0.5 percent of the repairs had failed. The Puerto Rico DOT used slots 41 mm wide with 25-mm-diameter dowels. [11] Each joint or crack was tested for joint efficiency and also undersealed if voids were detected. They have found that slabs placed on granular bases over plastic soils often have voids under the slab corners when the faulting is so severe as to require load transfer restoration.

A recent summary of the performance of 13 retrofit load transfer projects in 9 States found that dowel bars showed the smallest percentage of failure (debonding, material failure, or device failure) compared to other devices evaluated, and exhibited the least amount of joint faulting. [2] Only 2 percent of a total of 515 dowel bars retrofitted on the 13 projects had failed by the time the survey was conducted. The average age of the retrofit dowel projects was 3.8 years and the average ESALs was 2.6 million. Faulting of joints with retrofit dowels averaged only 1.0 mm for the 13 projects.

A recent retest of 12-to 13-year-old retrofit dowels on I-75 in Georgia showed up to 100 percent load transfer efficiency with up to 1.5 mm deflection with the load placed on each side of the joint. This is outstanding performance. [2,9]

While considered promising, the slot milling process does not have the same record of long-term performance as slot sawing. The initial testing of slot milling was conducted in November 1993 and June 1994 in Indianapolis, Indiana. The first uses of milling on regular construction projects were in 1995 on JRCP projects in New Jersey and West Virginia.

6.0 COSTS

Installation costs for retrofitted dowel bars have varied greatly, depending upon the size of the project. In recent years the price has dropped from about $100 per dowel for short experimental sections, to about $25 to $35 per dowel for routine installations. Costs vary greatly depending on the hardness of the aggregate in the existing concrete, labor wages, backfill material and total number of dowels retrofitted. Recent improvements in equipment to construct multiple slots have greatly increased productivity and reduced installation costs.

Washington State estimates that the cost for load transfer retrofitting is $40,000 less per km of 2-lane roadway than a conventional 90-mm asphalt overlay and will last 10 to 15 years. Their estimate includes slab replacement, load transfer restoration in the truck lane, diamond grinding, and joint and crack resealing. [14] For the 300 km of 2-lane roadways expected to be completed by the end of 1997, this represents a savings of $12 million.

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