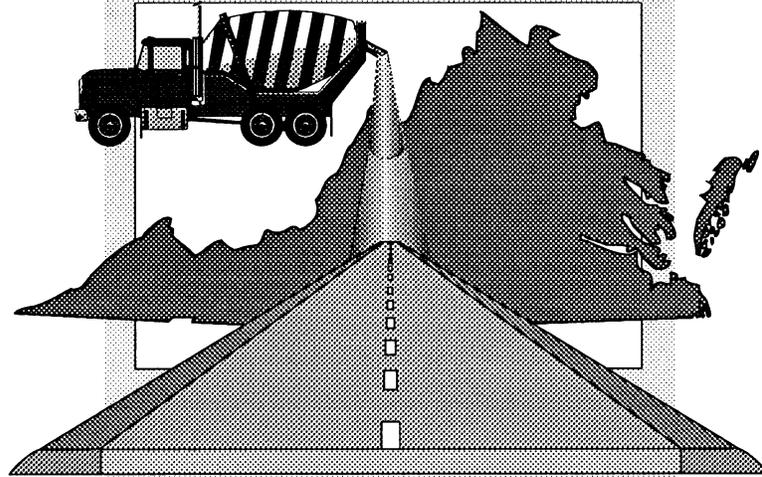


SUMMARY REPORT

# EVALUATION OF A CONCRETE PAVEMENT RESTORATION PROJECT IN VIRGINIA



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(The opinions, findings, and conclusions expressed in this  
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those of the sponsoring agencies.)

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## ABSTRACT

The purpose of this Federal Highway Administration Demonstration Project was to evaluate the installation and performance of a section of I-81 in Botetourt County, Virginia, that was rehabilitated by concrete pavement restoration (CPR) methods. The seven repair techniques used were (1) slab replacement, (2) patching, (3) slab stabilization, (4) surface grinding, (5) joint resealing, (6) subdrain installation, and (7) load transfer restoration. Although the individual repair techniques had varying degrees of success, CPR as an integrated system was generally effective in restoring the pavement's structural and functional integrity. It was recommended that the Virginia Department of Transportation routinely consider CPR as a viable alternative for pavement rehabilitation. It was also recommended that projects under consideration for restoration be carefully evaluated to ascertain whether their structural conditions render them suitable for CPR.

## **SUMMARY REPORT**

### **EVALUATION OF A CONCRETE PAVEMENT RESTORATION PROJECT IN VIRGINIA**

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#### **INTRODUCTION**

Throughout the 1980s the jointed, reinforced portland cement concrete pavements (PCCPs) in Virginia increasingly exhibited signs of deterioration. Many of the pavements were plagued with patch failures, faulting, joint spalling, slab pumping, and other distresses. At the time this study was undertaken, there were difficulties in finding effective repair strategies for these pavements. Consequently, the portion of the total lane miles represented by exposed PCCP was declining each year as repairs were deferred too long to render feasible any alternative other than overlaying with asphaltic mixtures.<sup>1</sup> However, the ability of concrete pavements to withstand today's high traffic loadings for long periods of time (often well beyond the original design life) makes it desirable to properly maintain and preserve them.

Although properly built PCCPs perform well for many years, they will eventually require major rehabilitation. Unfortunately, that time is now for many of these pavements in Virginia. The older reinforced concrete pavements, which vary in thickness from 7 to 10 in and are constructed of jointed slabs ranging in length from 30 to 61.5 ft, are those in need of immediate attention.

Historically, the Virginia Department of Transportation (VDOT) has not implemented an aggressive preventive maintenance program. A considerable amount of deficient jointed PCCP has been overlaid with asphaltic concrete. However, this rehabilitation technique has proved unsatisfactory as a result of the inherent tendency of asphaltic overlays to reflect underlying PCCP distresses; thus, the restoration of a pavement's original structural integrity has recently been considered a more worthy objective.

Concrete pavement restoration (CPR) is a rehabilitation technique in which the interaction of individual repair activities forms the basis for restoring a pavement's functional and structural integrity. CPR includes the following eight repair activities: (1) slab replacement, (2) pavement patching, (3) slab stabilization, (4) surface grinding, (5) joint resealing, (6) subdrain installation, (7) load transfer restoration, and (8) shoulder reconstruction.<sup>2</sup>

Like any other rehabilitation strategy, CPR is most cost-effective when used to treat pavements that fall within a range of conditions. The American Concrete Pavement Association calls this range a pavement's *window of opportunity* and emphasizes the need to ascertain whether the condition of a candidate for CPR falls within this range.<sup>3</sup>

## PURPOSE AND SCOPE

In response to an increasing interest in the potential of CPR as a viable rehabilitation alternative, VDOT and the Federal Highway Administration (FHWA) cooperatively undertook this study as FHWA Demonstration Project 69 (*Portland Cement Concrete Pavement Restoration*) to evaluate CPR's effectiveness in restoring the structural and functional condition of pavements. The scope of this study, the state's first CPR effort, included: (1) selecting a representative pavement in need of rehabilitation and assessing its condition prior to restoration, (2) monitoring the installation of repairs, and (3) visually evaluating the performance of the restored pavement under heavy traffic for a period of 5 years.

## METHODOLOGY

This project was executed in three phases: (1) site selection, (2) pavement condition assessment, and (3) repair installation and monitoring.

### Site Selection

A section of Interstate 81 (north and south directions) in Botetourt County, Virginia, was selected for restoration because of its high traffic volume and relatively poor structural and functional condition. This section, which is 14.55 mi in length, was originally constructed in three projects, the last of which was opened to traffic in December 1964. The average lifetime loading is 1,000 18-kip equivalent single axle loads (ESALs) per day, and the section currently supports 1,700 ESALs per day. The pavement consists of 9 in of jointed, reinforced portland cement concrete on a 2 in sand leveling course underlaid by 6 inches of crushed aggregate base material. The joint spacing is generally 61.5 ft, but there is some variability resulting from the location of bridges and previous patch repairs.

## Pavement Condition Assessment

A pavement distress survey was performed by an experienced rating team to document the overall condition of the section prior to rehabilitation. The survey also included an assessment of ride quality by measuring surface roughness in terms of International Roughness Index (IRI) with a Mays Meter mounted in a 1979 Chevrolet Impala. Results of the survey are summarized in Table 1.

Table 1  
CONDITION SURVEY

Type of Distress	Results
Joint Spalling Severity	low (spalls < 3 in wide)
Average Joint Faulting	3/16 in
Joint Faulting Range	< 1/16 in to 7/16 in
Pumping	evident in 5-10% of slabs
Joint Seal Damage	evident in 50% of slabs
Shoulder Condition	excellent
Average IRI <sup>a</sup>	159 in per mi
IRI of Roughest Mile	195 in per mi

a. The statewide average Mays IRI for PCCP is 130 in per mi.

## Repair Installation and Monitoring

The contract for this project specified carrying out seven of the eight CPR activities listed in the Introduction of this report. Reconstruction of the existing shoulders was not included in the contract because they were in excellent condition. Work began in June 1984.

### Slab Replacement

A slab was designated for full replacement if it visually exhibited moderate to severe deterioration. The slabs were sawed full depth along the transverse and centerline joints and transversely at 6-ft intervals to facilitate removal by lifting. After the exposed subbase was leveled and compacted, reinforcing steel mesh was placed on chairs designed to support the mesh at approximately the mid-depth of the slab. Undamaged steel dowel bars at adjacent joints were straightened, cleaned, and reused. Damaged dowel bars were cut with a torch and discarded. They were replaced by drilling new holes into the adjacent slabs, filling the holes with epoxy grout, and inserting new dowels. The dowels that extended into the repair area from the runoff side of the adjacent slab were lubricated with grease to permit movement of the surrounding concrete as a result of thermal expansion and contraction. Strips of preformed bituminous expansion joint filler were glued onto the exposed vertical faces of the two adjacent concrete slabs that formed the transverse boundaries of the repair area. A liquid asphalt bond breaker was applied to the exposed vertical face of the adjacent slab at the roadway centerline.

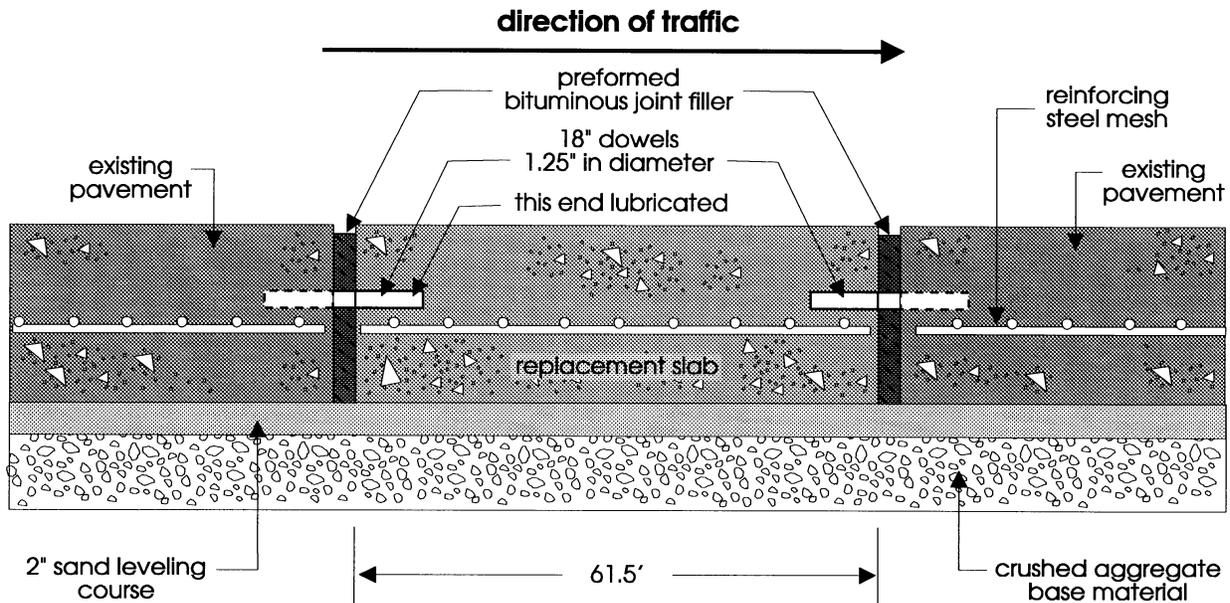


Figure 1. Profile of full slab replacement.

Concrete containing 800 lb of Type III portland cement was placed in the repair area, internally vibrated, and finished using a vibratory screed, bull float, and steel trowel. Concrete curing was accomplished by covering the repair with polyethylene sheeting. The slab replacement design is illustrated in Figure 1.

## Pavement Patching

### *Full-depth, Full-width Patches*

Pavement surfaces exhibiting severe cracks and spalls in conjunction with moderately to severely deteriorated joints were repaired by patching full-depth across the lane's entire width. Patches of this type ranged in length from 4 to 40 ft and were constructed using the inverted "T" design. The design specified the placement of concrete beneath the edges of the slabs transversely adjacent to the repair area, thereby resembling an inverted "T" in profile and providing a rigid support for transferring wheel loads from the abutting slabs to the patch. The removal of deteriorated concrete was accomplished by sawing full depth along the perimeter of the repair area and mechanically lifting the distressed material. The bottom of the repair was then excavated to accommodate the proper dimensions of the new concrete (see Figure 2). A strip of preformed bituminous expansion joint filler was glued onto the exposed vertical face of the runoff side of the adjacent slab. The preparation of the repair area, the placement of the reinforcing steel, and the materials and methods used to place, finish, and cure concrete in these patches were like those discussed previously for the replacement of complete slabs. Particular attention was given to vibrating the concrete extending beneath the transverse ends of the adjacent slabs to

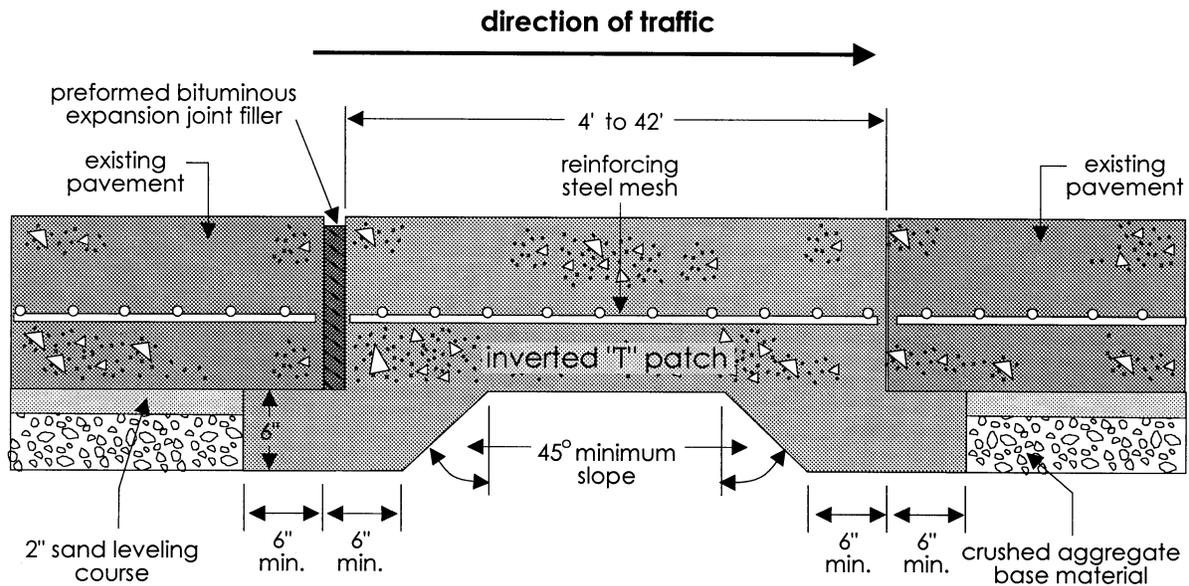


Figure 2. Profile of full-width, full-depth concrete patch.

ensure thorough consolidation. The performance of the inverted “T” patches and replaced slabs was monitored by visually examining the repairs periodically for signs of faulting, settling, cracking, and other anomalies.

### *Partial-depth Patches*

Pavement surfaces exhibiting superficial spalling were repaired by sawing (to a maximum depth of 3 in) just beyond the perimeter of the distressed area and removing the deteriorated material with a jackhammer. The repair area was then cleaned with compressed air, and all exposed surfaces were brushed with a cement slurry to facilitate bonding with the new concrete. Neither reinforcing steel nor dowels were used in the partial-depth patches. Concrete used to fill the repair areas was placed, finished, and cured as discussed in the preceding section. The performance of the partial-depth patches was monitored by conducting periodic visual examinations and documenting the type and location of distresses.

### **Slab Stabilization**

The purpose of slab stabilization is to fill voids beneath slabs that are caused by the ejection of saturated, fine-grained materials when the slab edges are displaced vertically under moving wheel loads. Such voids are also (but less frequently) the result of nonuniform settlement of the soil subgrade.

The contract called for stabilizing all slabs throughout the entire project with a flowable cement slurry. The slurry consisted of one part by weight of Type II cement to three parts of fly ash and enough water to achieve a consistency on the order of 15 sec as measured in accordance with ASTM C-995-83, *Time of Flow of Concrete Through an Inverted Slump Cone*.

A total of eight grout injection ports, 2 in. in diameter, were drilled through each slab at the corners and at uniform intervals along the slab centerline. Following the injection port drilling crew was a flatbed trailer that transported mixing water, dry cement and fly ash, a power supply, two colloidal mixing vats, a delivery vat, and a positive displacement injection pump.

Immediately after mixing, grout was pumped through a hose into a slab's injection port until one of the following occurred: (1) the monitoring gauge indicated a rise in pumping pressure, (2) grout visibly flowed out of an adjacent port or joint, or (3) the slab being stabilized began to lift as indicated by a strain gauge fixed to the Benkelman beam used to monitor this activity. At that time, a wooden plug was inserted into the filled hole, and the pumping operation moved to the next port. After the grout had hardened, the plugs were removed and the holes were patched with hydraulic cement mortar.

The effectiveness of this activity was evaluated by comparing the gross vertical deflections measured with a Benkelman beam at the transverse edges of slabs before stabilization with those deflections measured afterward. Deflections were induced by the static wheels of a dump truck loaded to 18 kips on the rear axle.

## **Diamond Grinding**

The primary objective of grinding is to restore or improve the ride quality of a pavement by removing irregularities in the surface profile. Flattening a pavement's profile also reduces the dynamic or impact loads to which the structure is subjected, thereby extending its service life. Grinding also improves skid resistance by creating a uniform, corduroy-like surface texture.

The contract called for texturing 100 percent of the pavement surface by diamond grinding. After completion of the slab replacement, stabilization, and patching, grinding was accomplished with a large diesel-driven machine onto which was mounted a 3-ft-wide cutting head composed of a series of gang-mounted diamond saw blades. The cutting head was raised and lowered as necessary in response to signals received from a profile sensor mounted on a guide arm in front of the grinder.

Since the cutting head was only 3 ft wide, four longitudinal passes were required in each lane to cover the entire surface. The water used to cool the cut-

ting head was mixed with the ground material to form a slurry, which was vacuumed from the pavement and disposed of.

The effectiveness of ride quality restoration was evaluated by comparing the Mays reading after the grinding with the project's initial Mays reading.

## **Joint Resealing**

The joint resealing component of CPR is intended to prevent the intrusion of water, incompressible materials, and deicing chemicals into the pavement structure through contraction, expansion, and construction joints. Surface water entering joints softens and erodes the foundation and may result in pavement faulting. Incompressible materials in joints cause spalling by reducing the lateral space available for thermal expansion. Deicing chemicals corrode reinforcing steel and metal load transfer devices.

The function of the sealant was simply to seal the joint between two concrete substrates; it was not intended to serve as an adhesive for bonding the substrates together. The sealant's ability to withstand repeated thermal and load-induced movements was far more critical than its strength.

Single component, low modulus silicone sealants have recently proved to be cost-effective, flexible, and durable when used to seal pavement joints; therefore, this type of sealant was specified for resealing all transverse joints up to 1 1/8 in wide and the longitudinal centerline joint. Compression seals were specified for sealing the wider transverse joints. Since the roadway shoulder throughout the length of the project was constructed of asphalt to which single component silicones do not effectively bond, a thermoplastic asphaltic sealant was specified to reseal lane-shoulder joints.

Transverse joints up to 1 1/8 in wide and the centerline joint were sawed to a depth of approximately 2 in to remove the existing sealant material and to create a sealant reservoir that, after installation of the backer rod, would accommodate the recommended sealant bead width-to-depth ratio of 2:1. After sawing, joint reservoirs were cleaned by wire brushing and water blasting. An air compressor was then used to remove loose debris and to dry the reservoirs. A closed cell, polyethylene foam backer rod slightly larger in diameter than the reservoir width was inserted into the cleaned joint. Finally, the joint was filled with silicone sealant by means of a mechanical applicator. Hand tooling was required to form a 1/4-in recess below the pavement surface for protection against traffic.

As a result of the ineffectiveness of silicones in sealing wide joints, those joints wider than 1 1/8 in were sealed with preformed neoprene compression seals. Joint reservoirs were cleaned by sawing, waterblasting, and blowing with compressed air as described above. After they were cleaned, vertical joint faces

were painted with a liquid bonding primer, and the seal was mechanically compressed and inserted into the reservoir to a depth just below the pavement surface.

The longitudinal joint between the shoulder and mainline pavement was cleaned by sawing a 3/4-by 3/4-in reservoir and blasting with water and compressed air. After the joint had dried sufficiently, a thermoplastic asphaltic sealant was used to fill the reservoir.

The performance of the resealed joints was monitored by periodically examining them for signs of sealant deterioration, adhesive and cohesive bond failures, spalling, and other problems.

### **Subdrain Installation**

Design professionals have recently placed great emphasis on removing subsurface water from pavement structures. Trapped water weakens the pavement foundation and directly contributes to distresses such as pumping and joint faulting. To mitigate the effects of water-related distresses, this contract called for the installation of modified subdrains at locations identified by the Project Engineer as having poor drainage characteristics. Subdrain installation involved excavating an 18-in-wide trench through the roadway shoulder along the edge of the mainline pavement to a minimum depth of 30 in. An attempt was made to construct the bottom of the trench with sufficient grade to maintain positive flow. A bedding layer of open-graded stone was placed in the trench to support the perforated pipe. The trench was then filled with stone up to the bottom of the shoulder pavement and capped with an asphalt base material (see Figure 3).

The subdrain pipes were connected to nonperforated, corrugated plastic lateral pipes that were installed perpendicular to the roadway at intervals of 250 ft. The laterals flowed beneath the shoulders, extended through the roadway embankment, and were terminated at prefabricated concrete headwalls designed to maintain the integrity of the pipe ends.

The effectiveness of the subdrains was evaluated by visually examining the outlet pipes for evidence of water. Whenever possible, the pipes were examined soon after a rain storm in an attempt to observe actual flows.

### **Load Transfer Restoration**

The purpose of load transfer restoration is to restore or establish a mechanism for transferring loads induced by vehicles from one slab to the next. Such mechanisms enable the uniform distribution of stresses across concrete sub-

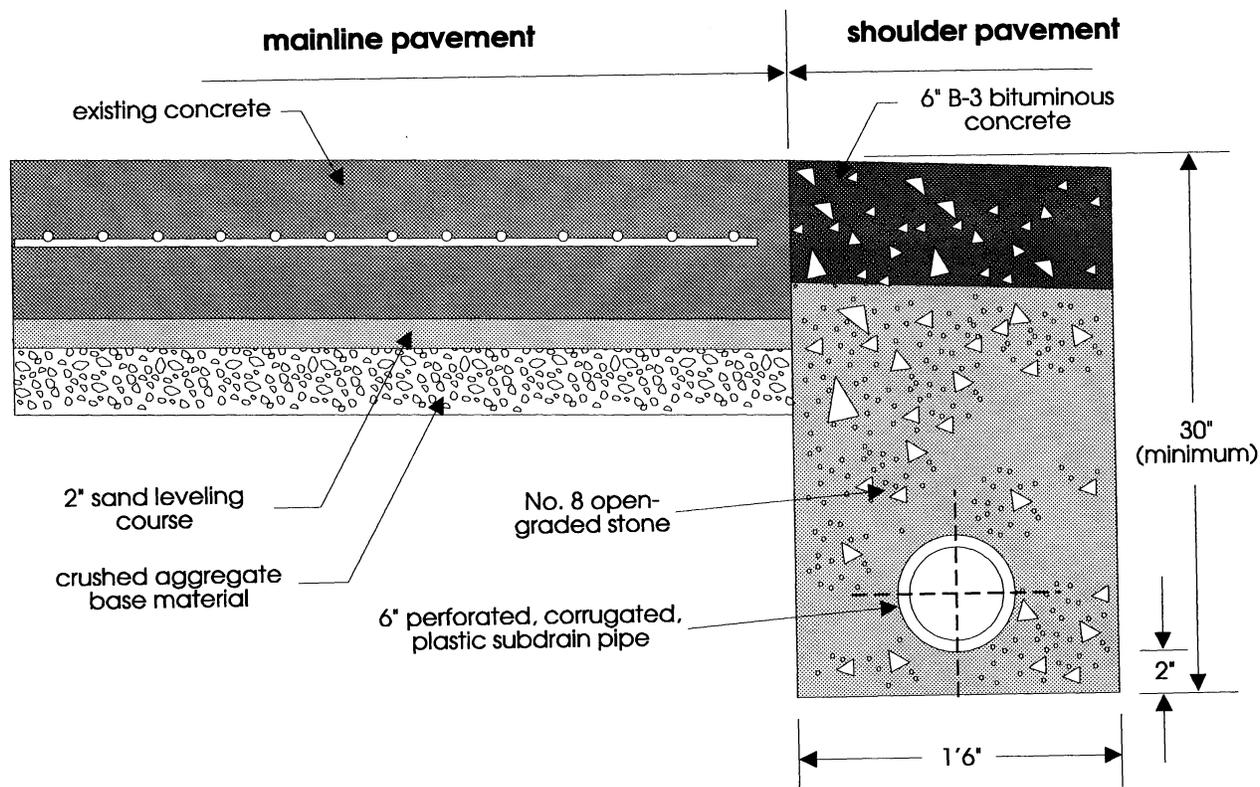


Figure 3. Typical subdrain section.

strates without developing excessively high stresses at the slab edges. Load transfer failures are typically manifested by faulted or settled slabs and patches and, in some cases, transverse cracks. Two types of load transfer mechanisms, which are described in detail in the next sections, were installed for evaluation.

#### *University of Illinois Load Transfer Device*

This is essentially a cross-shaped, stainless steel device grouted into a hole drilled to the full depth of the slab through a plane of vertical movement (see Figure 4). In preparation for installation, a plain patch (i.e., with no load transfer) was constructed several days in advance of the load transfer installation. Holes 6 in. in diameter were drilled with a standard core barrel through the interface of the patch and adjacent old concrete. To enhance mechanical bonding of the device to the walls, the holes were grooved with a special grooving device. Two load transfer devices were installed in each wheel path on each side of the patch, for a total of eight. Thorough cleaning of the core holes was accomplished by air drying, wire brushing, blowing with compressed air, and vacuuming. The walls of the holes were painted with a concrete-to-concrete bonding primer.

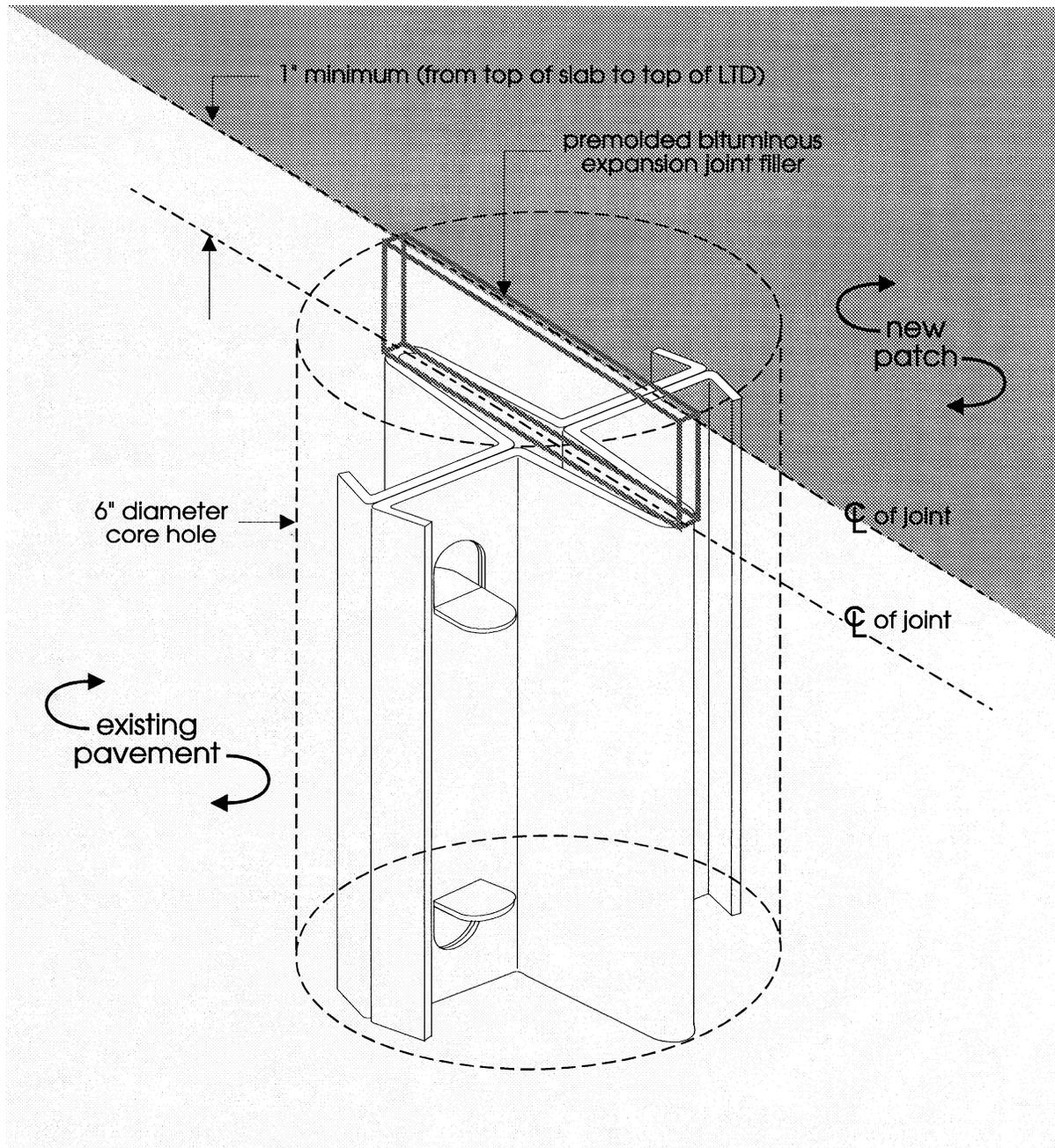


Figure 4. Isometric view of University of Illinois load transfer device.

Installation of each device involved mechanically compressing the device to a size smaller than the hole diameter and releasing the compression after insertion in the hole. All voids were filled with a polymer concrete, which was mixed at the site and vibrated into place. The top was struck off, and a joint was formed on top of the device with a strip of premolded bituminous expansion filler to correspond with the existing joint between the old concrete and the repair.

### *Embedded Dowels (Kerfs)*

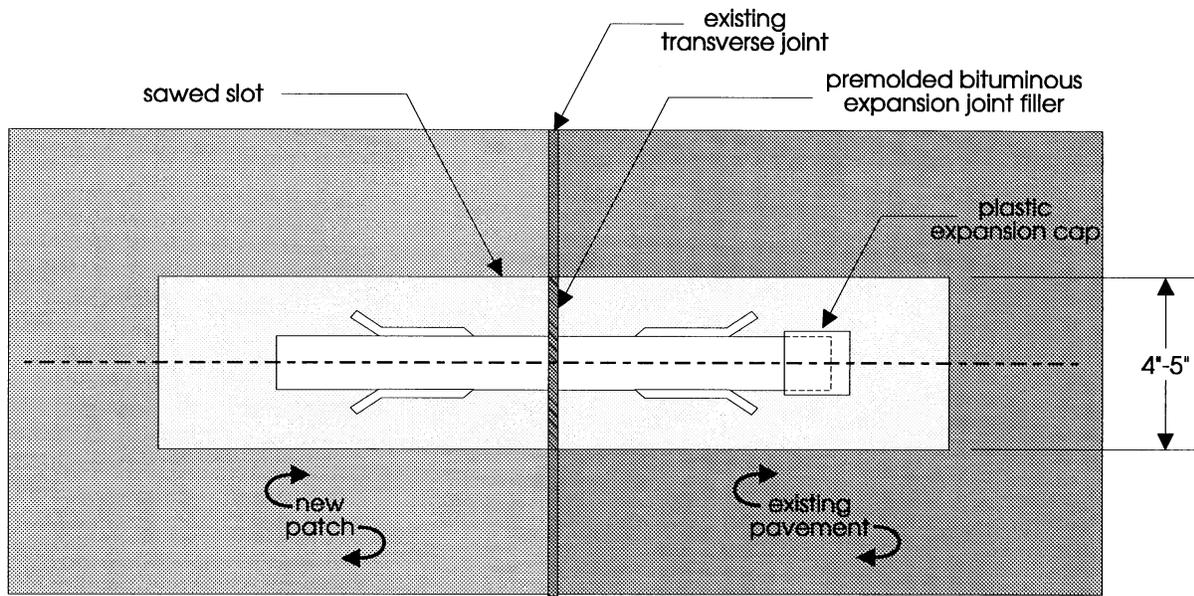
The installation of kerfs involved the partial-depth removal of concrete across a plane of vertical movement and the placement of a dowel embedded in grout. These were also installed in a plain patch placed ahead of time. Three kerfs were placed in each wheelpath on both sides of the patch, for a total of twelve. The first kerf was installed 18 in from the pavement edge, whereas the others were spaced at 18-in centers. The holes (slots), cut with a diamond concrete saw, were 24 in long, 4 to 5 in wide, and 5 5/8 in deep (to achieve mid-slab placement in the 9-in-thick pavement). The slots were cleaned by compressed air and painted with a concrete-to-concrete bonding primer. Metal chairs were placed in the bottom of the slots to hold the dowels secure and parallel to the roadway surface. Plastic, cylindrical expansion caps were fitted onto one end of the dowels to provide room for lateral movement caused by thermal expansion of the patches. A strip of premolded bituminous expansion filler was used to form a new joint within the slot that corresponded with the existing joint between the old concrete and the repair (see Figure 5).

The performance of both types of load transfer devices was monitored by conducting periodic visual examinations. The occurrence and location of patch faulting, settlement, and other distresses, if any, were noted.

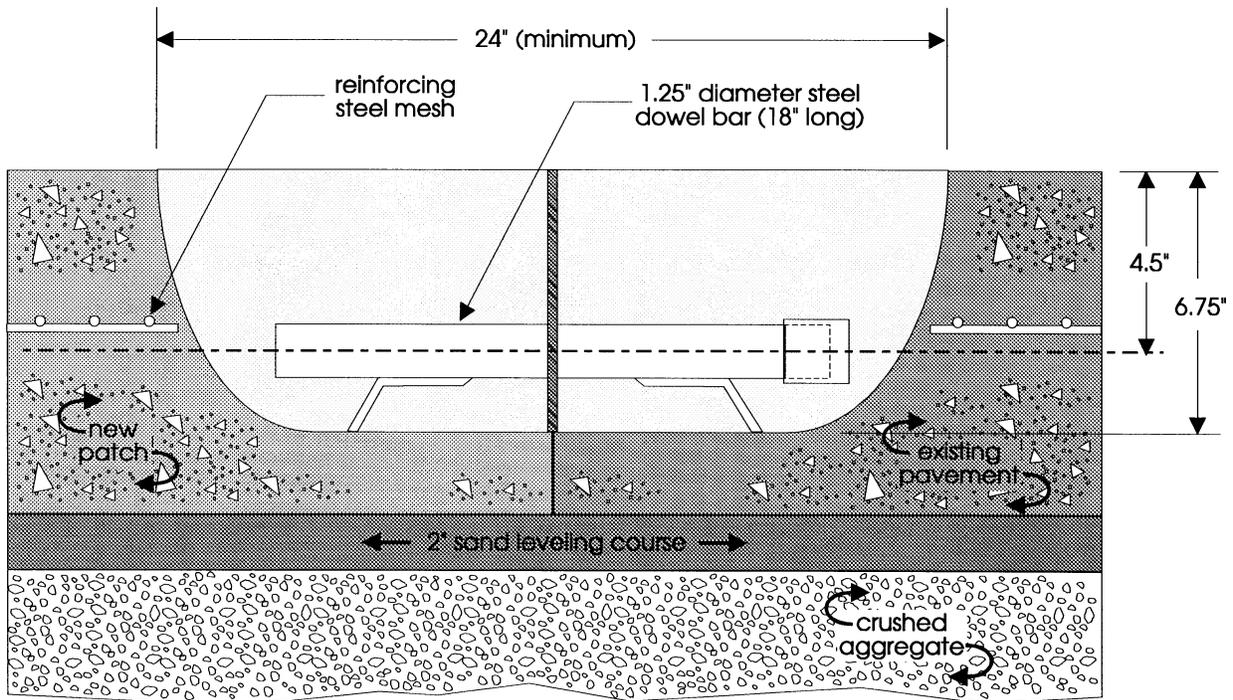
## DISCUSSION

At the time this study was undertaken, CPR was relatively new; therefore, the parties involved were inexperienced with the various techniques. During construction, patching and slab replacement activities were hindered by difficulties associated with sawing the expanding concrete during very hot weather. Some of the larger patches and replaced slabs developed hairline shrinkage cracks soon after placement. Cooler weather mitigated the formation of shrinkage cracks but contributed to a different problem: thermal contraction caused many joints between inverted "T" patches and the run-on side of the existing pavement to open. Such joints, which were previously unsealed, were sawed, cleaned, and sealed with silicone sealant.

Although most of the replaced slabs and partial-depth patches performed well throughout the 5-year evaluation period, all of the inverted "T" patches developed severe faulting and pumping within 3 years. When several of these patches were replaced, it was discovered that significant voids were present within the concrete that extended beneath the adjacent slabs, suggesting that adequate consolidation had not been achieved. The overall poor performance of the inverted "T" patches was attributed to difficulties associated with construction in addition to damage caused by water infiltration through open joints.



PLAN VIEW



SIDE VIEW

Figure 5. Plan and side views of embedded dowel (kerf) load transfer device.

Slab stabilization required an average of 9 ft<sup>3</sup> of grout per slab, which was considerably higher than the original unit estimate of 1 ft<sup>3</sup>. A comparison of deflection measurements made with a Benkelman beam before and after stabilization indicated that the activity reduced slab edge deflections slightly (from an average of 0.009 in to 0.006 in beneath an 18-kip axle load). However, the relatively low initial deflections, which formed the basis for the original volume estimate, were not indicative of voids large enough to require the volumes of grout actually taken. The author believes, therefore, that a substantial volume of grout flowed into the permeable sand leveling course located immediately beneath the concrete.

Surface grinding was very successful in restoring the pavement's ride quality. Grinding reduced the project's Mays IRI from 159 in per mi to 83 in per mi. Approximately 4 years after the completion of the project, the pavement had visibly lost much of its restored, corduroy-like surface texture. This relatively rapid loss of texture was attributed to abrasion by traffic of the inherently soft limestone aggregates used in the original concrete mix.

Although the joint resealing installation was essentially free of problems, the majority of silicone joints exhibited adhesive bond failures within a few months. The failures were attributed to a chemical reaction between the silicone and the dolomitic limestone portion of the concrete's coarse aggregate which interrupted the bond between the sealant bead and the joint reservoir wall. In response to the bond failures, the contractor removed and cleaned all silicone joints and sprayed the reservoir walls with a silicone bonding primer before resealing with the same brand of silicone sealant used previously. The primed joints performed well throughout the remainder of the evaluation period. Only isolated incidents of adhesive bond failure were subsequently noted.

Early in the evaluation period, water was observed flowing from some of the subdrain headwalls soon after rain storms. Silt and fine-grained sand deposits were regularly noted in the bottom of several lateral outlet pipes, which may indicate that some of the finer material within the sand leveling course was transported by water (piping) through the drainage system. If so, erosion of the sand layer likely contributed to the recurrence of pumping and faulting distresses subsequently observed in the inverted "T" patches. It appeared that the subdrains were effective in removing water from within the pavement structure, but they may have caused damage at the same time by contributing to the erosion of the supporting sand layer.

All of the Illinois Load Transfer Devices failed within 6 months of installation and were removed from the project. In all cases, the failures were manifested by cracking in the surface of the polymer concrete used to embed the devices, some of which was visible after only a few weeks, followed by the loss of material, and exposure. It appears that the devices were not capable of remain-

ing embedded when subjected to the concentrated stresses induced by moving wheel loads.

Although they were rather arduous to install, the embedded dowel load transfer devices generally performed well for the entire evaluation period. Very few of the patches retrofitted with kerfs exhibited signs of faulting or settlement.

## CONCLUSIONS

The progressive deterioration of Virginia's portland cement concrete pavements is presenting a significant challenge to those responsible for pavement maintenance and rehabilitation. The CPR method of rehabilitation is becoming widely accepted as an effective strategy for restoring a pavement's structural condition and for preventing or mitigating the recurrence of some distresses.

Although the present condition of the pavement used in this demonstration project indicates that major rehabilitation will be needed in the near future, its overall performance since restoration in 1984 suggests that CPR has been effective. Specifically, slab replacement, embedded dowel load transfer restoration, joint resealing (substructure protection), diamond grinding (dynamic load reduction) and, perhaps to a lesser extent, slab stabilization have effectively restored the pavement's load-carrying capacity. Similarly, slab replacement, partial-depth patching, diamond grinding (ride quality restoration), and joint resealing (moderated recurrence of faulting) have effectively improved the pavement's functional integrity.

The following conclusions and recommendations are offered:

1. Full-depth, full-width patches using the inverted "T" design are difficult to construct and do not provide an effective mechanism for transferring wheel loads between concrete substrates. Therefore, they should not be considered in the rehabilitation design of heavy concrete pavements.
2. The slight change in edge deflection measurements observed after injecting grout beneath slabs rendered the effectiveness of the slab-stabilization activity inconclusive. Additionally, the filling of air voids within the underlying sand leveling course with grout made it impossible to estimate the volume of void pockets beneath slabs. Therefore, the establishment of a correlation between edge deflection and void pocket volumes, which may have been useful in estimating subsequent grout requirements, was not possible.

3. The diamond grinding activity was very effective in restoring the pavement's ride quality. However, when considering the feasibility of grinding, attention should be given to the durability of the original concrete because of its influence on the longevity of the new texture.
4. The use of a silicone-to-concrete bonding primer is recommended for the installation of all silicone joints. Although the primer adds to the cost of joint resealing, it appears to offer effective protection against adhesive bond failures.
5. Retrofitting some pavements with subdrains may provide a catalyst for piping, potentially eroding underlying layers to the point of creating damaging void pockets. Consideration should be given to the ability of base layer materials to resist piping when evaluating the feasibility of retrofitting with subdrains.
6. The University of Illinois Load Transfer Device appears to be incapable of resisting the concentrated loads induced by heavy vehicles; therefore, it should not be considered a viable mechanism for load transfer restoration.
7. Embedded dowels were quite effective in restoring load transfer between patches and the old pavement. Additional research is recommended to evaluate their performance between full-length slabs and to improve their constructability.

In summary, CPR should be considered a viable rehabilitation alternative for certain pavements. However, the extent and severity of a pavement's distress should be consistently employed in the strategy selection and design process.<sup>3</sup> In other words, CPR is not cost-effective beyond a defined range of pavement conditions, so careful attention must be given to determining whether or not a candidate pavement is too severely deteriorated to render CPR cost-effective.

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