## CALIFORNIA DEPARTMENT OF TRANSPORTATION

### DIVISION OF DESIGN

**Office of Pavement Design**

**Pavement Design & Analysis Branch**

# Jointed Plain Concrete Pavement (JPCP) Preservation and Rehabilitation Design Guide

June 2, 2008

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## 1.0 INTRODUCTION AND PURPOSE

Preservation (both preventive maintenance and Capital Preventive Maintenance,(CAPM) and roadway rehabilitation programs for jointed plain concrete pavements (JPCPs) involve the use of a single or combination of several corrective techniques aimed at providing the best overall solution to extend the pavement life for a desired number of years. Their primary purpose is to bring up pavements that ride rougher than established thresholds, and/or exhibit minor to major structural distress, to good condition. Many of these distresses (see Section 2.0 of this Guide) indicate failure of the surface course and/or any structural layer within the pavement structure including the subgrade.

The purpose of this Guide is to provide the necessary information to the pavement engineer to design preservation and rehabilitation strategies for JPCPs. The Guide does not provide a comprehensive explanation or each strategy. Additional information on preventive maintenance treatments may be found in the Maintenance Manual, Chapter B – Rigid Pavement. More information on Capital Preventive Maintenance (CAPM) projects may also be found in Design Information Bulletin 81. More information on Roadway Rehabilitation projects may be found in Design Information Bulletin 79. All of these documents as well as others are available on the Department Pavement Engineering website.

Often, individual projects include a combination of various preservation and/or rehabilitation strategies, which are discussed in this Guide. The choice of strategies depends primarily on the current pavement condition, traffic impacts, life cycle cost considerations, and apparent rate of deterioration. The rate of deterioration is determined by applying experience to data gathered both in the field, and through review of successive annual Pavement Condition Survey Reports published by the Division of Maintenance.

Preservation and rehabilitation strategies are designed to provide satisfactory performance of the pavement during the selected design (or performance) life. According to Topic 612 of the Caltrans Highway Design Manual (HDM), the pavement design life "is the period of time that a newly constructed or rehabilitated pavement is engineered to perform before reaching a condition that requires CAPM." The pavement design life of a particular JPCP project will vary depending on the type of project being constructed and the overall cost to the Department over the life of the pavement determined by using life cycle cost analysis (LCCA). The current minimum standards for the pavement design life are found in the Topic 612 of the HDM. LCCA is a key tool used in pavement engineering to determine which pavement provides the most economic value over time, but it is not the only consideration. Evaluating the benefits and costs of JPCP preservation and rehabilitation is based on the selection of the appropriate strategy/strategies which will be based upon many issues that may include field analysis, testing, constructability, cost, materials testing, materials availability, ride quality, safety, visual inspection of pavement distress, and other factors relevant to the project. When doing LCCA, it is important that the pavement engineer compare rehabilitation alternatives that will provide identical improvements to the pavement.

In order to initiate a CAPM or roadway rehabilitation project, a review by a special Project Scoping Task Force is required. The task force review is scheduled and coordinated by the District. This Task Force functions as a project review team to ensure that the appropriate project scope and cost of work is expeditiously developed. The attendance roster for this Task

Force is included as an attachment to the CAPM Project Report and the Project Scope Summary Report (PSSR). For further discussion on this issue see Appendix G and Appendix H of the Project Development Procedures Manual (PDPM).

## 2.0 JPCP FAILURE TYPES

In order to determine the most probable cause of failure of a given pavement, sound engineering judgment is always required when interpreting the results of all of (1) observation, (2) appropriate tests, and (3) other collected data. There are many variables in materials and environment as well as other factors that affect the performance of pavement structures. This makes it nearly impossible to develop hard and fast rules for the rehabilitation of pavement structures. Therefore, the pavement engineer should rely on the experience, judgment, and guidance of engineers in pertinent functional engineering units who are familiar with the design, construction, materials, and maintenance of pavements in the geographical area of the project. Deflection testing and coring of concrete pavements and other tests provide data upon which the engineer may rely on to make appropriate decisions. As an example of the importance to determine causes of failure and their effect on selecting the accurate method of rehabilitation, consider pavement structures with subgrade problems. In such pavements, surface distortion is most commonly manifested in the form of uneven tilting of slabs or broken slab segments and sometimes by differential movement at joints. Step faulting at weakened plane transverse joints of uncracked slabs or at both transverse joints and intermediate transverse cracks, without uneven distortion, indicates that the problem is primarily confined to the pavement structure. A combination of the above conditions would indicate the problem is both in the pavement structure and the subgrade.

There are various ways in which a JPCP respond to both the traffic and environment that can affect its initial and long-term performance. The three principal ways in which a JPCP responds are:

- Curling stress – Slab curling is caused by difference in temperature between the top and bottom surfaces of the concrete slab. Since slab weight and friction with the base restrict its movement, stresses develop in the slab.
- Shrinkage/Expansion – Environmental temperatures causes JPCP slabs to expand (when hot) and contract (when cool) which create joint horizontal movement, in addition to curling.
- Load stress – Compressive and tensile stresses within the slab and any adjacent one (as long as load transfer efficiency is > 0) are created when loads are applied on the JPCP.

In order to select the most appropriate type of CAPM or roadway rehabilitation, the pavement engineer needs to understand the various distress modes and their potential causes. The most common structural pavement failure types of a JPCP are given below along with potential causes. For additional information and a comprehensive list of all types of failures and the Caltrans methods of characterization, see the Caltrans Pavement Survey Manual published by the Division of Maintenance on the Department Pavement Engineering website.

### 2.1 Faulting

Faulting (sometimes referred to as step faulting), is a vertical displacement of abutting slabs at the transverse joints creating a "step" in the pavement (see Figure 1).

**Figure 1. Faulting of a Transverse Joint**

In theory, the erosion of base material at the transverse joints causes faulting. This occurs mainly when erodible bases containing appreciable amounts of fines are present combined with presence of a source of water. The dynamic impact of traffic loading allows fines to be pumped up onto the pavement surface and/or from one side of slab to the other at the location of transverse joint. This is schematically shown in Figures 2 and 3. Faulting is a concern because it results in incomplete and nonuniform slab support while creating an unpleasant ride. More importantly, it indicates a potential for future slab breakup at those joints.

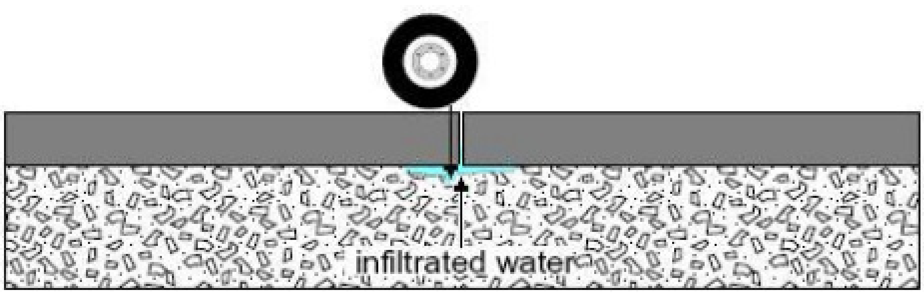



**Figure 2. Water Under Slab**

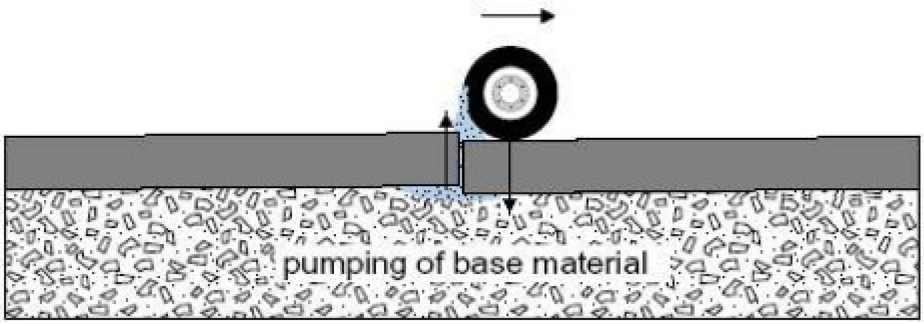



**Figure 3. Vertical Displacement Under Pumping Action of Traffic and/or Water**

This is a phenomenon that is common on California's non-doweled JPCPs. A badly faulted pavement generally exhibits shoulder distress adjacent to the edge of the traveled way, due primarily to the pumping of aggregate base fines from under the shoulder (see Figure. 4).

**Figure 4. Pumping Action from Water Being Pushed out Under Traffic Loading**

Faulting, which is usually preceded by loss of full base support, is considered to be a major contributing factor to slab cracking and eventual breakup.

## 2.2 Slab Cracking

Concrete pavement cracks generally result primarily from heavy wheel loading combined with lack of uniform base support. Cracking also results from weak subgrades, expansive soils, and differential settlement. Pavement cracks allow moisture infiltration leading to erosion of base/subbase support and the development of cracks that will eventually advance to concrete spalling if not sealed. The degrees of cracking are described below based on California distress identification method described in the Caltrans Pavement Survey Manual published by the Division of Maintenance.

### 2.2.1 First Stage Cracking

First stage cracks are transverse, longitudinal, or diagonal cracks that do not intersect, which divide the slab into two or more large pieces (see Figure 5).

**Figure 5. First Stage Cracking**

Transverse and diagonal cracks are caused by combination of heavy load repetitions and stresses due to temperature and moisture gradient, and drying shrinkage. Longitudinal cracks occur parallel to the centerline of the pavement and are often caused by a combination of heavy load repetitions on pavement with unsatisfactory roadbed support, thermal curling, faulting, shrinkage, and moisture induced warping stress.

### 2.2.2 Third Stage Cracking

Third stage cracks are interconnected cracks that divide the slab into three or more large pieces, as shown in Figure 6.

**Figure 6. Third Stage Cracking (cracks have been sealed)**

Fragmented slabs are characterized by interconnected irregular multiple cracks and breaks which divide the slab into several small pieces. Fragmented slabs are a severe form of third stage cracking. Slab breakup is usually caused by a combination of heavy load repetitions on pavement with unsatisfactory roadbed support, thermal curling, faulting, shrinkage, or moisture stress.

Third stage cracking and first stage cracking cannot co-exist in the same slab. However, corner cracking may co-exist with both first stage and third stage cracking.

### 2.2.3 Corner Cracking

A corner crack is a diagonal crack that meets both a longitudinal and transverse joint within 2 to 6 feet of the same slab corner as shown in Figure 7.

**Figure 7. Corner Cracking**

A corner crack usually has a characteristic "pie slice" appearance. A slab can have as many as four corner cracks. Corner cracks may co-exist with first and third stage cracking as can be seen in Figure 8.

**Figure 8. Settlement of Third Stage Cracked Jointed Plain Concrete Pavement**

Slab breakup is usually caused by a combination of heavy load repetitions on pavement with unsatisfactory roadbed support, thermal curling, faulting, shrinkage, or moisture stress.

### 2.3 Settlement

Settlement is a local sag in the pavement structure that results from differential settlement, consolidation, or movement of the underlying earth mass (see Figure 8 above). Sags most commonly occur above culverts due to the settlement or densifications of backfill, or at grade points between cut and fill sections. Sidehill slippage also contributes to differential settlement of the pavement and longitudinal cracking.

### 2.4 Blowups

Blowups are localized upward buckling and shattering of the slabs at transverse joints or cracks (see Figure 9).

**Figure 9. Blowup at Transverse Joint**

Any area where the transverse joint opening becomes filled with incompressible solids or where insufficient joint sawing depth has been provided is susceptible to blowup. Although blowups are not common in California, they have occurred in regions characterized with freeze-thaw cycles where the pavement is sanded during the winter season (where joints may become filled with sand) and in areas subject to large temperature swings. A large percentage of the blowups that have occurred, were on pavement originally placed in cold winter months. Movement of concrete becomes severely restricted when all available room for expansion have been occupied by incompressible materials.

### 2.5 Joint or Crack Spalling.

Spalling is the breakdown or disintegration of crack edges, resulting in the loss of concrete and progressive widening of the cracks (see Figure 10).

Spalling could also occur as a result of individual slab segments moving against one another under heavy load repetitions (see Figure 11). The greater the spalling the more movement the slabs would experience. More movement usually translates into accelerated slab failure.

**Figure 10. Spalled First Stage Crack**

**Figure 11. Joint Spalling Caused by Slab Movement**

## 2.6 Surface Polish

Surface polish is the loss of the original surface texture (see Figure 12), which result in early wearing off of surface texture due to traffic action and poor construction practices. This type of distress causes the pavement surface to lose its skid resistance especially when wet. The use of soft aggregates in the original construction can contribute to surface polish.

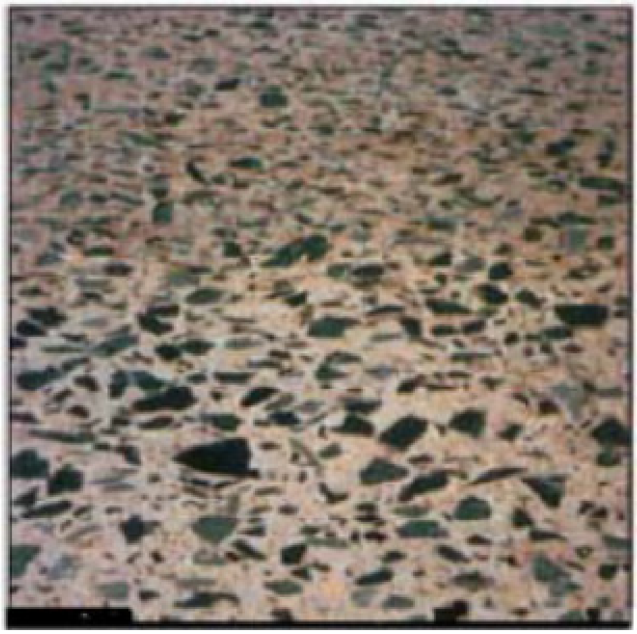


**Figure 12. Polished Aggregate on Pavement Surface**

### 2.7 Surface Attrition

Surface attrition or "surface abrasion" is abnormal surface wear of the concrete pavement (see Figure 13). It can result from either poor quality surface cement, coarse aggregate, or by the action of tire chains and studded tires. It is recommended that harder and higher quality aggregates be used in areas where tire chains and studded tires are used to minimize this effect.

**Figure 13. Severe Surface Abrasion with Third Stage Cracking**

## 2.8 D-Cracking

D-cracking is characterized by closely spaced hairline cracking pattern formations parallel to transverse and longitudinal joints that later multiply outward from the joints toward the center of the pavement panel (see Figure 14).

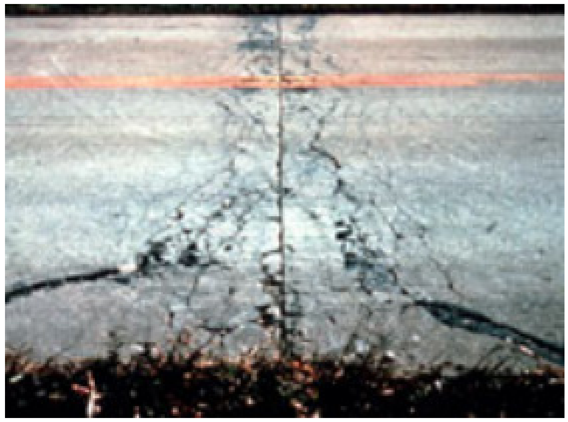


**Figure 14. High Severity D-cracking with Loose Material**

A freeze-thaw expansive pressure of certain types of coarse aggregates causes D-cracking. It weakens the concrete near the joint resulting in increased potential for blowups and spalling. This type of distress has been rarely seen in California.

## 2.9 Popouts

Popouts are characterized by the breaking away of a small piece of concrete from the surface (see Figure 15). This type of pavement distress is generally caused by chemical or material reactions such as Alkali-Silica Reactivity (ASR) or by expansive, nondurable or unsound aggregates or by freeze-thaw action.


**Figure 15. A Popout**

## 3.0 JPCP PRESERVATION AND ROADWAY REHABILATATION STRATEGIES

### 3.1 Definitions

Preventive Maintenance is used to provide preventive treatments to preserve pavements in good condition. Preventive Maintenance projects are typically done by the Department's Maintenance forces or through the Major Maintenance Program. The District Maintenance Engineer typically determines which preventive treatment to apply and when. Traffic safety and other operational improvements, geometric upgrades, or widening are normally not included in preventive maintenance projects. Strategies and guidelines on preventive maintenance treatments currently used by the Department can be found in the Maintenance Technical Advisory Guide (MTAG).

Capital Preventive Maintenance (CAPM) is a short-term repair project program (≤10 years) agreed between the Department and FHWA in 1994. CAPM is part of the Department's pavement preservation program, which is more closely related to maintenance than rehabilitation and is considered to be non-structural improvement (i.e., it does not address future traffic loading needs.) Instead CAPM is intended to make minor repairs to pavements with only minor distress and/or poor ride to prevent them from deteriorating into conditions requiring major roadway rehabilitation. In addition to this Guide, further discussion on the CAPM program can be found in the Design Information Bulletin 81 "Capital Preventive Maintenance Guidelines" and in Topics 603 and 624 of the HDM. .

Pavement Preservation is a collection of pavement treatments used to maintain or repair a pavement that is still structurally sound. Preventive Maintenance and CAPM are both considered to be part of pavement preservation.

Roadway Rehabilitation is generally regarded as heavy, non-routine engineered maintenance work intended to restore and extend the service life of the pavement that exhibits major structural distress, as well as provide upgrades to enhance safety and operation where needed. Roadway rehabilitation projects may also include additional items of work such as upgrading other highway appurtenances such as drainage facilities, structures, lighting, signal controllers, and fencing that are failing, worn out or functionally obsolete. Besides this Guide, further discussion on roadway rehabilitation can be found in Design Information Bulletin 79 "RRR Design Criteria" and the Highway Design Manual Topics 603 and 625.

### 3.2 Treatment Selection Criteria

Table 1 lists the various common JPCP failure types along with the recommended preventive maintenance, CAPM, or rehabilitation strategies that are needed to address them. After identifying the various types of distresses, the pavement engineer needs to examine the appropriateness of each strategy provided in Table 1. The selection of the appropriate strategy should be based upon life-cycle cost analysis, load transfer efficiency of the joints, materials testing, ride quality, safety, maintainability, constructability, visual inspection of pavement distress, and other factors listed in Topic 611 of the HDM. The Materials Report should discuss any historical problems observed in the performance of rigid pavement constructed with aggregates found near the proposed project and subjected to similar physical and environmental conditions.

**Table 1. JPCP Failure Types and Recommended Strategies**

| JPCP PRESERVATION AND REHABILITATION STRATEGIES | Pavement Failure Types | | | | | | |
|---|---|---|---|---|---|---|---|
| | Faulting | Slab Cracking | Settlement | Blow-ups | Joint or Crack Spalling | Surface Attrition | Surface Polish |
| **Preventive Maintenance Strategies:** | | | | | | | |
| Diamond Grinding | | | | | | ✓ | ✓ |
| Grooving | | | | | | | ✓ |
| Joint Resealing | | | | | ✓ | | |
| Crack Sealing | | | | | ✓ | | |
| Spall Repair | | | | | ✓ | | |
| **CAPM Strategies:** | | | | | | | |
| Slab Replacement | | ✓ | ✓ | ✓ | | ✓ | |
| Diamond Grinding | ✓ | | ✓ | | | | |
| Dowel Bar Retrofit[1, 2] | ✓ | | | | | | |
| **Roadway Rehabilitation Strategies:** | | | | | | | |
| Lane Replacement | ✓ | ✓ | ✓ | ✓ | | | |
| Unbonded Rigid Overlay with HMA Interlayer | ✓ | ✓ | ✓ | ✓ | | | |
| Crack and Seat Slabs, and Flexible Overlay | | ✓ | | | | | |

Notes:
1. Dowel Bar Retrofit (DBR) should only be used on cracked slabs where the crack is functioning as a joint.
2. DBR is intended for existing non-doweled jointed plain concrete pavement, which has little to no cracking but is experiencing poor load transfer at the joints.

In the following sections, the various treatments listed in Table 1 under each program are discussed.

## 3.3 Preventive Maintenance Strategies

### 3.3.1 Diamond Grinding

Diamond grinding is used as a preventive maintenance strategy to enhance surface friction characteristics and safety of an old concrete pavement and to remove roughness resulting from studded tires, chains, or other factors that could cause surface attrition. A gang-mounted diamond saw blades (see Figure 16) are used to shave off a thin 0.06-0.75 inches of the top layer of an existing concrete surface in order to restore smoothness and to enhance surface friction characteristics and safety of an old concrete pavement. Diamond grinding should leave a level surface with longitudinal texture as shown in Figure 17.

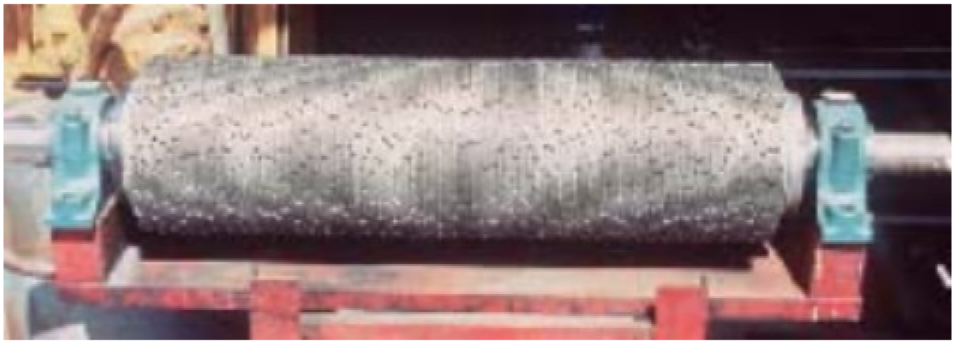


**Figure 16. Diamond Saw Blade**

**Figure 17. Acceptable Diamond Grinding**

Research on diamond grinding of concrete pavements indicates that the required surface texture and skid resistance can be achieved by such a treatment and can be maintained for a relatively long period of time. Therefore, grooving a pavement in addition to diamond grinding and re-grooving of a once grooved concrete pavement, subsequent to a diamond grinding operation, should not be necessary unless there are extenuating circumstances.

**3.3.2 Diamond Grooving**

Pavement grooving is the cutting of grooves on existing concrete pavement in the longitudinal direction as can be seen in Figures 18 and 19. The grooving should cover the full width of the lane.

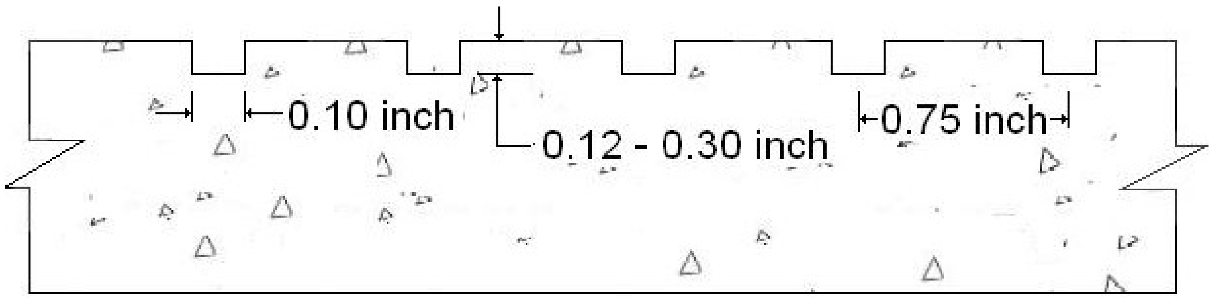



**Figure 18. Section View of Grooved Pavement**

**Figure 19. Close-up View of Grooved Pavement**

Cutting grooves in existing pavement has proven to be an effective technique in the reduction of hydroplaning and wet weather skidding problems. The grooved surface is expected to remain effective for at least 10 years. The life of grooving is reduced where there is exposure to tire chains and studs. The longevity of effective grooving varies inversely with the volume and gross weight of vehicles with chains and directly with the durability or abrasion resistance of the concrete.

In this treatment, a power driven, self-propelled machines with diamond blades that are 0.10-inch wide and spaced at 0.75 inch on centers are used to cut 0.12-0.30 inch deep grooves transversely on the concrete layer. Care should be taken in cutting grooves not to leave vertical ridges in excess of 0.50 inch or affect the cross slope, or other drainage pattern.

Large motorized equipment is used for grooving (and grinding) operations, using multiple diamond-studded blades operating on a single shaft, to impart a groove of varying depth (typically 0.12 inch to 0.30 inch). The equipment uses water applied to the pavement both as a cooling agent for the cutting blades; therefore the byproduct of both operations is slurry of ground concrete particles and water. Vacuums within the grinding and grooving machines, which must then be disposed off in a safe and environmentally friendly manner, pick up the slurry. Design Information Bulletin 84 provides guidance for the "Removal and Disposal of Concrete Pavement Grooving and Grinding Residues" and can be found on the Division of Design website at http://www.dot.ca.gov/hq/oppd/dib/dib84-01.htm#1.

### 3.3.3 Joint Resealing

This work includes the removal of the existing joint seals, cleaning (see Figure 20) and resealing the transverse and longitudinal joint with liquid sealants (see Figure 21).

**Figure 20. Sandblasting a Joint for Resealing**

The purpose of resealing the concrete pavement joints is to prevent water and incompressible materials from entering the pavement structure, thus slowing the rate of deterioration of the concrete pavement. Joint faces must be in good condition with very little to no spalling. Resealing is typically done with silicone or asphalt rubber on older concrete pavements.

Asphalt joint sealants are the hot-poured liquid sealants with abilities to provide resistance and resiliency. Asphalt sealants are generally the less expensive of the two available liquid sealants, though their lifespan is from 2 to 3 years. In most cases, traffic can resume on the pavement once the sealant has cooled.

Silicone sealants are cold-applied, often self-leveling materials that are highly flexible for transverse contraction and expansion joints, as well as longitudinal, center line, and shoulder joints. Silicone polymer sealants are more expensive than asphalt sealants but last longer, typically from 10 to 15 years.

**Figure 21. Liquid Sealant Being Applied in a Joint**

The design engineer is required to specify the type of joint sealants to be used for their project. The design engineer should consult with the District Maintenance Engineer and District Materials Engineer for selecting the appropriate joint seals or sealants type.

Transverse and longitudinal joints sealing should be specified in freeze-thaw areas, where winter application of anti-icing or de-icing treatments such as sand tends to fill unsealed joints with incompressible materials and to minimize water intrusion into the pavement structure. Water intrusion causes subgrade softening, and erosion of fines by pumping action (see Figure 22) that could lead to loss of pavement support (see Figure 23).

Resealing joints is necessary in older pavements with deteriorated sealants. It is not practical or necessary that joints be completely watertight.

Table 2 (based on an FHWA report[1]) may be used to determine whether resealing of pavement joints is required in relation to the condition of existing sealants, condition of the pavement, climatic condition, and traffic level.

[1] Materials and Procedures for Repair of Joint Seals in Portland Cement Concrete Pavements, Manual of Practice. FHWA Report No. FHWA-RD-99-146.

**Figure 22. Visible Fines Between Lane and Shoulder**

**Figure 23. Settled Concrete Shoulder due to Loss of Support**

**Table 2. Resealing Recommendations**

| Sealant Rating ** | Pavement Rating | Traffic Rating | Climatic Region | | | |
|---|---|---|---|---|---|---|
| | | | Freeze | | Non-freeze | |
| | | | Wet | Dry | Wet | Dry |
| Fair | Good | Low | Possibly a good idea | Possibly not a good idea | Possibly a good idea | Possibly not a good idea |
| Fair | Good | Medium | Yes | Possibly not a good idea | Possibly a good idea | Possibly not a good idea |
| Fair | Good | High | Yes | Yes | Yes | Possibly not a good idea |
| Fair | Fair | Low | Yes | Possibly not a good idea | Possibly not a good idea | Possibly not a good idea |
| Fair | Fair | Medium | Yes | Yes | Yes | Possibly not a good idea |
| Fair | Fair | High | Yes | Yes | Yes | Possibly a good idea |
| Fair | Poor | Low | Possibly a good idea | Possibly not a good idea | Possibly a good idea | Possibly not a good idea |
| Fair | Poor | Medium | Yes | Yes | Yes | Possibly not a good |
| Fair | Poor | High | Yes | Yes | Yes | Yes |
| Poor | Good | Low | Yes | Possibly a good idea | Possibly a good idea | Possibly a good idea |
| Poor | Good | Medium | Yes | Yes | Yes | Possibly a good idea |
| Poor | Good | High | Yes | Yes | Yes | Yes |
| Poor | Fair | Low | Yes | Yes | Yes | Possibly a good idea |
| Poor | Fair | Medium | Yes | Yes | Yes | Yes |
| Poor | Fair | High | Yes | Yes | Yes | Yes |
| Poor | Poor | Low | Yes | Yes | Yes | Possibly a good idea |
| Poor | Poor | Medium | Yes | Yes | Yes | Yes |
| Poor | Poor | High | Yes | Yes | Yes | Yes |

** "Good" condition sealants do not require to be replaced.

### 3.3.4 Crack Sealing

Crack sealing involves the routing or sawing, cleaning and sealing of cracks in the concrete pavement that are greater than 12 inches in length and greater than 0.1 inch in width. Concrete pavement that exhibits a slow rate of deterioration should have a high priority for crack sealing. The purpose of sealing the cracks in the concrete pavement is to reduce the potential of water and incompressible from entering the pavement structure, which leads to spalling and more cracking.

### 3.3.5 Spall Repair

Spalling is the cracking, breaking, chipping, or fraying of concrete pavement edges at the joints as a result of individual slab segments moving against one another under heavy load repetitions. The more movement the slabs would experience the greater the potential to spalling, which is usually translated into accelerated slab failure. Most spalls should be treated before they extend below the top third of the slab. Repairs of this nature are commonly referred to as "partial depth."

The repair of spalled joints in concrete pavement includes partial depth patching by removing the broken, damaged, or disintegrated concrete pavement. The limits of the damaged or defective areas should be determined by striking the pavement along the sides of each joint with a hammer or similar tool (see Figure 24) to detect concrete that sounds hollow. The defective area is then marked by making a rectangle 2 inches beyond the outer limits of the unsound concrete area as a guide for sawing.

**Figure 24. Detecting Unsound Concrete around Spalled Joint**

When the spalled joint is less than 6 inches long and 1.50 inches wide, thoroughly clean and reseals the joint as specified in Section 3.3.3 of this Guide. Saw the rectangular marked areas with near vertical faces at least 2 inches but no more than 3 inches deep. Unsound material is removed within the sawed area with a chipping hammer as shown in Figure 25.

**Figure 25. Chipping of Unsound Concrete within Sawed Area**

Before placing the patching material, saw the face of the existing transverse joints bordering the repair areas. Saw at least 5 inches deep and 0.25 inches wide with the full depth of the saw cut extending at least 1 inch beyond the limits of the repair areas in each direction, and immediately thoroughly clean the surfaces within the repair areas by sandblasting and air blasting to remove oil, dust, dirt, slurry and other contaminants caused by the sawing operation before placing the patching material. A 0.25 inch wide piece of closed cell polyethylene foam shaped to fit the saw cut in the joints bordering the repair areas is placed as shown in Figure 26.

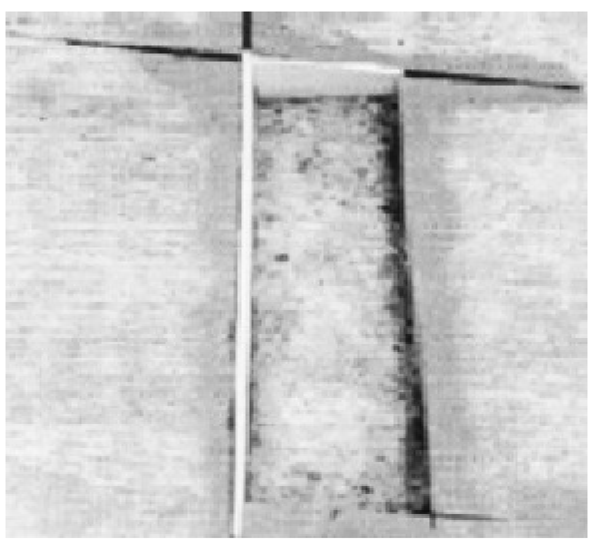


**Figure 26. Foam Bordering the Repair Area at a Joint**

## 3.4 CAPM Strategies

CAPM procedures for improving the performance of existing JPCPs include slab replacement, diamond grinding, and dowel bar retrofit. These are explained in the following sections.

### 3.4.1 Slab Replacement

This section supplements the "Slab Replacement Guidelines" found on the Department Pavement Engineering website at http://www.dot.ca.gov/hq/esc/Translab/pubs/SlabReplace/SlabReplacementGuidelines-All.pdf, providing additional information, details, and other tools for designers in preparing project scoping documents, plans, and special provisions.

In "Slab Replacement Guidelines", slab replacement is defined as the removal of individual slabs (or panels) of concrete pavement. The total length of consecutive individual slabs (or concrete panels) to be replaced using these procedures is less than 100 ft. When slabs have lost their structural capacity as well as ride quality, this strategy is used under this condition to replace individual slabs that have multiple cracks and/or severe crack (Stage 3 cracking) or joint spalling or depressions (see Figure 27 and 28). Diamond grinding of the replaced slabs is recommended to provide a smooth finish. Diamond grinding is discussed later in this Guide.

**Figure 27. Multiple Slab Replacement with Dowel Basket and Dowel Bars Being inserted at the Joint.**

**Figure 28. Newly Replaced Slab**

Concrete slabs should be replaced with similar concrete materials. However, the use of rapid strength concrete in the replacement of concrete slabs should be given consideration to minimize impact on traffic and to enable opening the facility to traffic in a minimal amount of interruption time.

Hot mix asphalt (HMA) should not be used to replace concrete slabs. This is because the HMA will not provide support to adjacent concrete slabs, thus causing them to deteriorate faster. As an exception, however, HMA may be used in the following situations:

1. As an emergency fix (as determined by District Maintenance) for the slabs that need to be replaced before a project could be programmed and/or put out to construction.
2. As a temporary fix for a roadway that has a programmed project to either replace the lane, overlay the lane with concrete, or crack-seat-and-HMA overlay the lane within 4 years.

Note that for emergency fixes, if it will take longer than 4 years to program and put a slab replacement project out to construction, then using concrete to replace the slabs is recommended. When HMA is used as an emergency fix, the HMA will need to be removed and replaced when the follow-up slab replacement project is constructed.

Slab replacement may include replacing existing cement treated base (CTB) or lean concrete base (LCB) with rapid strength concrete placed in a separate lift from the surface concrete. Before an adequate design for slab replacement can be developed, it is important that an assessment of the underlying base be made. Falling Weight Deflectometer (FWD) testing or coring of the pavement and/or a visual inspection of the underlying material is highly recommended. Failure to adequately repair underlying base layers during a slab replacement will result in premature failure of the slab leading to higher maintenance costs and more negative impacts on traffic. Consult with the District Materials Engineer for pavement studies including

FWD study, subsurface investigation to assess the condition of the underlying base and subgrade, and pavement structure recommendations, including recommendations for removal of existing base(s). Both FWD testing and pavement coring can be arranged with the Pavement Field Testing Unit in Materials Engineering and Testing Services (METS) if your District does not have this capability.

In the absence of field testing, the following "rules–of-thumb" are recommended for determining whether to replace the base layer in a slab replacement project that is intended to last for 10 years or less:

- if the existing base is cement treated, asphalt treated, or a permeable base and the slab has settled by 1/2 inch or more, to the base needs to be removed.
- when lean concrete base is the existing base, then most likely it is still in good condition.
- if the existing base is a granular base, the base will need to be re-graded and compacted prior to placing the new concrete. Specifications should include language requiring the contractor to have Class 2 Aggregate Base on site and be available to replace any missing or poor material found.

Because field conditions cannot accurately predict when or when not to replace the base layer, designers need to provide flexibility in the design details and contract documents to be sure that the resident engineer knows what the expectations are and has the tools for making the right decisions in the field. Including supplemental funds in the contract estimate for additional slab or base replacement and providing good notes to the resident engineer will help provide these tools.

The slab replacement and grinding (see Section 3.4.2 for this topic) combination rehabilitation strategy when performed at the right time is expected to provide approximately and additional 10 years of service without significant pavement maintenance (some additional slabs may need to be replaced within the 10 years). Standard Plan P8 provides standardized details for individual slab replacements. The details and recommendations found in the standard plans and this guide are only for designs intended to last 10 years or less.

Care should be taken to review and compare percentage of slab cracking from Pavement Condition Survey reports over several years, which can be accessed in the Department Pavement Engineering website, to determine the rate of deterioration. The rate of deterioration will indicate how many additional slabs are expected to need slab replacement at the time of construction, which will help establish what quantities and costs to include in scoping documents and final plans. If the rate of deterioration (slab cracking) is increasing rapidly, consideration should be given to using a rehabilitation strategy. Also, a rehabilitation strategy should be done if the life cycle cost analysis indicates that it is more cost effective than slab replacement.

The Table on page 21 of the Slab Replacement Guidelines describes the various types of slab replacements and the design features that should be included with each type.

Standard Plan P8 is used for details on slab replacements. Construction details sheets of the design plans should show a plan and cross section view of a typical replacement showing limits, depths (including the extent of base being replaced), materials used for replacement, limits of lifts for placing the replacement material, and existence of dowel bars and tie bars. Table 3 below lists additional standard plans, which provide additional details related to typical lane, shoulder, and slab replacements. The applicable details should be included in the project construction details sheets.

**Table 3. List of Standard Plans Needed in Slab Replacement Projects.**

| Design Feature | Standard Plan | Comments |
|---|---|---|
| Dowel Bar Details | P10 | 1. Include for all lane replacements using Std Plan P1 or P2.<br><br>2. Include for slab replacements with dowel bars |
| Dowel Bar Basket Details | P12 | 1. Include for all lane replacements using Std Plan P1.<br><br>2. Include for slab replacements with dowel bars where it is possible that consecutive slabs will be replaced. |
| Tie Bar Basket Details | P17 | 1. Include for lane replacements where adjacent lanes/shoulders are being replaced or project includes individual slab replacements in the adjacent lanes/shoulders.<br><br>2. Include for slab replacements with tie bars. |
| Lane Schematics and Isolation Joints Detail | P18 | 1. Include when transverse joints for replacement lanes, shoulder, or slabs are not aligned with existing adjacent slabs.<br><br>2. Include when an existing isolation joint needs to be replaced. |
| Joint Details | P20 | 1. Include for lane/shoulder replacements<br><br>2. Include for slab replacements where joint seals are warranted per Ch. 9 of the "Slab Replacement Guidelines" |
| Drainage Inlets | P45 & P46 | Include as needed when drainage inlets are to be placed within the limits of concrete pavement. |

It is preferred that the Designer identifies the locations of all slabs to be replaced on the project plans. This will provide the best information to the Resident Engineer and Contractor in identifying locations of slabs to be replaced, traffic control needs, and to visually determine how many slabs have been completed. Although not preferred, a quantity table can be used as an alternative to show the location and number of slabs to be replaced. In this case, the quantity table will need to include longitudinal location (station or post mile), horizontal position (offset from station line or lane# or shoulder reference), width of replacement, and length of replacement for each slab being replaced.

#### 3.4.1.1 Partial Slab Repair

Partial, full-depth slab repair involves removing and replacing at least a portion of a slab to the bottom of the concrete in order to restore areas of deterioration. Partial slab repairs can improve pavement ride quality and structural integrity, and can extend pavement service life. Partial slab repairs are typically used at deteriorated joints or cracks.

The following is a list of the steps involved in partial slab full-depth repairs:

- Full-depth saw cut around the perimeter (12 ft wide and 6 ft long) of the repair area.
- Removing the deteriorated concrete.
- Compacting existing or added base material.
- Installing full depth 0.25 ft thick polyethylene foam expansion joint filler along the transverse joints prior to placing the new concrete necessary to inhibit spalling along the transverse joints.
- Reestablishing load transfer along the full-depth sawcut (see Figure 29).
- Opening to traffic once the desired strength of the concrete has been attained (see Figure 30).

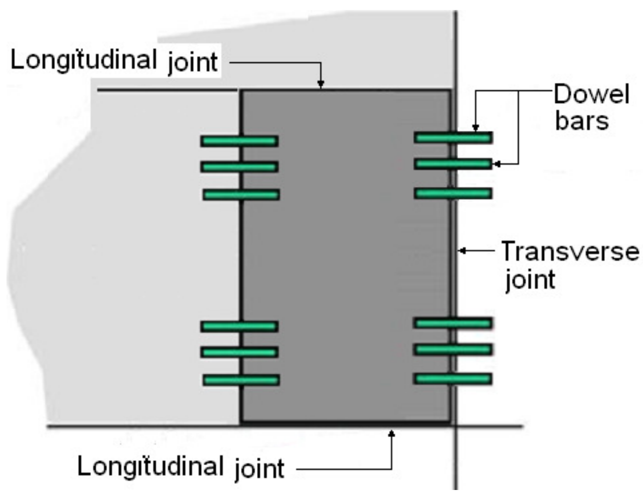



**Figure 29. Dowel Bars Tied to Existing Concrete Slab**

**Figure 30. Finished Partial Repaired Concrete Slab**

A bond breaker should be used between the base and the concrete. There are four options for bond breakers with two different circumstances in which they may be used. If the base material is to be left in place, paving asphalt or pigmented curing compound should be applied. If the base is to be removed, and RSC is used as the base, then curing paper or polyethylene film should be placed. The curing compound or paving asphalt should not be used when base is removed and RSC is placed because these bond breakers would need to "break or set up" before the final wearing course is placed.

When replacing base and wearing course, there are two reasons why it is not recommended that concrete (rapid set or conventional) be placed full depth:

(1) Section of concrete will have problems dissipating the heat of hydration that could lead to premature cracking. Unexpected thicker pavement structures cause problems for Maintenance working at slab repairs and for Contractors because they require much more effort to remove them.

(2) The Department has agreed to maintain the existing paving structures to provide consistency for future maintenance and rehabilitation efforts.

**3.4.1.2 Standard Special Provisions (SSPs)**

Several standard special provisions (SSPs) have been developed for slab replacement. SSPs can be found on the Caltrans Pavement Engineering website Plans & Specs page. These SSPs cover most but not all situations that may be encountered during construction.

Instructions are included in the SSPs for making several modifications to adapt the SSP for project specific issues. For situations which are not covered in the SSP instructions, see the procedure for developing and obtaining concurrence for nonstandard special provisions on the

Pavement Engineering website. Table 4 below provides a summary of various cases of slab replacement and the standard special provision developed for each case.

**Table 4. Slab Replacement Design Life and Related SSPs**

| Category | Use for | SSP | General Comments |
|---|---|---|---|
| Slab Replacement (no dowels) | 1. Emergency situations<br><br>2. Short term slab replacement (1-5 years)<br><br>3. Long term with very short (< 8 hrs) construction windows | 40-020 - “Replace Concrete Pavement (Rapid Strength Concrete)” | The only option available for use is the rapid strength concrete. If conventional concrete is to be used, contact METS – Office of Rigid Pavement Materials and Structural Concrete for assistance in modifying SSP. |
| Slab Replacement (with dowels) | Long term slab replacement (5-10 years) | No SSP currently exists for this option. Contact METS – Office of Rigid Pavement Materials and Structural Concrete for assistance in developing a special provision. | |

#### 3.4.1.3 Cost Estimation

For slab replacement, all the costs for removing and replacing concrete layer and base layer are paid for under Item 401108 “Replace Concrete Pavement (Rapid Strength Concrete)” except as noted below:

- Drill and bond dowel bars are paid for separately.
- Diamond grinding of finished slabs is paid for separately.
- Dowel bar retrofit is paid for separately if included in the project.

Generally, unit cost will vary with the material used and the size of the project. A good rule of thumb is "the shorter the construction window allowed, the higher the cost". Mobilization of equipment, traffic handling and removal of equipment each evening is associated costs that must be considered.

A contractor's production will increase as longer construction windows are provided. In some instances, it may be advantageous to have an entire weekend closure (approximately 55 hours) for a specific section of freeway to facilitate contractor's production. In many cases, an incentive/disincentive clause should be considered if work is critical for a particular highway depending on the traffic conditions.

It is important for the design engineer to make a reasonable estimate in their PSR or PSSRs to adequately fund slab replacements. In many instances, this item has been under-funded. This occasionally causes projects to shorten limits, revise work items, or even going back to the California Transportation Commission for additional funds request. Inadequate funding can be a significant stumbling block. When completing the final engineers estimate prior to PS&E, it is also important to include supplemental funds for unforeseen slab and base replacement. "Replace concrete" unit prices have varied from project to project statewide. It is strongly suggested that the designer check the latest Contract Cost Data for unit price information and make an appropriate estimate based on the type of work projected. Contract cost data information can be found in the Caltrans Office of Engineer web site at http://t8web.dot.ca.gov/design/contractcost/. Designers should check with their District Construction personnel in regards to what concrete plant would be willing to handle specialty cements or using accelerating admixtures. Concrete haul routes, delivery times, availability of scheduling production for specialty concretes can affect the costs. Relying solely on historical data may be erroneous.

As a rule of thumb, the following multipliers of Item 401000 "Concrete Pavement" may be used when historical data is limited for estimating cost for Item 401108 "Replace Concrete Pavement (Rapid Strength Concrete)":

- For 6 to 8 hours construction window: cost is 3 to 5 times that of conventional concrete
- For 12 to 24 hours construction window: cost is 2 times that of conventional concrete
- For 24 hours or more construction window: cost is equal to that of conventional concrete plus a percent of the conventional concrete price.

#### 3.4.1.4 Calculating Working Days

Adequate contract time needs to be estimated to allow for obtaining Rapid Setting Concrete materials, testing, and constructing and evaluating test strips. Modulus of rupture test results will be required for 21-day breaks. Failing 21-day breaks could indicate corrective work is necessary. The working days should allow for the advance testing and 21-day breaks, but not corrective work.

### 3.4.2 Diamond Grinding

In CAPM projects, diamond grinding is used to remove roughness caused by slab faulting. While it can reduce roughness due to faulting of transverse joints and cracks, it will not address the cause of faulting nor it will it prevent roughness in the future as a result of additional faulting. Chapter 9 in the "Slab Replacement Guidelines" provides additional information on diamond grinding.

Further discussion on diamond grinding can be found in Section 3.3.1 of this Guide.

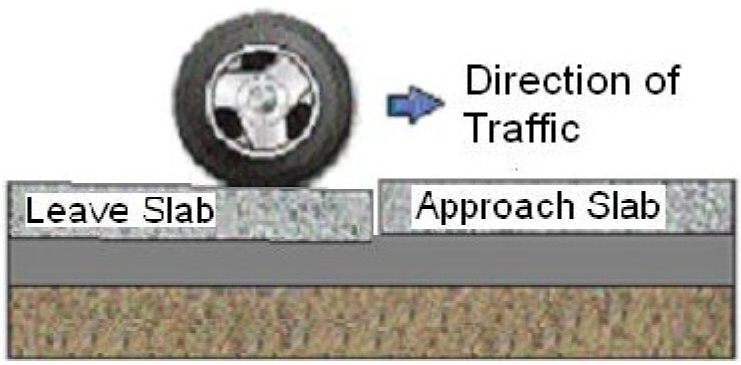
### 3.4.3 Dowel Bar Retrofit

Dowel Bar Retrofit (DBR) is a pavement rehabilitation technique that is used to increase or restore lost load transfer capability of existing, in-service, nondoweled jointed plain concrete pavements (NDJPCPs).

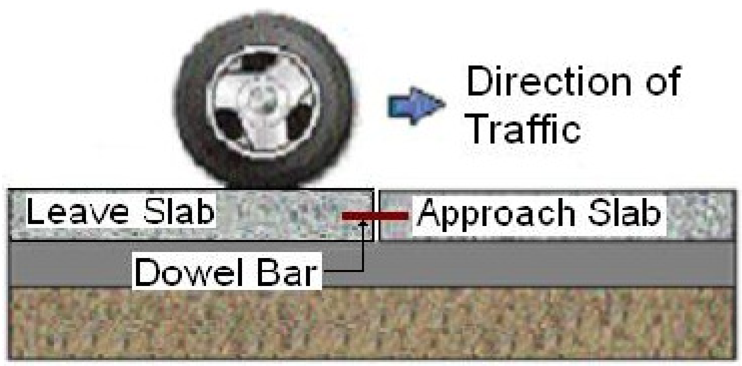
The following are the differences in load transfer efficiency for doweled and nondoweled slabs:

- Nondoweled slab on aggregate base 30% - 50%
- Nondoweled slab on lean concrete base 50% - 70%
- Doweled slab on either lean concrete base or cement treated base 80% - 95%

Load transfer is the mechanism through which wheel loads are conveyed from one slab to the next through shear action (See Figure 31) that develops along the transverse joints.




**Load Transfer = 0% (Poor)**




**Load Transfer = 100% (Good)**

**Figure 31. A schematic of Load Transfer Across Transverse Joint**

It is an important consideration in the design of concrete pavements because the effective transfer of the wheel load from one slab to the next will significantly reduce the magnitude of the stresses and deflections at the transverse joints thus reducing their potential to breaking and faulting. This is accomplished through the placement of mechanical load transfer devices; commonly steel dowels, coated with epoxy, in sets of 3 or 4, within each wheel path of the traveled lane(s) (see Figure 32) at the transverse joints locations. Dowel bar retrofitting is usually followed by pavement surface grinding.

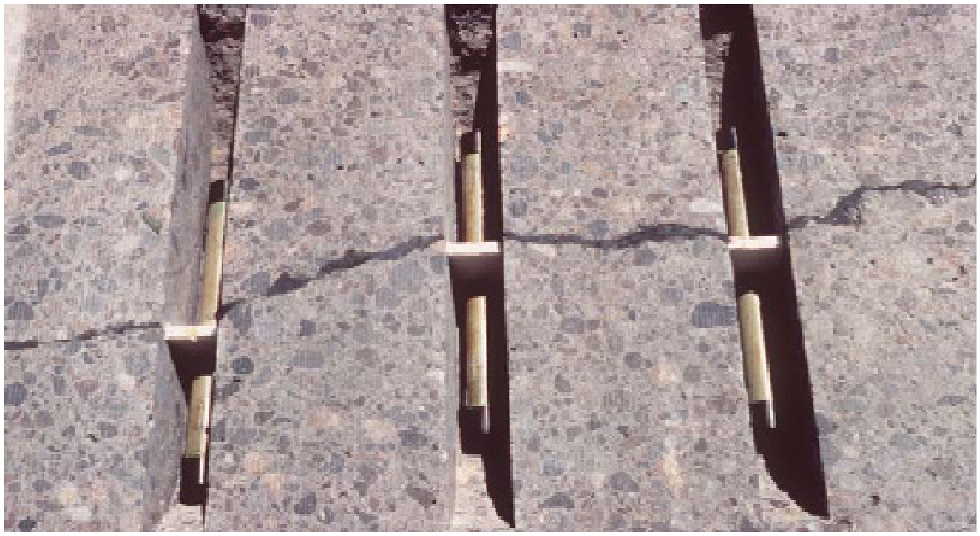


**Figure 32. Dowels Placed in Slab Across a Functional Transverse Crack**

Load transfer efficiency (LTE) of transverse joints or functional transverse cracks may be determined through nondestructive testing using falling weight deflectometer (FWD). LTE is determined as the ratio (expressed in percentage) between the deflection measured at the unloaded side of the joint and the deflection measured at the loaded side of the joint. As illustrated in Figure 31, when two adjacent slabs are disconnected, LTE is zero, and when there is full load transfer the LTE approaches 100%. In a subsequent section of this Guide, criteria for determining the need for DBR based on LTE, faulting, and percentage of cracked slabs are presented.

### 3.4.3.1 Identifying Candidate Projects

Dowel bar retrofitting is well suited for existing non-doweled JPCP (NDJPCP) that has poor load transfer at the transverse joints and/or mid-panel transverse cracks, but also have significant remaining structural service life. NDJPCP considered for dowel bar retrofit should have few, if any, joints with deterioration related to poor concrete durability and/or fatigue cracking. A good example of a pavement that is a candidate for dowel bar retrofitting is a pavement with structurally adequate slabs (proper thickness), but a significant loss of load transfer due to poor aggregate interlock, and/or erosion of the base or subbase that has caused the loss of support at the joint. A second example is a relatively new pavement that, because of insufficient slab thickness, excessive joint spacing, 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.

Not good candidates for DBR are:

- Pavements that have little remaining structural life, as evidenced by a substantial amount of slab cracking or faulting. 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 load transfer restoration is not a cost-effective rehabilitation option. A recommended rehabilitation strategy for these pavements is slab replacement with dowel bars in the truck lanes (see Guide for Rehabilitation of JPCP- Section 3.2 and Appendix B for this topic).

- Pavements exhibiting D-cracking (see Figure 33) because the concrete in the vicinity of the joints and cracks is likely to be weakened and thus retrofit dowel bars would not have sound concrete to bear against. D-cracking occurs when freezing and thawing cycles cause crack formations parallel to transverse and longitudinal joints and toward the center of the center of the slab as shown in Figure 14. 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 reactivity (ASR). Reactive aggregate distress occurs in pavements in which certain types of siliceous aggregates react with the alkalis in the portland cement, producing a gel product that expands in the presence of water and fractures the cement matrix, eventually producing cracks in the slab. As with D-cracking, the concrete in the vicinity of joints and cracks is likely to be weakened and the dowel bar retrofit would not have sound concrete to bear against.

**3.4.3.2 Measuring Load Transfer Between Slabs**

A determination of load transfer for a representative number of transverse joints in a given project should be made to identify whether or not transverse joints would benefit from dowel bar retrofit. Heavy-load deflection devices such as the Falling Weight Deflectometer (FWD) are employed to perform deflection measurements. A load is applied at one side of the transverse joint and deflection of slab is measured under the load as well as on the other side of the joint (the unloaded side). The load transfer efficiency (LTE) is the ratio between the unloaded side deflection and the loaded side deflection is expressed as percentage.

Some general condition criteria that warrant DBR include:

- Faulting ≥ 0.10-inch and < 0.50-inch and number of panels cracked ≤ 10%,
- Faulting ≥ 0.50-inch (12.5 mm), number of panels cracked ≤ 10% & ADT ≤ 50,000,
- Load transfer efficiency of 60% or less
- Differential deflection (between both sides of the joint) of 10 mils or more
- IRI = 150 – 200 inches/mile, or Ride Score 20 – 40.

No DBR will be needed if faulting < 0.10-inch and number of cracked panels ≤ 10%. Also, if faulting ≥ 0.50-inch, number of panels cracked ≤ 10%, and ADT > 50,000 no DBR will be beneficial, and instead reconstruction is recommended.

**3.4.3.3 Design and Material Considerations**

Dowel bars are made of steel with a diameter of either 1-1/4 inch or 1-1/2 inch. The larger diameter bar is used in thicker pavements ≥ 0.70 ft. Dowel bars are spaced 12-inches on center in sets of three or four per wheel path at the transverse joints locations. The edge distance from the longitudinal joint to the first dowel bar varies for the outside truck lane. This edge distance is dependent on whether the existing outer shoulder is asphalt or concrete pavement without tie bars in the longitudinal joint in the retrofit lane. If tie bars are not located in the longitudinal joint then the edge distance will be reduced to resist the greater stresses that occur along the edge of pavement.

Industry and FHWA recommend the dowel bar retrofit assembly as shown on Standard Plan P7. The smooth dowel bars provide shear load transfer while also permitting horizontal opening and closing of the joint in response to daily and seasonal temperature and moisture fluctuations. The dowel bars, including the ends, must be protected from corrosion using a factory-applied epoxy coating as specified in Section 52-1.02B – Epoxy-coated Reinforcement. All dowel bars are coated with a bond breaker application of petroleum paraffin based lubricant or white-pigmented curing compound to keep the backfill grout from adhering to the bar.

Saw cutting of the concrete pavement is performed by a gang saw that can simultaneously saw uniformly parallel 6 or 8 cuts for the 3 or 4 slots. The use of single blade saw cutting machines cannot reliably create parallel cuts and therefore, are not allowed. Saw cuts that are not parallel will create misaligned dowel bars that will cause the joint to lock up and subsequent cracking to occur. Saw cuts can be made up to 6 days prior to concrete fin removal. Traffic may be allowed over these saw cuts prior to removal.

Saw cuts are made to the correct depth to place the dowel bar in the mid-panel depth when the slot material is removed. Saw cuts that are too deep will cause corner cracking after traffic is allowed on the pavement. Corner cracks are cracks that proceed at a 45° angle from the outside slot to the edge of the pavement.

#### 3.4.3.4 Dowel Bar Installation

Dowel bars are placed after the concrete pavement slots have been saw cut to the correct depth and cleaned. Prior to the dowel bars installation, dowels are fitted with an expansion cap to allow for horizontal movement on the longitudinal axis. Mounting chairs are used to position the dowel bar in the slot. These chairs elevate the dowel bar above the bottom of the slot to allow backfill grout material to flow around the dowel bar. A foam core insert placed in the transverse joint is also needed to re-establish the transverse joint through the backfill material and to prevent the backfill material from flowing into the slot created below the joint saw cut or into the sides of the existing joint. Caulking filler is used as added protection to prevent backfill grout from entering the slot created by the saw cut in the transverse joint. The caulking filler and foam core insert placement are extremely important. If grout enters the joint, then the joint may "lock-up" resulting in cracking or joints spalling.

Fast setting grout is used as the backfill material. The grout material specified will have minimal shrinkage and quick curing properties. Normally, dowel bars will be used in urban areas where traffic control will restrict the daily construction windows to overnight work. This will require the grout to cure in a 3 or 4 hour time period and limit the contractor's production somewhat due to the mobilization and construction windows set by the contact. In addition, the temperature requirement for placing grout is restricted to pavement temperatures of 10°F or warmer. Longer construction windows and daytime operations will enhance productivity and may reduce unit costs for dowel bar retrofits.

#### 3.4.3.5 Effective Placement

Dowel bars should be placed in lanes where there is truck or bus traffic (HOV/Outside lanes). Three or four dowel bars should be placed directly beneath truck tire wheel path to support the load transfer between slabs. Four dowel bars should be used where anticipated future traffic loading is greater than 15,000 AADTT or a Traffic Index of 12. Placing dowel bars in non-truck lanes is not cost effective considering the lower stresses due to lighter vehicle traffic. If traffic loading is great enough, then retrofitting dowel bars in non-truck lanes is justifiable. In areas where the lane lines do not coincide with the longitudinal joints, placement of dowel bars may not be aligned with the wheel path, thus negating the effectiveness of the dowel bars as a load transfer device. Engineers should consult with Office of Pavement Design for advice on dealing with this situation. In all likelihood, placing dowel bars at 12-inches on center across the transverse joint and perhaps adding tie bars across the longitudinal joint will alleviate this problem. It should be noted that the dowel bar placement should be parallel to the longitudinal joint without regard to the lane lines.

#### 3.4.3.6 Use of Dowel Bar Baskets when Multiple Adjoining Slabs are to be Replaced Within the Same Lane

Occasionally, Designers or Contractors have requested to use dowel bars with dowel bar baskets in the transverse joints of adjacent slabs, which are to be replaced in the same lane. Dowel bar baskets (refer to Standard Plans P10) are not a retrofit strategy, but a new JPCP feature. If this is to be done, it is important that the dowel bar baskets ordered match the existing joint's skew configuration (either skewed or perpendicular). Using dowel bars with dowel bar baskets will work, but the Designer / Contractor should avoid intermixing dowel bar retrofit with regular dowel bar installation. Unless there are a significant number of locations where multiple adjoining slabs within the same lane are to be replaced within one project, construction contract administration can be complex and unit costs can be expensive. When using dowel bar baskets, the dowel bars are to be spaced at regular intervals as shown on the Standard Plan P10 for new transverse joint locations. If dowel bars with dowel bar baskets are to be used, then the appropriate SSP and details from Standard Plans P10 and P12 need to be included in the project plans and specifications, along with project plan sheets showing the specific locations where dowel bar baskets are to be placed. The appropriate bid items will also need to be added to the Engineer's estimate for the project.

Dowel bar retrofitting followed by diamond grinding provides for an extended life and smoother riding surface for existing concrete pavements. The Department's design standards for dowel bar retrofit are detailed in Standard Plan P7 and corresponding Standard Special Provision 40-015, "Retrofit Existing Concrete Pavement with Dowel Bars at Transverse Joints". The most current versions of these standards should be incorporated into the project PS&E documents. The latest versions of these standards may be found at the Office of Engineer website at http://www.dot.ca.gov/hq/esc/oe/project_plans/highway_plans/stdplans_US-customary-units_06/viewable_pdf/2006-Std-Plns-for-Web.pdf.

#### 3.4.3.7 Performance

Dowel bar retrofits have performed well in other States. Georgia, Florida, Washington and Minnesota are some of the States that have used dowel bar retrofit successfully. In some locations, concrete slabs that have been dowel bar retrofitted have been in service and have performed well for 15 years under heavy traffic. In Caltrans, DBR is considered to be a 10-year strategy.

#### 3.4.3.8 Cost

The average cost has ranged from $25 to $35 per dowel bar for routine installations in 2006. Note that cost will vary based on location of project, quantity requested, and the price of raw material and labor. For the most recent bid prices, check out the Contract Cost Data on the Office Engineer website at http://t8web.dot.ca.gov/design/contractcost/.

## 3.5 Roadway Rehabilitation Strategies

### 3.5.1 Lane Replacement

Lane replacement is the removal of consecutive slabs 100 ft or more in total length that would be replaced and may include the removal/replacement of base and subbase. Lane replacement is done when the concrete pavement structure has deteriorated to the point that preservation strategies are not practical or cost effective. Alternatives might include full lane replacement for the outer (truck) lanes with minor work on the inside lanes. This strategy is most useful when only some of the lanes need rehabilitation or if overlays are not practical because of project constraints. This strategy can achieve a 20- to 50-year life depending on the structural thickness used for the lane replacement and the condition of the foundation. While lane replacement strategy involves, as a minimum, removing and replacing the concrete surfacing, the removal of the base and subbase may also be required depending on whether they are still in good condition or not.

When at least 10% of the slabs in a given lane warrant replacement, replacing the entire lane has typically been more cost-effective alternative than slab replacement. This can be verified on a project-by-project basis with life cycle cost analysis.

The pavement engineer should do the following when designing this rehabilitation strategy for a given project:

a) If the transverse joints between the new and existing pavement do not match each other in orientation and location, or the adjacent lane shows signs of distress (fatigue cracking, corner cracking), then tie bars shall not be placed. Instead, an isolation joint should be placed, separating the existing from the new concrete pavements. The isolation joint is a separate pay item. Note that transverse joint spacing patterns for new pavement shall not be altered from what is in the current standard plans in order to match old joint spacing patterns, particularly those with joint spaces greater than 15 feet. Research has shown that slabs longer than 15 feet crack at least twice as often and slab shorter than 15 feet.

b) If the outside through lane is to be replaced and the adjacent through or auxiliary lane has more than 3% of its slabs with Stage 3 cracking, then the adjacent lane should be replaced as well. Replacing both outer lanes (lanes where trucks are permitted) at the same time is typically more cost effective than replacing them at separate times, especially when one considers that paving machines are typically built to pave two lanes at once and that the duplication of traffic control costs to replace the lanes separately can be avoided. This can be verified with a life cycle cost analysis.

c) Outer lane replacement can create problems with the existing edge drains. Generally, care must be taken to prevent clogging of the existing edge drain system during rehabilitation. In this situation the length of slotted edge drain adjacent to, and 12 inches beyond each end of the concrete pavement slab(s) must be removed along with the existing treated permeable material at the same time the existing slab(s) are removed to provide space for the side forms. After the concrete pavement has cured and the forms have been removed, Class 2 aggregate base, if needed, is placed in the trench previously occupied by the treated permeable material and compacted up to the bottom of the existing slotted drain stubs. Unslotted PVC pipe is attached using band couplers to reconnect the edge drain system and additional Class 2 aggregate base is placed and compacted to within 3.0 inches of the top of the new concrete pavement slab. The remaining 3.0 inches is backfilled with hot mix asphalt (HMA).

In the following sections, some issues that need to be considered when planning and performing lane replacement for a project are provided, along with information necessary for the pavement design engineer.

#### 3.5.1.1 Field Investigation and Design

Lane replacement is engineered using the catalogs found in Index 623.1 of the HDM. Attention should be given to maintaining existing drainage patterns underneath the surface layer, (see Chapter 650 of HDM for further guidance).

Before an adequate design for lane replacement can be developed, it is important that an assessment of the condition of underlying base be made. Falling Weight Deflectometer (FWD) testing and/or coring of the pavement and a visual inspection of the underlying material is highly recommended. Underlying base layers that are not in good condition should be adequately repaired during a lane replacement so that premature failure of the new pavement structure leading to higher maintenance costs and more negative impacts on traffic can be avoided. Any existing base or subbase in good condition should remain. In order to have a uniform underlying material, the new pavement structure should be engineered by selecting the same existing base and subbase material. The thickness of the base or subbase material determined in the new design and used in construction is adjusted by how much of the existing base or subbase material that is to remain in place. Consult with the District Materials Engineer for pavement studies including FWD study, subsurface investigation to assess the condition of the underlying base, subbase, and subgrade, and pavement structure recommendations, including those for removal of existing base(s). Both the need and scheduling of FWD testing and pavement coring can be arranged through District Materials Engineer. Although not recommended, if no base investigation was performed, the following could be assumed for estimating purposes:

- If the existing base is cement treated base, hot mix asphalt base, or a permeable base and the slab has settled by 1/2 inch or more, one can assume that the base needs to be removed.
- When the existing base is lean concrete base, then most likely it is still in good condition.
- For lane replacements on older pavements (exceeded original pavement design life), replacing the base and subbase layers with new pavement structures will typically increase the life and enhance the performance of the new pavement. This is because bases and subbases deteriorate over time from loads, water intrusion, and other reasons.

Because field conditions may not accurately predict when or when not to replace the base layer, designers need to provide flexibility in the design details and contract documents to be sure that the resident engineer knows what the expectations are and has the tools for making the right decisions in the field. Including supplemental funds in the contract estimate for additional slab or base replacement and providing good notes to the resident engineer will help provide these tools.

#### 3.5.1.2 Standard Plans and Construction Details

Table 5 below lists a number of standard plans necessary for the design engineer overseeing typical lane and shoulder replacement projects and should be included in the project construction details sheets. The criteria when to do doweled or nondoweled replacements are covered in HDM Index 622.4 – Dowel Bars and Tie Bars.

**Table 5. Standard Plans Used in Lane Replacement Projects**

| Design Feature | Standard Plan | Comments |
|---|---|---|
| Jointed Plain Concrete Pavement | P1 | Include this plan for slab and lane replacements with dowel bars and tie bars where slabs will be replaced. |
| Jointed Plain Concrete Pavement – Widened Slab Details | P2 | Include this plan for widened slab and lane replacements in the adjacent shoulders. |
| Jointed Plain Concrete Pavement – Nondoweled Shoulder Addition/Reconstruction | P3 | Include this plan in shoulder addition or reconstruction where adjacent lanes are nondoweled. |
| Dowel Bar Details | P10 | 1. Include this plan for all lane replacements using Standard Plan P1 or P2.<br><br>2. Include this plan for slab replacements with dowel bars |
| Dowel Bar Basket Details | P12 | 1. Include this plan for all lane replacements using Standard Plan P1.<br><br>2. Include this plan for slab replacements with dowel bars where it is possible that consecutive slabs will be replaced. |
| Tie Bar Basket Details | P17 | 1. Include this plan for lane replacements where adjacent lanes/shoulders are being replaced or project includes individual slab replacements in the adjacent lanes/shoulders.<br><br>2. Include this plan for slab replacements with tie bars. |
| Lane Schematics and Isolation Joints Detail | P18 | 1. Include this plan when transverse joints for replacement lanes, shoulder, or slabs are not aligned with existing adjacent slabs.<br><br>2. Include this plan when an existing isolation joint needs to be replaced. |
| Joint Details | P20 | 1. Include this plan for lane/shoulder replacements.<br><br>2. Include this plan for slab replacements where joint seals are warranted per Chapter 9 of the "Slab Replacement Guidelines". |
| Drainage Inlets | P45 & P46 | 1. Include these two plans as needed when drainage inlets are to be placed within the limits of concrete pavement. |

Lane and shoulder replacements are usually shown in the same manner as widening and new construction on the project typical sections and layout sheets.

### 3.5.1.3 Standard Special Provisions (SSPs)

Several standard special provisions (SSPs) have been developed for lane/shoulder replacements and others are being developed. SSPs can be found on the Caltrans Pavement Engineering website at http://www.dot.ca.gov/hq/oppd/pavement/specs.htm. These SSPs cover most but not all situations that may be encountered during construction. Instructions are included in the SSP for making several modifications to adapt the SSP for project specific conditions. For projects where modifications are needed but are not covered in the SSP instructions, see the procedures for developing and obtaining concurrence for nonstandard special provisions (nSSP) on the Pavement Engineering website.

In many ways, the specifications used for lane/shoulder replacements are the same as would be used for new pavement or widening. Standard specifications and special provisions for removing existing pavement and placing new pavement can be found on the Pavement Engineering website. Note that specifications for every possible type of work have yet to be developed. Where no specification or special provision exists for a type of work needed for your project, contact the specification caretaker for similar specifications. A list of caretakers is found on the same pavement specification page of the Pavement Engineering Website. For example, currently no special provision exists for the placement of rapid set concrete pavement for lane replacements. If this special provision is needed, METS – Office of Rigid Pavement Materials and Structural Concrete (who is the caretaker for concrete specifications) should be contacted for assistance in developing a special provision. Note that not all concrete mixes are the same. Some may achieve strength faster but also may not last as long as other types of mixes. Until more detailed research and guidelines are developed, designers should work with the Office of Rigid Pavement Materials and Structural Concrete in METS on the most appropriate type of concrete to use for lane replacements.

### 3.5.1.4 Cost Estimation

For lane replacements, the costs for removing and replacing concrete pavement and base layer (if necessary) are divided in the following items of work:

- Removal of existing concrete pavement.
- Removal of underlying layers (base/subbase), as needed. This may be combined with concrete pavement removal.
- Placement of new base layer(s), as needed.
- Drill and bond tie bars and/or dowel bars.
- Placement of new concrete pavement.
- Diamond grinding of adjacent existing concrete pavement that will remain following construction.

Determining the unit cost of lane replacement work will vary depending on the type of materials used. The Contractor will select concrete cementing materials based on the length of the construction window dictated in the traffic handling charts. Note that the shorter the construction window allowed, the higher the cost. Mobilization of equipment, traffic handling and removal of equipment each evening is associated costs that must be considered.

A contractor's production will increase as longer construction windows are provided. In some instances, it may be advantageous to have an entire weekend closure (approximately 55 hours) for a specific section of freeway to facilitate contractor's production. In many cases, an incentive/disincentive clause should be considered if work is critical for a particular highway depending on the traffic conditions. It is important for the design engineer to make a reasonable estimate in their PSR or PSSRs to adequately fund slab replacements. In many instances, this item has been under-funded. This occasionally causes projects to shorten limits, revise work items, or even going back to the California Transportation Commission for a funds request. Inadequate funding can be a significant stumbling block.

When completing the final engineers estimate prior to PS&E, it is also important to include supplemental funds for unforeseen base repair/replacement that were overlooked in the pavement distress evaluation process that require rehabilitation not shown in the project plans.

The volume of concrete is calculated based on the width, thickness, and length shown on the project plans. The quantity of concrete is measured and paid for by the cubic yard of including furnishing and placing the dowel bars, tie bars and saw cutting and sealing of joints. See Section 40-010 of the Special Provisions for additional information on measurement and payment of concrete pavement.

### 3.5.2 Unbonded Rigid Overlay

#### 3.5.2.1 Definition

Unbonded overlays are the placement of concrete over an existing concrete pavement with a relatively thin hot mix asphalt (HMA) interlayer as a bond breaker that would otherwise be established between the existing and new concrete (see Figure 33). The HMA interlayer serves to reduce reflective cracking and provides flexibility for curling of the concrete pavement due to temperature differentials between the concrete top and bottom surface.

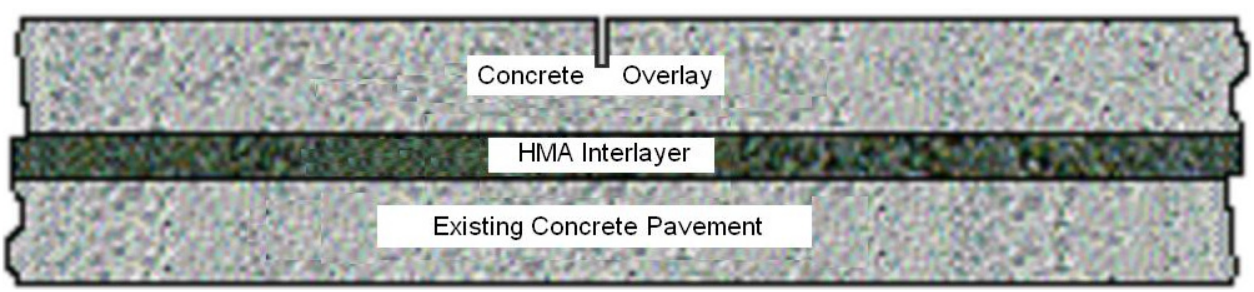



**Figure 33. Typical Section of Unbonded Concrete Overlay**

The HMA interlayer is the critical portion of unbonded overlays. The pavement over which the interlayer is to be placed must be clean of any loose materials and repaired using rotomilling if excessive voids exist or loss of support is evident (see Figure 34 and 35).

**Figure 34. Rotomilling of Existing Pavement**

**Figure 35. HMA Bond Breaker over Rotomilled Pavement**

The top of the HMA interlayer should be cured with a wax-based compound to ensure no bond forms between the HMA layer and the concrete overlay. The curing compound also allows for reflection of heat and/or energy that may increase the surface temperature of the interlayer.

If the existing concrete pavement structural section is in poor condition (greater than 10% third stage cracking), exhibits severe D-cracking, is a composite pavement (HMA over concrete pavement) with severe rutting, or the pavement structure is exhibiting rocking of the slabs due to voids in the base layer or lack of support, then this strategy may be considered. Existing saturated subgrade conditions and poor soils may benefit from this strategy as preparation of the pavement structure or repair of the subgrade is minimized since the overlay will be placed over the existing surfacing.

### 3.5.2.2 Design

The thickness design of the unbonded concrete overlay follows the design for new JPCP as outlined in HDM Tables 623.1B through 623.1M, based on the project design traffic index, basement soil R-value, and climatic condition. Therefore, the minimum concrete pavement thickness for unbonded overlays is 0.70 feet. Depending on the thickness of the overlay, this strategy can generally achieve 20 to 40 years of service life.

### 3.5.2.3 Construction

Repair of the existing pavement structure is needed if shattered slabs, settlements, deflecting and pumping slabs exist. Deflection testing is recommended to assess the support condition of the pavement. Transverse joint deterioration such as spalling, D-cracking, and faulting should be corrected by filling in with patches or by partial slab replacement if the deterioration goes through the entire slab thickness. Faulting of slabs greater than 0.10 inch should be repaired by grinding. The cause of the faulting should be addressed and the cause remedied as explained earlier in Table 1.

The concrete overlay should follow the placement and finishing requirements for new construction, including texturing, joint placement, joint sealing, and pavement sealing (see Figure 36). Dowel bars and tie bars are to be included, respectively, for load transfer in transverse joints and in longitudinal joints just as in new JPCP construction in accordance with HDM Index 622.4.

**Figure 36. Construction of Unbonded Concrete Overlay**

Traffic can use the adjacent lanes during construction and, if structurally adequate for anticipated traffic, the shoulders may also be utilized. If shoulders are not structurally adequate to carry the traffic, they may require reconstruction. Also, if the shoulders are concrete, they should be tied to the adjacent lane, and if the shoulders are flexible, then a widened outside lane (14 feet) should be placed to minimize edge stresses. Due to the increase of vertical grade, overhead facilities should be at a minimum and this tends to define the facilities where this strategy is beneficial. For instance, vertical clearance at structures often requires reconstruction of the pavement structure and tapers to adjust the profile grade. Tapers to existing bridges also often require reconstruction and should taper into the bridge approach slab.

#### 3.5.2.4 Standard Plans and Construction Details

Unbonded concrete overlay are usually shown in the same manner as widening and new construction on the project typical sections and layout sheets and should be included in the project construction details sheets. The criteria when to do doweled or nondoweled concrete overlay are covered in HDM Index 622.4 – Dowel Bars and Tie Bars.

#### 3.5.2.5 Cost Estimation

For unbonded concrete overlay, the costs for removing and replacing concrete pavement and base layer (if necessary) are divided in the following items of work:

- Partial slab replacement as needed
- Diamond grinding of existing concrete as needed to repair faulting greater than 0.10 in or rotomilling existing concrete pavement to repair excessive voids.
- Placement of new hot mix asphalt.
- Drill and bond tie bars and/or dowel bars.
- Placement of new concrete pavement.
- Diamond grinding of adjacent existing concrete pavement that will remain following construction.

Generally, unit cost will vary with the material used and the size of the project. A good rule of thumb is "the shorter the construction window allowed, the higher the cost". Mobilization of equipment, traffic handling and removal of equipment each evening is associated costs that must be considered.

The volume of concrete is calculated based on the width, thickness, and length shown on the project plans. The quantity of concrete is measured and paid for by the cubic yard of including furnishing and placing the dowel bars, tie bars and saw cutting and sealing of joints. See Section 40-010 of the Special Provisions for additional information on measurement and payment of concrete pavement.

The quantity of HMA is measured and paid for by the ton including furnishing and compacting. See Section 39 of the Standard Specifications for additional information on measurement and payment of HMA.

### 3.5.3 Crack, Seat, and Flexible Overlay

#### 3.5.3.1 Construction

The cracking of JPCP involves breaking the slabs into nominal 4 ft × 6 ft wide segments to create closely spaced pieces so that vertical and horizontal movement is reduced but aggregate interlock is maintained to permit load transfer across the cracks with little loss of structural capacity that would serve as a stable base for the overlay. The slabs are broken into panels with heavy spring arm drop hammer equipment (see Figure 37) intended to produce hairline cracks through the full depth of the concrete slab conforming to Standard Special Provisions 41-250 " Crack Existing Concrete Pavement".

**Figure 37. Spring Arm Drop Hammer**

Cracked concrete is then seated using heavy rollers to: (1) create a relatively uniform grade to support paving operations, and (2) press the fragments downward to ensure firm contact with the supporting base layer, thus re-establishing adequate support between the base and the fractured concrete slab. Seating of broken panels prevents or minimizes their rocking and is performed according to Section 39-5.02 "Compacting Equipment" of the Standard Specifications.

This strategy is used where concrete pavement has an unacceptable ride, loses its structural integrity caused by extensive third stage cracking (over 10%) and is in intermediate to advanced structural deterioration. With this strategy, it is futile to try to "keep up" with individual slab replacement and grinding.

After cracking and seating, a leveling course of HMA is placed followed by a pavement reinforcing fabric (PRF) interlayer, and finally with a predetermined thickness of HMA. The cracking and seating of concrete slabs not only stabilize the slab segments to minimize any differential vertical movement under traffic but it also reduces the magnitude of thermal movement and strains that are transmitted into the PRF and the HMA overlay. This slows the reflective cracking tendency that has been observed on flexible pavement overlays placed directly over concrete pavements.

The PRF should be placed such that it extends at least 2 feet outside the edge of concrete pavement into the shoulder area. The PRF retards infiltration of surface water and aids in minimizing reflection cracking. It is critical that traffic not run over the leveling course for extended periods during construction as the reflective cracking that may initiate can compromise the flexible structural section's ability to absorb reflective cracking, significantly shortening the life of the rehabilitation.

#### 3.5.3.2 Design

Caltrans' historical overlay design is a dense graded hot mix asphalt overlay with a pavement reinforcement fabric (PRF) sandwiched in between that will enhance pavement serviceability for the time frame specified. Following cracking and seating of the concrete pavement slabs, the combination strategy used is to place 0.1 foot HMA leveling course, followed by a pavement reinforcing fabric (PRF), followed by the final hot mix asphalt overlay. See HDM Index 625.2 for standard overlay thicknesses. If a PRF is not desired, and additional 0.10 feet of HMA could be added to the overlay.

The standard method of crack, seat, and flexible overlay with a pavement interlayer combination is based on a design developed to last 10 years without requiring significant pavement maintenance and then extrapolated for a 20 year design life.

If rubberized asphalt concrete –gap grades (RAC-G) is used for this strategy, use a Stress Absorbing Membrane Interlayer - Rubberized (SAMI-R); i.e., a rubberized chip seal, in lieu of a PRF which can be susceptible to melting or to loss of its strength due to high RAC-G temperature at time of placement. The District Materials Engineer should be consulted before the RAC-G is considered with a crack, seat, and overlay rehabilitation strategy. The HDM Section 631.3 should be consulted to determine the required thickness of RAC-G overlay.

Where the slab deterioration is primarily limited to the outer lane or lanes on multilane facilities, an economic analysis should be made to compare the cost of lane replacement with the cost of crack, seating, and overlaying all lanes and shoulders. In order to ensure that raveling of the flexible pavement is avoided at the conform area, the preferred method of conforming the flexible pavement to the existing concrete pavement transition is to replace the pavement within the taper with a flexible, composite or rigid pavement structure designed to meet 20 year pavement design life standards. If the existing concrete pavement was built with an end anchor (see Standard Plan P30), the existing rigid pavement may be diamond ground up to a remaining thickness of 0.65 feet so long as the flexible overlay is no less the 0.25 feet with a PRF.

The District Materials Engineer (DME) must be consulted on the effectiveness of installing retrofit or upgrading the existing edge drains on all crack, seat, and HMA overlay pavement rehabilitation projects.

#### 3.5.3.3 Cost Estimation

For crack, seat, and HMA overlay, the costs for cracking and seating existing concrete and placing HMA on top of the pavement are divided in the following items of work:

- Crack and seat existing JPCP.
- Placement of 0.1 ft HMA leveling course.
- Placement of PRF or SAMI-R if the surface layer is to be RAC-G.
- Placement of new HMA or RAC-G.

## 4.0 TRAFFIC HANDLING AND SAFETY

Two considerations in developing a pavement structure rehabilitation or preservation project are safety and traffic handling. Adequate attention must be given to safety and traffic handling to obtain the required quality of work with minimal increases in project costs. There are various types of closures that should be evaluated for a given project, and are briefly explained below. Additionally, the Department has developed traffic closure analysis software called CA4PRS, which can estimate the number of closures needed and anticipated user costs of the various types of closures to be imposed during freeway rehabilitation. Further information on this program can be found on the Department website at http://www.dot.ca.gov/research/roadway/ca4prs/index.htm.

### 4.1 Complete Roadway Closure

Maximum productivity, quality, and economy result if the roadway can be closed completely during the entire rehabilitation/preservation period. This requires the rerouting of traffic through the use of detours over other routes (see Caltrans Traffic Manual – Typical Application 5-9 in the Department website at http://www.dot.ca.gov/hq/traffops/signtech/signdel/trafficmanual-current.htm).

### 4.2 Continuous Lane Closure

Since the outside (truck) lane(s) generally suffer the greatest pavement damage, lane replacement, for instance, can sometimes be accomplished by complete closure of the lanes(s) during the reconstruction stage. Temporary re-striping, narrower lanes, or added median paving can be considered. Median paving must be designed to meet traffic loads. The use of temporary concrete barrier rail should be considered for added safety. Adequate space needs to be provided for paving machines and construction works to work between the temporary concrete barrier and the area to be paved. Where practicable, a minimum of 6 feet of clearance should be provided between traffic and paving operations. Typical Application 5-11 in the Caltrans Traffic Manual, which can be accessed in the Department website at http://www.dot.ca.gov/hq/traffops/signtech/signdel/trafficmanual-current.htm, illustrates a lane closure on a two lane low-volume road. Reference to the Manual of Traffic Controls for Construction and Maintenance is available through the Traffic Operations Branch.

When a lane is closed on a multilane road, a transition area containing a merging taper is needed. Typically, the advance warning area contains three warning signs, such as ROAD WORK AHEAD, RIGHT or LEFT LANE CLOSED AHEAD, and the Lane Reduction Transition sign.

When an interior lane is closed for use as a workspace, consideration should be given to closing an adjacent lane also. This procedure provides additional space for vehicles and materials and facilitates the movement of equipment within the workspace. On multilane undivided roads and streets where the left lane is closed, such additional space can be obtained by also closing the left lane in the opposing direction.

### 4.3 Weekend Closures

Weekend closures should be considered in high volume traffic areas, where lane closures may cause severe congestion, resulting in accidents and delays to the motorist. This type of closure (sometimes referred to as a 55-hour closure) may impact businesses, therefore the Office of Public Affairs should be contacted to coordinate a concerted effort to minimize traffic impacts and educate the traveling public. When replacing concrete pavement slabs, rapid strength concrete will need to be specified to permit reopening to Monday morning traffic.

### 4.4 Weekday Closures

Weekday closures are similar to weekend closures except that they occur usually Monday evening through Friday morning. They are typically viable on rural routes which have higher traffic on the weekends.

### 4.5 Nighttime Closures

This is the least desirable alternative because of traffic impacts, but sometimes it is the only feasible solution. When replacing concrete pavement slabs, rapid strength concrete must be specified and the cost of the work is relatively much higher.

### 4.6 Other Options

Additional traffic handling alternatives that may be appropriate include the use of construction staging, temporary ramps, detours and signing. The District Division of Traffic Operations, the Office of Traffic Management, and the Public Information Office should be consulted for guidance on all traffic handling, safety issues, and communications.

***END OF GUIDE***